

# **STOCHASTIC MODELLING OF SEISMIC HAZARD AND RISK ASSESSMENT FRAMEWORK FOR UGANDA**



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To my lovely wife, Quin-Gift for her prayers, care and patience; and to my parents and sisters for their unwavering support and faith in me towards the achievement of my academic and professional ambitions.

To my country, Uganda, especially the victims of past natural-hazard-induced disasters

## DECLARATION

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I declare that no portion of the work contained in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institution of learning. The work is my own except where indicated. All quotations have been distinguished by quotation marks and the sources acknowledged.

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## ABSTRACT

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Uganda is situated between the eastern and western branches of the world's largest seismically active continental rift, the East African Rift System. Over the past decades, many catastrophic earthquakes (e.g., 1929 Masaka, 1966 Rwenzori, 1994 Kisomoro and 2016 Bukoba) have had detrimental consequences on the socio-economic welfare and resilience of communities across Uganda. Moreover, the disastrous impacts of earthquakes have been exacerbated by co-seismic and rainfall-induced landslides. For instance, the unprecedented 2010 Bududa landslide which occurred in eastern Uganda killed at least 388 people and over 8500 people were affected. The socio-economic welfare and resilience of the communities located in disaster-prone areas can be directly affected by the catastrophic impacts of earthquakes and landslides. With increasing population, urbanisation and rapid construction, earthquake and landslide risks are escalating fast and is compounded by the high vulnerability of buildings and inadequate disaster prevention and mitigation strategies. Hence, there is urgent need to assess Uganda's resilience against seismic risks. As a precursor towards building an earthquake risk and resilience framework, this study employs the probabilistic event-based risk calculator of the *OpenQuake*-engine to holistically assess the potential losses resulting from future earthquakes. In the first part of the dissertation, probabilistic seismic hazard assessment is conducted using a fault-oriented spatially distributed seismicity approach. A logic tree is implemented to better manage the associated epistemic uncertainties and site conditions are modelled using the upper 30 m average shear wave velocity across Uganda. Seismic hazard findings confirm that western Uganda is exposed to the highest level of seismicity where for instance Rwenzori and Kigezi regions can expect bedrock peak ground accelerations increasing up to 0.27 g over a 475-year return period. The second part of this thesis demonstrates the ability of fuzzy logic and geospatial methods in deriving a national co-seismic and rainfall-induced landslide hazard susceptibility framework for Uganda. In addition to the earthquake characteristics, the most prevalent predisposing and geomorphological landslide conditioning factors considered in this study include slope angle, topographic slope position, proximity to major active faults and geology. The final relative co-seismic landslide hazard findings conclude that the Kigezi and Rwenzori sub-regions in western Uganda are highly prone to co-seismic slope failures while landslide occurrences across the other parts are fundamentally driven by rainfall. Detailed absolute landslide hazard analysis is encouraged in regions of moderate landslide regions comprising highly weathered outcropping rocks of Precambrian granites, dominantly metasedimentary, granulites and gneisses geologies within 80 km from active faults: where bedrock PGA  $\geq 0.1$  g over a 475-year return period, topographic position index  $\geq 3.8$ , slope gradient  $\geq 10$  degrees, and distance from streams  $\leq 1.25$  km. The final part of this thesis focusses on assessing potential losses due to future earthquakes in Uganda by combining seismic hazard predictions with the country's building exposure and global analytical vulnerability models. By and large, the earthquake risk model derived in this study predicts an overall economic mean annual loss of US\$ 74.722 million coupled with a mean annual death toll increasing up to 71.3 persons across the whole country. The findings herein will not only be a significantly big step towards the urgent need to kick-start the update of the Uganda Seismic Code, but also strategically contribute to land use planning patterns, optimisation of earthquake insurance pricing and improvement of the National Policy for Disaster Preparedness and Management.

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## ABBREVIATIONS AND ACRONYMS

---

|        |                                                     |
|--------|-----------------------------------------------------|
| AAL    | Average Annual Loss                                 |
| ADO    | Adobe blocks                                        |
| AfCFTA | Africa's Continental Free Trade Area                |
| ASC    | Active Shallow Crust                                |
| ASZ    | Area Source Zone                                    |
| AUC    | Area Under Curve                                    |
| BSZ    | Background Source Zone                              |
| CB     | Concrete blocks                                     |
| CDL    | Low ductility class                                 |
| CDM    | Medium ductility class                              |
| CL     | Fired clay bricks                                   |
| CUT    | Congo-Uganda-Tanzania craton                        |
| DCL    | Low Ductility Class                                 |
| DCM    | Ductility Class Medium                              |
| DEM    | Digital Elevation Model                             |
| DGSM   | Directorate Of Geological Survey and Mines          |
| DNO    | Non-Ductile                                         |
| DRC    | Democratic Republic of the Congo                    |
| DRM    | Disaster Risk Management                            |
| DRR    | Disaster Risk Reduction                             |
| DSHA   | Deterministic Seismic Hazard Analysis               |
| EARS   | East African Rift System                            |
| ERA    | Earthquake Risk Assessment                          |
| ERS    | Eastern Rift System                                 |
| EWV    | Exterior Vegetative Walled building                 |
| FE     | Finite Element                                      |
| FMD    | Frequency-Magnitude-Distribution                    |
| FSZ    | Fault Source Zone                                   |
| GDP    | Gross Domestic Product                              |
| GEM    | Global Earthquake Model                             |
| GFDRR  | Global Facility for Disaster Reduction and Recovery |
| GIS    | Geographical Information System                     |
| GMPEs  | Ground Motion Prediction Equations                  |
| GMTK   | Ground Motion Toolkit                               |
| GSHAP  | Global Seismic Hazard Assessment Project            |
| HMTK   | Hazard Modeller's Toolkit                           |
| ISC    | International Seismological Centre                  |
| ISU    | Institution of Surveyors of Uganda                  |

|       |                                                              |
|-------|--------------------------------------------------------------|
| LFIN  | Infilled-wall lateral load resisting system                  |
| LWAL  | Shear wall and/or masonry wall lateral load resisting system |
| MC    | Monte Carlo                                                  |
| MCF   | Confined Masonry building                                    |
| ME    | Building of Metals, except steel                             |
| MEMD  | Ministry of Energy and Mineral Development                   |
| MFPED | Ministry of Finance, Planning and Economic Development       |
| MMI   | Modified Mercalli Intensity                                  |
| MRDPM | Ministry of Relief, Disaster Preparedness and Management     |
| MUR   | Unreinforced Masonry building                                |
| NASA  | National Aeronautics and Space Administration                |
| NBRB  | National Building Review Board                               |
| NFA   | National Forest Authority                                    |
| NIS   | National Insurance Scheme                                    |
| NPA   | National Planning Authority                                  |
| NPDPM | National Policy for Disaster Preparedness and Management     |
| NPV   | Net Present Value                                            |
| OPM   | Office of the Prime Minister                                 |
| PGA   | Peak Ground Acceleration                                     |
| POE   | Probability of Exceedance                                    |
| PSHA  | Probabilistic Seismic Hazard Analysis                        |
| RC    | Reinforced Concrete building                                 |
| RFB   | Rwenzori Fold Belt                                           |
| ROC   | Receiver Operating Characteristic                            |
| RSA   | Response Spectral Acceleration                               |
| S     | Structural Steel building                                    |
| SA    | Spectral Acceleration                                        |
| SCC   | Stable Continental Crustal                                   |
| SDOF  | Single Degree of Freedom                                     |
| SECED | Society For Earthquake and Civil Engineering Dynamics        |
| SES   | Stochastic Event Sets                                        |
| SPT   | Standard Penetration Test                                    |
| SRTM  | Shuttle Radar Topography Mission                             |
| SSA   | Sub-Saharan Africa                                           |
| STDRE | Dressed stone masonry,                                       |
| STRUB | Rubble or semi-dressed stone                                 |
| TPI   | Topographic Position Index                                   |
| TRC   | Total Replacement Cost                                       |
| UBoS  | Uganda Bureau of Statistics                                  |

|             |                                                        |
|-------------|--------------------------------------------------------|
| UHS         | Uniform Hazard Spectra                                 |
| UIPE        | Uganda Institution of Professional Engineers           |
| UKADR       | United Kingdom Alliance for Disaster Research          |
| US 319:2003 | Uganda seismic code of practice for structural designs |
| USA         | Uganda Society of Architects                           |
| USGS        | United States Geological Survey                        |
| W           | Wooden/Timber building                                 |
| WCEE        | World Conference on Earthquake Engineering             |
| WRS         | Western Rift System                                    |
| WWD         | Wattle and Daub building                               |

## NOTATIONS

---

|            |                                                                                      |
|------------|--------------------------------------------------------------------------------------|
| $\Gamma$   | Site class: rock sites with soil depths < 5 km, $\Gamma = 0$ otherwise, $\Gamma = 1$ |
| %          | Per cent                                                                             |
| $\mu(x)$   | Combined membership function                                                         |
| $\mu_i$    | Fuzzy membership function for the $i^{th}$ fuzzy overlay map                         |
| $A_D$      | Area of dwelling or establishment                                                    |
| $C_A$      | Cost per area of building typology                                                   |
| $d$        | Distance or spatial window (in km)                                                   |
| $FN$       | False negative count of erroneously categorised pixels                               |
| $FP$       | False positive count of erroneously categorised pixels                               |
| $g$        | Acceleration due to gravity ( $= 9.81 \text{ m/s}^2$ )                               |
| km         | Kilometres                                                                           |
| $M$        | Magnitude                                                                            |
| m          | Metres                                                                               |
| m.a.s.l    | Metres above sea level                                                               |
| $m/s$      | Metres per second                                                                    |
| $m_b$      | Body-wave magnitude                                                                  |
| $M_L$      | Local magnitude                                                                      |
| $M_{max}$  | Maximum magnitude                                                                    |
| $M_{min}$  | Minimum magnitude                                                                    |
| $M_s$      | Surface-wave magnitude                                                               |
| $M_w$      | Moment magnitude                                                                     |
| $N$        | Total number of surrounding points employed in the evaluation                        |
| $N_{(LP)}$ | Total number of landslide pixels in the region of interest                           |
| $N_{(P)}$  | Total number of pixels in the selected landslide conditioning factor class           |
| $N_{(P)i}$ | Number of landslide pixels in a landslide conditioning factor class                  |
| $N_B$      | Number of buildings for each typology                                                |
| $N_D$      | Number of dwellings or establishments                                                |
| $N_J$      | Number of units per storey                                                           |
| $N_K$      | Number of storeys per building class                                                 |
| $N_T$      | Total number of pixels in the study area                                             |
| °          | Degrees                                                                              |
| $R$        | Epicentral distance                                                                  |
| $r_{jb}$   | Joyner-Boore distance                                                                |
| $t$        | Time or temporal window (in days)                                                    |
| $T(s)$     | Spectral period, in seconds                                                          |
| $TN$       | True negative count of correctly grouped pixels                                      |

|                |                                                                                    |
|----------------|------------------------------------------------------------------------------------|
| $TP$           | True positive count of correctly grouped pixels                                    |
| US\$           | United States Dollars                                                              |
| $V_{s,30}$     | 30-metre average shear wave velocity                                               |
| $Z_n$          | Altitude of surrounding cells within a local window                                |
| $Z_o$          | Denote elevation at the central point                                              |
| $\beta$        | Relative landslide frequency in the overall study area                             |
| $\beta_i$      | Relative landslide frequency within a specific landslide conditioning factor class |
| $\gamma$       | Parameter chosen in the range of 0 and 1. Effect of large and small $\mu_i$ values |
| $\varepsilon$  | Normally distributed error                                                         |
| $\lambda_{FP}$ | False positive rate                                                                |
| $\lambda_{TP}$ | True positive rate                                                                 |

# CHAPTER 1

## INTRODUCTION

### 1.1 Background and problem statement

The severity of natural-hazard-induced disasters like earthquakes, landslides and floods is tremendously rising, especially in many developing countries like Uganda (Corominas et al., 2014; Petley, 2012). Such disasters can potentially cause widespread and devastating damage to the built and natural environment (Baker et al., 2021; Daniell et al., 2011). The socio-economic welfare and resilience of communities located in disaster-prone areas can be directly affected by the catastrophic impacts of disasters. The main socio-economic sectors that suffer due to landslide and earthquake-related disasters include health, infrastructure, education, economy, politics and institutional governance. Moreover, the effect of natural-hazard-induced disasters on capital-intensive service sectors such as transport and communication services can lead to a decline in regional trade, especially in terms of exports and imports. Although Uganda faces various disasters, earthquakes and landslides are responsible for over 17 % of the deaths related to natural-hazard-induced disasters from which 4 % of the population across the country is affected (Doocy et al., 2013; Kato and Mutonyi, 2011; Masaba et al., 2017). Moreover, 12 % of the houses destroyed and/or damaged are attributed to landslide and earthquakes. Uganda has suffered from the disparaging effects of earthquakes and landslides that resulted in deaths, injuries, physiological distress and extensive infrastructural damages as well as destruction of property. Overall, more than 3000 fatalities and destruction of at least 13000 houses have been caused by landslides and earthquakes between 1933 and 2020 (DesInventar, 2020).

Uganda is located between the Albertine (western) and Gregory (eastern) branches of the world's largest seismically active continental rift, the East African Rift System (EARS); and as such, destructive earthquakes across the country's territories are predominantly driven by the EARS (Asefa and Ayele, 2021; Midzi et al., 1999). The most catastrophic earthquakes that struck Uganda from the start of the twentieth century are summarised in Table 1.1. The worst event was the 1966 Toro earthquake of surface-wave magnitude ( $M_s$ ) 6.6 which hit western Uganda and caused deaths and injuries coupled with building damages and collapses.

**Table 1.1** List of the most destructive earthquakes of  $M_s \geq 5.5$  between 1900 and 2024. Adopted from Oleng et al. (2024)

| $M_s$ | Date       | Name                 |
|-------|------------|----------------------|
| 6.5   | 09.07.1912 | Kitgum earthquake    |
| 6.3   | 10.02.1929 | Masaka earthquake    |
| 6.0   | 18.03.1945 | Sembabule earthquake |
| 6.6   | 20.03.1966 | Toro earthquake      |
| 5.5   | 09.10.1991 | Butiaba earthquake   |
| 6.2   | 05.02.1994 | Kisomoro earthquake  |
| 5.8   | 10.09.2016 | Bukoba earthquake    |

With one analogue single-component station installed in Entebbe, the Directorate of Geological Survey and Mines (DGSM), a government agency under Ministry of Energy and Mineral Development (MEMD), commenced earthquake monitoring and recording in 1918 (Nyago, 2013). Later between 1900 and 1999, three micro-earthquake analogue seismological equipment were installed in Kilembe, Hoima, and Mbarara. However, little documented evidence of historical events can be found, partly due to historically low population density and poor historical records. On the other hand, there has been a wider reporting of landslides across Uganda due to the increasing frequency of events over the past decades (DesInventar, 2020). The impact of the worst landslides in Uganda is shown in Table 1.2. Although most landslides have been triggered by rain, earthquakes and flooding (Knapen et al., 2006), it is worth noting that the influence of climate change (e.g., extreme weather conditions and resulting rainfall) partly due to human activities such as deforestation and inappropriate land use patterns can substantially exacerbate the impact of natural-hazard-induced disasters.

**Table 1.2** Impact of the worst landslides in Uganda: 1933 and 2018 (DesInventar, 2020)

| Year  | Deaths | Injuries | Missing | Affected | Relocated | Damage to buildings, infrastructure and property |         |           |            |           |
|-------|--------|----------|---------|----------|-----------|--------------------------------------------------|---------|-----------|------------|-----------|
|       |        |          |         |          |           | Houses                                           | Schools | Hospitals | Crops (ha) | Roads (m) |
| 1933* | 50     | 0        | 0       | 0        | 0         | 0                                                | 0       | 0         | 0          | 0         |
| 1966† | 36     | 0        | 0       | 0        | 0         | 0                                                | 0       | 0         | 0          | 0         |
| 1970* | 120    | 0        | 0       | 0        | 0         | 0                                                | 0       | 0         | 0          | 0         |
| 1994† | 14     | 3        | 0       | 0        | 150       | 0                                                | 0       | 0         | 2500       | 0         |
| 1997* | 129    | 0        | 0       | 0        | 0         | 97                                               | 0       | 0         | 0          | 0         |
| 2001* | 25     | 12       | 0       | 5626     | 2000      | 50                                               | 2       | 0         | 0          | 0         |
| 2002♀ | 21     | 8        | 0       | 81       | 0         | 3                                                | 1       | 0         | 625.46     | 0         |
| 2003* | 38     | 2        | 0       | 50       | 500       | 254                                              | 0       | 0         | 0          | 0         |
| 2007* | 26     | 27       | 0       | 1172     | 0         | 224                                              | 15      | 0         | 236        | 0         |
| 2009* | 20     | 4        | 0       | 6300     | 0         | 42                                               | 4       | 0         | 0          | 0         |
| 2010* | 1926   | 6        | 950     | 355191   | 100       | 1311                                             | 31      | 2         | 2388.36    | 76420     |
| 2011♀ | 239    | 24       | 17      | 49650    | 462       | 348                                              | 0       | 0         | 0          | 4115      |
| 2012* | 36     | 29       | 0       | 5161     | 500       | 2                                                | 0       | 0         | 0          | 0         |
| 2013♀ | 2      | 2        | 0       | 1952     | 0         | 38                                               | 2       | 0         | 1954       | 0         |
| 2015* | 8      | 0        | 0       | 491      | 0         | 0                                                | 0       | 0         | 120        | 0         |
| 2017* | 20     | 0        | 0       | 250      | 0         | 0                                                | 0       | 0         | 0          | 0         |
| 2018* | 1      | 0        | 0       | 497      | 1759      | 42                                               | 0       | 0         | 0          | 0         |

The symbols preceding the year of landslide occurrences indicate the dominant landslide triggering factors, these correspond to: †co-seismic; \*rainfall-induced; and ♀landslide due to flooding and heavy downpour.

The majority of landslides which have consequentially led to destruction of the ecosystem, homesteads and infrastructure like schools and bridges are induced by rainfall and other land use factors (Masaba et al., 2017). For instance, the unprecedented 2010 Bududa landslide which occurred in eastern Uganda killed at least 388 people, with over 8500 people affected (Atuyambe et al., 2011; Broeckx et al., 2019). Co-seismic landslides in western Uganda have caused over 56 deaths, leaving more than 14000 people destitute (Jacobs et al., 2016). Damages due to the most destructive landslides and earthquakes across Uganda are shown in Fig 1.1e-f.

Building damages and residents removing the wreckage of a damaged house following the 1994 Kisomoro earthquake which was extensively preceded by co-seismic landslides is shown in Fig 1.1a-b. The March 2010 Bududa landslide was induced by heavy torrential rains and killed over 23 people coupled with injuries as families were buried in mud-engulfed homes in addition to destruction of crops and livestock, as shown in Fig 1.1c. On the other hand, Fig 1.1d-e show damaged buildings in Rakai and accommodation crisis at Minziro in Uganda; following the 2016 Bukoba tremor from which economic losses worth US\$ 458 million were estimated in the Kagera region. Lastly, as depicted in Fig 1.1f, the Kabale-Kisoro national highway in western Uganda was recently torn apart by landslides that occurred in May 2023.



**Fig 1.1** Damages to buildings, infrastructure and property across Uganda, due to past earthquake and landslide disasters: **(a-b)** 1994 Kisomoro earthquake, **(c)** 2010 Bududa landslide, **(d-e)** 2016 Bukoba earthquake, and **(f)** 2023 Kabale-Kisoro road landslide

Earthquake and landslide damages to structures, injuries and fatalities in future events are likely to escalate due to the rapidly increasing population growth and urbanisation across the country. Uganda's population has grown at an average annual rate of 3.19 %; and as at June 2022, the population of the country is estimated at over 44.2 million (UBoS, 2022). Although the majority of earthquake epicentres are less populated compared to the rest of the country, the growing economic activity and rapid urbanization are likely to spike the population in these areas thereby posing an increased seismic risk. In addition to the rapid population growth and urbanisation, Uganda's building stock largely comprises traditional timber, daub and wattle, adobe blocks with mud mortar, baked clay bricks and cement mortar; all with grass-thatched, galvanised iron-sheet and/or burnt clay tile roofs (Hashemi, 2017; Twesigomwe, 1997).

The largest proportion of Uganda's building stock is substandard, and more than half of the stock comprises non-ductile unreinforced masonry constructions which poses a significant risk as it is intrinsically more vulnerable to earthquakes especially when seismic design principles are neglected. Moreover, modern construction practices have adapted the European-style structural systems which are more vulnerable to ground motion due to their inherently lower earthquake resistance capacities (Brzev et al., 2013; Silva et al., 2015; Vicente et al., 2011). With increasing population, urbanisation and rapid construction, earthquake and landslide risks are escalating fast and are compounded by high vulnerability of buildings and inadequate disaster prevention and mitigation strategies. Yet, a comprehensive study published on the associated earthquake, co-seismic and rainfall-induced landslide hazards and risks does not exist.

At a national level, mitigation of earthquake risk largely requires the formulation and implementation of appropriate seismic design codes. The current Uganda seismic design code of practice for structural designs (US 319:2003) (UNBS, 2003) is not only obsolete, but also not in line with modern seismic design codes. However, hazard and socio-economic level of the country need to be quantified first. In this regard, seismic risk in Uganda ought to be comprehensively evaluated to develop a reliable national risk mitigation strategy for the country. Such remedies include reinstating and enforcing standards and regulations towards the design and construction of earthquake resistant structures, strengthening the existing buildings located in earthquake and landslide prone areas, adequate planning of emergency response, and transfer of the financial cost of reconstruction and repair through creation of insurance and reinsurance schemes (Baker et al., 2021; Gkimprxis et al., 2021; Salgado-Gálvez et al., 2017).

Prompted by the fact that the efficacy of disaster management and mitigation strategies can be strongly undermined by the absence of a comprehensively robust and reliable disaster risk framework, this study presents the first probabilistic seismic risk assessment for Uganda by combining the earthquake hazard model with seismic vulnerability of the existing building

inventory comprising the country's exposure model. The stochastic event-based probabilistic hazard and risk calculators of the *OpenQuake* engine (Pagani et al., 2014; Silva et al., 2014), developed by the Global Earthquake Model (GEM)<sup>1</sup> Foundation, is employed herein. In addition, a co-seismic landslide hazard susceptibility framework for Uganda is developed using a geospatial-based fuzzy logic methodology.

## 1.2 Research aim and objectives

### 1.2.1 Aim

The overall aim of this study is to develop a multi-hazard seismic risk assessment framework for substandard buildings in Uganda. The novelty of this work is in the application of existing frameworks and tools to a new case study area whilst incorporating local knowledge and experiences in order to gain fresh insights into the associated seismic risks. The outputs of this study which relies on readily available information for local surveys will provide an appraisal tool towards a more resilient built environment owing to reduced earthquake-related human and economic losses. This framework can reliably be used as a starting point for the update and continuous improvement of a more robust version of US 319:2003 and the findings will strategically contribute to land use planning patterns, earthquake insurance pricing and the improvement of the National Policy for Disaster Preparedness and Management. Moreover, the developed model can be incorporated into a multi-hazard earthquake risk assessment framework, aimed at providing policymakers, practitioners, insurance companies and government stakeholders with practical risk appraisal techniques geared towards reducing future landslide and earthquake-related losses across the country.

### 1.2.2 Specific objectives

To achieve the aim of this study, the specific objectives associated with the development of a reliable seismic risk assessment framework for Uganda include:

1. To stochastically develop an event-based probabilistic earthquake hazard assessment framework for Uganda using a fault-oriented spatially distributed seismicity method:
  - (a) Compile and merge the earthquake catalogue for Uganda and execute catalogue homogenisation, declustering and completeness analyses.
  - (b) Characterise seismic sources based on the geology and seismo-tectonic environment of Uganda, prior to the definition of the associated seismicity parameters for each source zone.

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<sup>1</sup> The GEM Foundation is a non-profit, public-private partnership that drives a global collaborative effort to develop scientific and high-quality resources for transparent assessment of earthquake risk and to facilitate their application for risk management around the globe.

- (c) Through a logic-tree implementation, generate ground motion field realisations using suitable ground motion prediction equations (GMPEs) developed based on strong ground motion records for regions of similar geo-tectonic settings.
  - (d) Derive bedrock and site-specific seismic hazard curves, uniform hazard spectra, earthquake disaggregation, and seismic hazard maps corresponding to a 475- and 2475-year return periods.
  - (e) Apply seismic hazard analysis for a case study region (e.g., Kampala) in Uganda and make comparisons with existing regional and/or national hazard estimates.
  - (f) Compute the elastic and design spectral pseudo-accelerations representing seismic actions in the horizontal direction for two case study sites located in high hazard regions (Fort Portal and Mbarara cities); and compare with the design spectrum derived according to Uganda Seismic Code with design spectrum derived following modern seismic design guidelines.
2. To develop earthquake-induced and rainfall-triggered landslide hazard susceptibility framework for Uganda:
- (a) Gather landslide inventory catalogues (landslide locations and pixel distribution) and generate isoseismals for known scenario earthquakes that triggered landslides within Uganda and/or its immediate environs.
  - (b) Use refined high resolution digital elevation model (DEM), geology and major active fault maps to model geomorphologic parameters associated with initiation of landslides across Uganda.
  - (c) Apply a geospatial-based fuzzy logic method to produce relative co-seismic and rainfall-induced landslide susceptibility maps for Uganda.
  - (d) Verify the predictive capabilities of the derived co-seismic and rainfall-triggered landslide hazard susceptibility models using the area under the receiver operating characteristic curve method.
  - (e) Make recommendations towards detailed absolute landslide hazard assessments for scenario sites which are moderately and highly exposed to co-seismic landslides.
3. To perform a Monte-Carlo (MC) based probabilistic seismic risk assessment towards informing the National Policy for Disaster Preparedness and Management:
- (a) Compile the social indicators relating to Uganda's population distribution and growth rate, gross domestic product per capita, and human development index.
  - (b) Collect relevant information relating to the distribution of existing building stock and develop an exposure model for various building typologies across Uganda.
  - (c) Generate a taxonomy mapping scheme by selecting appropriate analytical vulnerability curves for equivalent single degree of freedom (SDOF) models of various building typologies and derived for different tectonic regimes.

- (d) Combine the seismic hazard and exposure models with the vulnerability curves to predict mean annual losses and derive loss exceedance curves for Uganda.
- (e) Compare seismic risk indicators and mean annual losses derived in the present study with previous regional and/or national estimates.

### 1.3 Layout of the thesis

This thesis is written following the article-based format. The main outcomes of this study (presented in Chapters 2, 3 and 4) are and will be published in peer-reviewed journals. The contents of each chapter of this thesis are described as follows:

- Chapter 2 encompasses the stochastic event-based probabilistic earthquake hazard assessment framework for Uganda. It commences with a review of previous hazard studies in the region, followed by a sequential description of the underlying methodology adopted. The subsequent parts explain data collection and processing, seismic source characterisation, logic tree implementation of GMPEs and the site condition model. The remaining parts of this chapter present and discuss the MC-based PSHA results, developed using fault-oriented spatially smoothed seismicity.

The entire content of Chapter 2, submitted to and accepted by *Bulletin of Earthquake Engineering*, was published online as an open access article on 23<sup>rd</sup> January 2024:

Oleng, M., Ozdemir, Z., and Pilakoutas, K. (2024). Probabilistic seismic hazard assessment framework for Uganda: a stochastic event-based modelling approach. *Bulletin of Earthquake Engineering*. <https://doi.org/10.1007/s10518-024-01856-6>

- Chapter 3 entails the co-seismic and rainfall-triggered landslide hazard susceptibility framework which is developed based on fuzzy logic and geospatial modelling techniques. This chapter starts with a review of landslide assessment methodologies and previous studies conducted in the region, followed by a description of the geospatial-based fuzzy logic approach employed for the case study area in question. The earthquake and landslide datasets used in the study and an explanation of landslide inventory analysis and model design are then presented. The remaining parts present the results, validation and discussions into the relative landslide hazard assessment framework developed for Uganda. Chapter 3, has been accepted for publication as follows:

Oleng M, Ozdemir Z, and Pilakoutas K (2024). Co-seismic and rainfall-induced landslide hazard susceptibility assessment framework for Uganda derived using fuzzy logic and geospatial modelling techniques. *Natural hazards*. <https://doi.org/10.1007/s11069-024-06744-5>.

- Chapter 4 focusses on a probabilistic seismic risk assessment framework for Uganda, derived using a stochastic event-based modelling approach. This chapter essentially begins with a generic review of seismic risk assessment approaches, followed by a sequential description of the underlying method adopted. Then, the fault-oriented spatially smoothed seismicity technique used to develop the MC-based PSHA model, largely adopted from Chapter 2, is briefly explained. The next section presents building typologies and their estimated replacement costs, prior to selecting vulnerability curves used to describe the probability distribution of loss ratios for a combination of intensity measure types and levels. The final parts present and discuss earthquake ruptures, hazard maps, loss exceedance curves, mean annual loss maps and the aggregated asset loss statistics.

In its entirety, an original manuscript entailing the content of Chapter 4 is submitted for consideration of possible publication in the *Bulletin of Earthquake Engineering*:

Oleng M, Ozdemir Z, and Pilakoutas K (2024). Stochastic event-based probabilistic seismic risk assessment framework for Uganda: towards informing the National Policy for Disaster Preparedness and Management. *Bulletin of Earthquake Engineering*.

- Lastly, Chapter 5 summarises and provides conclusions following the main findings of the entire study. The rationale for earthquake and landslide risk reduction and management, with a review of the National Policy for Disaster Preparedness and Management (NPDPM, 2010), is discussed herein. The final part of the chapter indicates the limitations of the present study and suggests recommendations for further research.

#### 1.4 Conference abstracts and papers

A significant portion of this thesis has been presented in conference proceedings in form of abstracts and conference papers, listed as follows:

- Oleng, M., Ozdemir, Z., and Pilakoutas, K. (2023). Seismic Risk and Resilience Assessment Framework for Uganda: towards improving the National Policy for Disaster Preparedness and Management. United Kingdom Alliance for Disaster Research (UKADR): *2030 and Beyond: Risk-informed decision making, investment and behaviour*. 18-19 December 2023, Huddersfield, UK.  
[https://ukadr2023.buildresilience.org/wp-content/uploads/2023/12/UKADR\\_2023\\_Book\\_of\\_abstracts.pdf](https://ukadr2023.buildresilience.org/wp-content/uploads/2023/12/UKADR_2023_Book_of_abstracts.pdf)
- Oleng, M., Ozdemir, Z., and Pilakoutas, K. (2023). Fault-oriented spatially distributed seismicity model and co-seismic landslide hazard assessment framework for Uganda. So-

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- Oleng, M., Ozdemir, Z., and Pilakoutas, K. (2023). A practical probabilistic earthquake hazard analysis: towards the continuous update of the Uganda seismic code of practice (US 319:2003). 26<sup>th</sup> National Technology Conference and Exhibition: *Tapping engineering opportunities for accelerated Africa's continental free trade area (AfCFTA) -Uganda's Perspective*. 17-18 August 2023, Hotel Africana, Kampala, Uganda. <https://uipe.co.ug/about-ntc-2023/>
- Oleng, M., Ozdemir, Z., and Pilakoutas, K. (2024). Probabilistic earthquake risk assessment framework for Uganda: event-based modelling approach. 18<sup>th</sup> World Conference on Earthquake Engineering (WCEE): *June 30 to July 5, 2024, Milan, Italy*. <https://www.wcee2024.it/>

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# CHAPTER 2

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## PROBABILISTIC SEISMIC HAZARD ASSESSMENT FRAMEWORK FOR UGANDA: A STOCHASTIC EVENT-BASED MODELLING APPROACH

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### Abstract

Uganda lies between the eastern and western arms of the East African Rift System (EARS), the largest seismically active rift above sea level. With increasing population, urbanisation and rapid construction, seismic risk in the country is escalating fast and is compounded by the high vulnerability of the building stock and inadequate disaster prevention and mitigation strategies. Hence, there is an urgent need to assess Uganda's resilience against seismic risks. This paper presents a Monte-Carlo (MC) based probabilistic seismic hazard model for Uganda, as the first step towards the development of a seismic risk and resilience assessment framework for the country. In addition to fault segment data, earthquake catalogues are compiled for the period between 1900 and 2022 to estimate recurrence parameters for source zones in the area of interest. Area source zones incorporating focal mechanisms are used to stochastically model a national hazard framework for Uganda. A logic tree approach is applied to implement four ground motion prediction equations (GMPEs) for both stable continental and active shallow crust geologies. Mean hazard curves, uniform hazard spectra, earthquake disaggregation and spectral pseudo-accelerations for major Ugandan cities are derived in addition to hazard maps for the country. The findings are largely consistent with previous regional studies and confirm that western Uganda is exposed to the highest level of seismicity. The model presented herein can be used to kick-start the update and continuous improvement of Uganda Seismic Design Code and the National Policy for Disaster Preparedness and Management.

**Keywords** Probabilistic seismic hazard analysis (PSHA); Monte-Carlo (MC) simulations; Fault-oriented model; Spatially smoothed seismicity; Logic-tree implementation; Uganda

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## 2.1 Introduction

The impact of earthquakes on the socio-economic growth and development of communities, particularly in developing countries, can be devastating due to the potentially huge economic and human losses that may result by damage to the natural and built environment. Health, education, infrastructure, economy, politics and institutional governance are amongst the main socio-economic sectors that can suffer consequentially. Over the previous decades, several destructive earthquakes occurred in various parts of Uganda; resulting in loss of lives, injuries, physiological distress and damage to property. The recent 2016 Bukoba earthquake left many Ugandans homeless and resulted in high economic losses (USGS, 2016), due primarily to the substandard building stock. The proliferation of substandard constructions coupled with rapid population increase and urbanisation, exposes Uganda to a massively increasing risk resulting from earthquakes. Hence, there is an urgent need to quantify this risk so that the appropriate mitigation measures can be taken.

Destructive earthquakes in East Africa are largely driven by the East African Rift System (EARS), which is a well-known tectonic feature in the region (Midzi et al., 1999). Due to Uganda's geographical location between the eastern and western arms of the EARS (shown in Fig 2.1a), the country has experienced a couple of earthquakes with moment magnitude ( $M_w$ ) between 6.0 and 7.2. Moreover, many seismic events with  $M_w < 6.0$  have been recorded across the country. Despite the existence of the EARS which is largely responsible for earthquakes in the region, little documented evidence of historical events can be found; partly due to historically low population density and poor historical records.

Uganda and the surrounding regions have previously been hit by many catastrophic earthquakes. The location of the EARS relative to major cities and epicentres of the worst events are shown in Fig 2.1b. In the past century, the 1929 Masaka earthquake with a body-wave magnitude ( $m_b$ ) of 5.9 was widely felt across Uganda and was preceded by numerous foreshocks and followed by several aftershocks. In the epicentral region, landslides occurred extensively and changes were observed in hot springs (Maasha, 1975). In 1945, another earthquake with a surface-wave magnitude ( $M_s$ ) of 6.0 hit Masaka and caused 5 deaths, several injuries and many building collapses (Bisset, 1945; Loupekine, 1966; Maasha, 1975). The worst event of the twentieth century was an earthquake of 6.6  $M_s$  which struck the Rwenzori region (western Uganda) in 1966; causing 160 deaths, 1,300 injuries, and destroying over 7,000 houses (Maasha, 1975; Sykes, 1967).

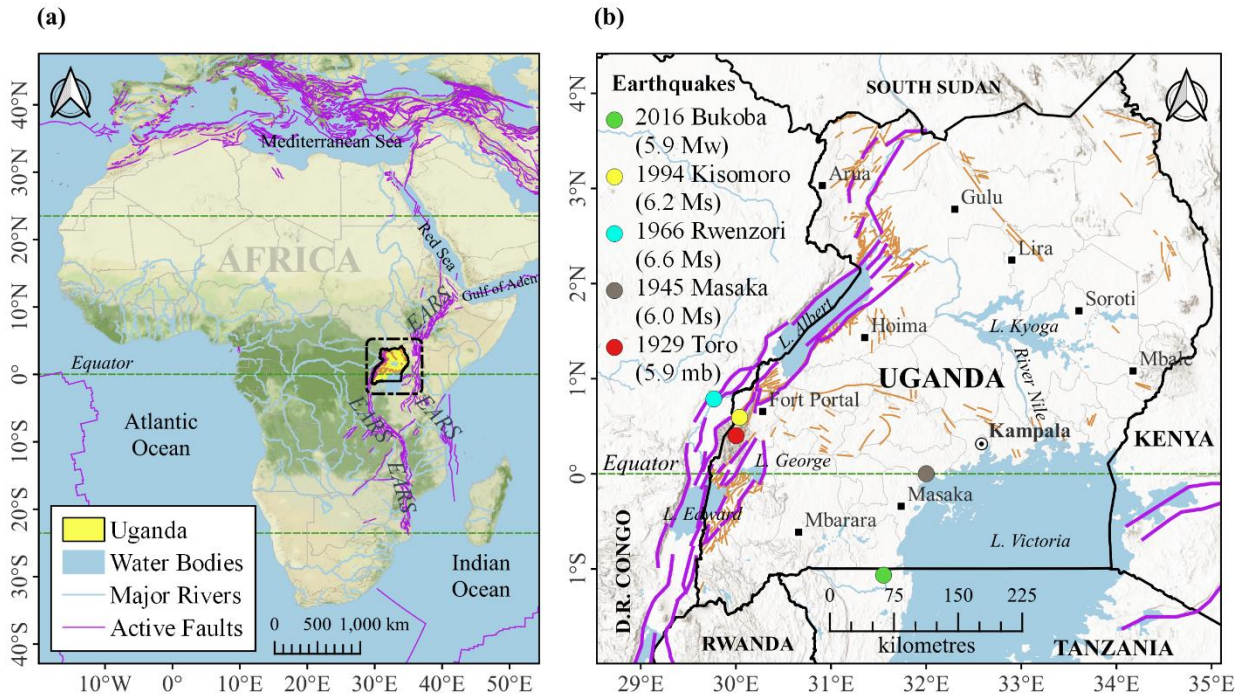


**Fig 2.1 (a)** Geographical location of Uganda on the African continent, and **(b)** Location of the active fault system (EARS) relative to major cities and epicentral locations of the most destructive earthquakes which occurred in Uganda and around its neighbouring countries

Later in 1994, the Kisomoro earthquake of 6.2  $M_s$  hit the districts of Bundibugyo, Kabarole and Kasese and prompted the emergence of hot springs in Buranga (Sempaya) geothermal field (Cheriberi and Yee, 2022; Hampton, 1995; Midzi and Manzunzu, 2014). The National Earthquake Disaster Committee reported that this event killed 8 people, caused several injuries (NEDC, 1994) and economic losses worth US\$ 60 million were incurred in the districts of western Uganda (Kahuma et al., 2006). Recent earthquake events have caused higher economic losses in the region. For instance, the 2016 Bukoba earthquake with 5.9  $M_w$  struck north Tanzania on the western shore of Lake Victoria; causing 11 deaths, more than 440 injuries and economic losses estimated in excess of US\$ 458 million in the Kagera region of Tanzania. Although the majority of the effects were felt in the neighbouring country, Rakai district of Uganda (located at the Uganda-Tanzania border) registered 4 deaths and over 590 people were affected in this unprecedented disaster (Balikuddembe and Sinclair, 2018).

Even though past earthquakes have resulted in relatively small losses, it is worth noting that damages are likely to escalate due to fast population growth and urbanisation. According to the most recent national census, the population of Uganda increased from 9.5 million in 1969 to 34.6 million in 2014, with a 3 % average yearly growth rate between 2002 and 2014. By June 2022, Uganda's population was estimated at over 44.2 million (UBoS, 2022). Increased losses may arise due to a growing population of substandard building stock (Hashemi, 2017; Twesigomwe, 1997). Despite damages due to past earthquakes, seismic design principles are

often ignored and as such, the displacement capacity of most existing buildings is not enhanced. Moreover since modern constructions are larger and heavier than traditional constructions, they are inherently more vulnerable to damage in the event of ground motion, especially when seismic design is neglected (Brzev et al., 2013; Vicente et al., 2011).

To manage earthquake risks and significantly reduce fatalities, casualties and economic losses, appropriate pre- and post-disaster risk mitigation strategies ought to be developed and adequately implemented. Whilst several earthquake risk assessment tools such as HAZUS (FEMA, 2003) and RADIUS (Villacís, 1999) have been developed to manage the associated seismic risks, their applicability in developing countries like Uganda is still difficult; partly due to scarce records of historical earthquakes, lack of empirical data required to calibrate and numerically verify site-response models, and scanty information on active fault characteristics (Sianko et al., 2020). Despite Uganda's lack of detailed information relating to earthquakes, there is high demand for a seismic risk assessment tool which relies on data that can be readily obtained from local agencies or by local surveys.

At a national level, mitigation of earthquake risk largely requires the formulation and implementation of appropriate seismic design codes. The current seismic design guidelines of Uganda (US 319:2003) (UNBS, 2003) are not only obsolete, but also not in line with modern seismic design codes like Eurocode 8-1 (CEN, 2004). In that respect, there is an urgent need to review and update US 319:2003 (UNBS, 2003) so as to reflect advanced understanding of the seismic behaviour of structures developed in recent decades. However, the hazard and socio-economic (including the national building inventory) level need to be quantified first.

Even though future earthquake occurrences cannot be predicted accurately, sufficient understanding of global and local seismology, geology and tectonics is often used to arrive at reasonable estimates of earthquake hazards. This work presents a rigorous probabilistic seismic hazard assessment (PSHA) that relies mostly on the readily available seismic data for Uganda. Using *OpenQuake* engine (Pagani et al., 2014), a stochastic event-based modelling approach is used to generate synthetic earthquake catalogues by randomising key hazard parameters such as epicentral location, maximum magnitude, hypocentral depth, and basic geo-tectonic setting.

This paper commences with a review of previous hazard studies in the region, followed by a sequential description of the underlying methodology adopted. The following sections explain the data collection and processing, seismic source characterisation, and implementation of ground motion prediction equations (GMPEs) used to characterise site response. The remaining parts present and discuss the Monte-Carlo (MC) based PSHA results for Uganda, developed using a fault-oriented spatially smoothed seismicity technique (Pagani et al., 2023; Weatherill, 2014).

## 2.2 A review of previous seismic hazard studies within and around Uganda

Prompted by the increasing human and economic losses due to previous earthquakes in Sub-Saharan Africa (SSA), several seismic hazard studies have been conducted for Uganda and its neighbouring countries. [Twesigomwe \(1997\)](#) compiled instrumental catalogues from 1900 to 1991 and produced a classical PSHA for Uganda. Earthquake magnitudes were homogenized to  $M_s$  scale based on conversion equations suggested by [Ericsson \(1971\)](#). Due to insufficient strong ground motion records, the ground motion prediction relationship of [Krinitzsky et al. \(1988\)](#) was semi-theoretically calibrated. Seismic hazard across Uganda was subsequently described in terms of mean peak ground acceleration (PGA) only. Results show that for a 10 % probability of exceedance (POE) in 50 years, western Uganda can expect a PGA of 0.22 g; whereas PGAs between 0.05 and 0.06 g were predicted across the other parts of the country.

[Midzi et al. \(1999\)](#) used the earthquake records compiled by [Turyomurugendo \(1996\)](#) and *FRISK88M* ([McGuire, 1996](#)) software to perform a conventional PSHA for Southern and Eastern Africa. Assuming a *Poisson* model of earthquake occurrences, dependent events were removed using the [Lazarov and Christoskov \(1981\)](#) declustering algorithm. Then, the regional GMPEs established by [Jonathan \(1996\)](#) and [Twesigomwe \(1997\)](#) were used to generate hazard maps for a 10 % POE in 50 and 100 years. The results show a relatively higher seismic hazard with a maximum PGA raising to 0.27 g along the western arm of the EARS. In another study, [Mavonga and Durrheim \(2009\)](#) used the regional GMPEs of [Mavonga \(2007b\)](#), [Atkinson and Boore \(2006\)](#) and [Jonathan \(1996\)](#) to conduct a classical PSHA for Democratic Republic of the Congo (DRC). A linear regression curve fitting method was used to calculate the Gutenberg-Richter recurrence parameters from the incremental and cumulative values obtained using *Seisan* ([Havskov and Ottemöller, 2003](#)) software. However, a maximum likelihood method which implicitly makes assumptions regarding the stationarity of events for all periods would give more efficient and unbiased results ([Felzer, 2008](#)). Nonetheless, the study predicted that Lake Tanganyika rift was prone to the highest level of seismic hazard, in which a maximum PGA of 0.16 g was expected for a 10 % POE in 50 years.

[Delvaux et al. \(2017\)](#) performed a classical PSHA based on a novel seismo-tectonic zonation which integrates neotectonic fault systems, seismology, geology, location of thermal springs and basin architecture of the Kivu rift region. One major drawback in this study is that completeness magnitudes were estimated visually from the change in slope of Frequency-Magnitude-Distribution (FMD), yet the other statistical approaches appraised by [Woessner and Wiemer \(2005\)](#) would effectively give more realistic estimates. Nevertheless, hazard maps were computed using *R-CRISIS* ([Ordaz and Salgado-Gálvez, 2017](#)) software and the results indicated lateral variation in tectonic setting and higher PGAs raising to 0.43 g around Bukavu

city in eastern DRC. The higher PGAs can be attributed to the use of GMPEs (Mavonga, 2007a; Jonathan, 1996 and Twesigomwe, 1997) that are semi-empirically derived and not calibrated against actual strong motion records.

Another study on the seismicity of the Albertine region used the GMPE suggested by Pankow and Pechmann (2006) and predicted maximum PGA values of 0.256, 0.195 and 0.162 g for 2, 5 and 10 % POE in 50 years respectively (Bwambale et al., 2015). As this study focused on the Albertine graben only, outputs cannot arguably be used to assess seismic risk for Uganda, as a whole. Conversely, Cheriberi and Yee (2022) conducted a preliminary PSHA for the entire country. Unfortunately, hazard maps showing 10 % POE in 5, 10, 20, 50, 100 and 500 years were produced in terms of PGA only and damped Response Spectral Acceleration (RSA) was not considered in the analysis. In a more comprehensive pilot study by the Global Earthquake Model (GEM) and *AfricaArray*, Hazard Modeller's Toolkit (HMTK) (Weatherill, 2014) was used to explicitly perform an assessment of seismic hazard related to the EARS (Poggi et al., 2017). Even though this study investigated the entire SSA with a fairly wide mesh of 10 km, the results were largely consistent with the previous Global Seismic Hazard Assessment Project (GSHAP) model initially proposed by Midzi et al. (1999).

This study presents a detailed compilation and refinement of the Uganda earthquake catalogue, prior to the estimation of the associated recurrence parameters. Herein, the zonation proposed incorporates the geology and seismo-tectonic setting of the country in a more refined manner; with the investigation area comprising a mesh spacing of 2.5 km. Although site-dependent hazard predictions may be useful, additional bedrock hazard results are derived by assuming free rock conditions with a fixed 30-metre average shear-wave velocity reference of 760 m/s assigned to each site of the investigation mesh. Whereas past studies have largely utilised the conventional PSHA method, the novelty of this work is that it employs a MC-based PSHA approach. Herein, physics-based GMPEs are implemented to generate ground motion fields from which intensity measures are simulated at various locations in Uganda. The MC-based PSHA model developed in this study can be used to propose more realistic elastic and design response spectra for a new version of the Uganda seismic design code, towards enhancing the country's resilience against future earthquake risks.

### 2.3 Geology, tectonics and morphology of Uganda

The tectonic history of Africa is largely characterised by the EARS, a divergent continental plate boundary superimposed on the African plate (Chorowicz, 2005; Ebinger, 1989). The EARS is an extension plate boundary between the Nubian and Somalian plates, opening at an average annual rate of 6-7 mm (Fernandes et al., 2004). With time, as the Nubian and Somalian plates move further away from each other, the area between them will drop below sea level as

the crust grows thinner. This phenomenon could eventually lead to the formation of a new oceanic lithosphere along the centre of the rift, thus producing a new narrow ocean basin with its own mid oceanic ridge (Chen and Scawthorn, 2003; Macgregor, 2015).

The orientation of the rifts, highlands and associated volcanic activity suggests that rifting of the continental lithosphere (36-43 km thickness) is possibly due to a rising mantle plume formed beneath the *Afar* region. Accompanied by large flood basalts, this rifting causes stretching and fracturing of the brittle lithosphere (Kampunzu et al., 1986). Since Uganda is located between the two active arms of the EARS, its unique geography and morphology offer an ideal basis for observing the seismicity, tectonics and geological processes associated with the rift system. A review of Uganda's geology and geodynamic development from historical data indicates that extensive variations in geochronological, structural, petrologic and geochemical development have been recorded during a long geological timescale of over three billion years (Maasha, 1975; Schlüter, 2008). As presented in Fig 2.2, Uganda's geology largely comprises Neo and Mesoarchean lithospheric fragments welded together by Palaeo, Meso and Neoproterozoic fold belts. A few regions consist of Neogene, Paleogene and Permian-Upper Carboniferous segments of Phanerozoic structure (Westerhof et al., 2014). In light of Uganda's geology and seismo-tectonic environment, the major features responsible for the seismicity of the country are shown in Fig 2.2; and these include:

1. The EARS is an approximately 4000 km long Cenozoic age continental rift stretching from *Afar* triple junction to western Mozambique. Its geology mainly consists Precambrian metamorphic rocks, sedimentary rocks of Miocene age, and a series of Neogene and quaternary lacustrine and fluvial deposits (Fairhead and Stuart, 1982; Sykes and Landisman, 1964). The development of the EARS, whose magmatically very active eastern branch contains the world's most potassium-rich rocks, is attributed to the Neogene extension (Albaric et al., 2010). The formation of the EARS likely started from Turkana rift located along its eastern branch (Furman et al., 2006; McDougall and Brown, 2009); followed by its western arm which has a larger concentration of earthquakes starting from South Sudan and terminating in Malawi (Roberts et al., 2012). It is worth noting that the EARS is amongst the world's most seismically active continental rifts (Asefa and Ayele, 2021). Uganda's western border lies along the Western Rift System (WRS) of the EARS. The northern segment of the WRS (Albertine and Rwenzori rifts) is the locus of the Rwenzori Mountains, which is a peninsula of up to 5109 m in altitude and the world's most extreme expression of rift-flank uplift (Maasha, 1975; Twesigomwe, 1997). The WRS is composed of a series of linked half-graben basins (typically 80-160 km long and 30-60 km wide) which are occupied by large lake systems (Karp et al., 2012).

2. The geology of the Rwenzori Fold Belt (RFB), which stretches from the boughs of the Rwenzori Mountains in western Uganda, mainly comprises Paleoproterozoic low to high grade metamorphic rocks of the Buganda-Toro system and selected sediments of undifferentiated Granites. Geological evidence shows that faulting observed along the RFB continues across Lake Victoria to Speke Gulf and Kavirondo rift in south-western Kenya; and terminates across the Tanzanian border (Darracott, 1974; McConnell, 1972). These are generally strong tectonic nature folds of east to west orientation; and are superimposed on the Archean rocks of Uganda's shield (Cahen et al., 1966; Spooner et al., 1970; Tanner, 1970). Numerous tertiary and quaternary faults strike parallel to the general trend of the RFB; partly due to the initially imposed uplift stresses in western and eastern Uganda, and down warping of the Lake Victoria basin (Maasha, 1975).

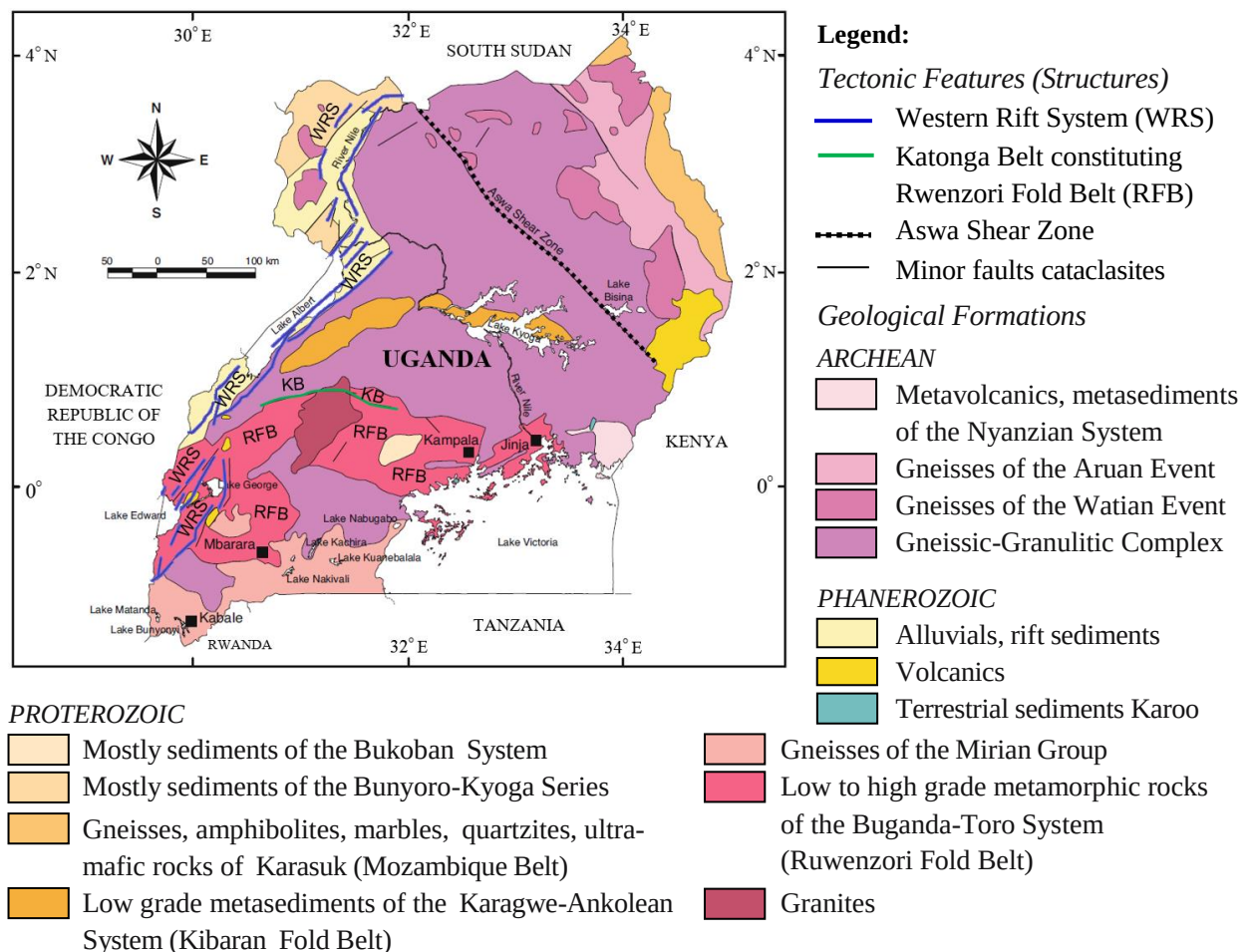


**Fig 2.2** Map of Uganda showing the generalised geology and major tectonic features responsible for the seismicity of the country (MacDonald, 1966; Muwanga et al., 2001; Schlüter, 2008)

3. Other than the WRS and RFB which have over time experienced low and moderate seismicity, the other parts of the country constituting the Uganda craton have (in the past)

recorded little seismicity. The major tectonic feature in this shield is the Aswa Shear Zone, which is a cataclasites superimposed on a stable continental crust (Gneissic-Granulitic Complex) (Schlüter, 2008). Therefore, the Aswa Shear Zone typically exhibits inactive seismicity except at its northern end where it intercepts the WRS (Hartnady et al., 1992).

On the other hand, Uganda has previously experienced some volcanic activity, for instance across the Elgon and Muhabura mountains, in addition to fault-related seismicity. Recently, the National Geophysical Data Center in conjunction with the World Data Service reported catastrophic impacts due to the May 2021 volcanic eruption of Mountain Nyiragongo, located 10 km from Goma in the neighbouring DRC (NGDC and WDS, 2022). Although volcanic activity is not included in this work, future studies will aim at the development of the associated volcanism hazard assessment framework for Uganda.

## 2.4 Monte Carlo (MC) based PSHA: methodology

In this work, the stochastic event-based PSHA calculator for distributed seismicity, embedded within the *OpenQuake* engine (Pagani et al., 2014), is used to perform a MC-based PSHA which relies on earthquake data available for Uganda. Regarding source typologies, the present study adopts area source zones (ASZs) which are tectonically and seismically homogeneous. ASZs are treated independently, and the *Poisson* model is assumed for all possible rupture scenarios (Crowley, 2005; Johnson and Pagani, 2021). For each rupture scenario, sample realisations from each intensity measure are determined using MC simulations (Musson, 1999).

The MC-based procedure for predicting seismic hazard at a particular site of interest essentially starts with earthquake catalogue refinement through magnitude harmonisation, de-clustering and completeness analysis; prior to delineating ASZs based on geological, seismological and spatial distribution of earthquakes. Following the procedure proposed by Crowley and Bommer (2006), synthetic earthquake catalogues (occurrence, magnitude and location of event in a particular year) are then produced by randomizing key parameters obtained from past seismicity, tectonic regimes and geological data to represent the future seismic behaviour of the area of interest. The distances between earthquake events (from all sources) and the sites of interest are then computed for each year of synthetic catalogue. The ground motion intensities at a particular site are calculated using GMPEs, fault typologies and soil parameters. The ground shaking intensities at a specific site due to all events occurring in a particular year of synthetic catalogue are then determined. This process is repeated for a given number of simulations; for instance, 1000 simulations of 100 years of earthquake catalogue. All ground motion levels at a given site are subsequently combined and sorted in decreasing order of severity. Finally, ground shaking values at a specific site for the desired return periods are determined; and the process repeated for all sites (Sianko et al., 2020).

As opposed to the conventional PSHA method, the MC-based PSHA approach provides several advantages because of its convenience when applying physics-based GMPEs in which intensity measures are computed as realisations instead of probability distributions (Graves et al., 2011). This stochastic modelling approach is beneficial for spatially distributed seismicity where intensity measures are simulated at various locations, thereby allowing model flexibility. On the contrary, the computational cost of the MC-based PSHA is quite demanding as such simulations produce a substantial amount of data. Moreover, a sufficient number of realisations ought to be simulated to generate an adequate number of stochastic event sets (Baker et al., 2021). Additional descriptions of a stochastic event-based PSHA using MC simulations can be found in literature (e.g., McGuire, 2004; Field et al., 2003 and Musson, 1999).

## 2.5 Earthquake catalogue for Uganda

In PSHA, earthquake catalogues are required to quantify seismicity, determine seismic source zonation and parameters associated with earthquake occurrence in such source zones, and to generate synthetic earthquake catalogues. The first step taken towards performing a PSHA is to compile and merge existing historical and instrumental catalogues prior to homogenisation, declustering and completeness analyses. Considering the design earthquake for SSA, a minimum buffer zone of at least 50 km is assumed within the selected geographical area (-2.7° to 5.9° North, 28.1° to 36.5° East) for acquisition of earthquake data. The GEM catalogue toolkit (Weatherill et al., 2016) is then used to update the earthquake records. The following sections describe the steps taken to produce and refine the earthquake catalogue for Uganda.

### 2.5.1 Catalogue compilation

The first earthquake catalogue is obtained locally from the Directorate of Geological Survey and Mines (DGSM), under the Ministry of Energy and Mineral Development (MEMD) in Uganda. However, due to the existence of large solution uncertainties caused by insufficient station coverage and absence of historical records, catalogues are obtained from other credible global agencies and bulletins. Catalogues from global databases are merged with the records from DGSM. Considering all events with  $M_w \geq 4$  as the minimum threshold capable of causing structural damage, earthquake catalogues (Appendix A) are selected and prioritised as follows:

#### 2.5.1.1 ISC-GEM catalogue

This global instrumental catalogue, compiled by International Seismological Centre (ISC) in conjunction with GEM, is a refined version of the ISC bulletin (ISC, 2022) and with all event magnitudes homogenised to the  $M_w$  scale. It presents an improvement on the accuracy of the location and magnitude for events with  $M_w > 5.5$ , and occurring between 1900 and 2014 (Di Giacomo et al., 2018; Storchak et al., 2013; Storchak et al., 2015). In this work, 84 events are

recorded in the ISC-GEM catalogue. This catalogue is prioritised over the other global bulletins because it is refined. Since the ISC-GEM catalogue includes hypocentral depths for all events, its records are primarily adopted to perform reasonable statistical analyses of hypocentral depth distribution across the study area.

#### 2.5.1.2 USGS catalogue

This is a global database consisting of seismic data recorded by the United States Geological Survey ([USGS, 2022](#)). Although event magnitudes are later harmonised to the  $M_w$  scale, events in this database are recorded using various magnitude scales. For the study region, this database recorded 364 events (out of 1512 events), including the hypocentral depths of all events. In this work, the records obtained from the USGS catalogue are given second priority.

#### 2.5.1.3 ISC reviewed bulletin

This bulletin initially provided one of the primary earthquake catalogues which are manually reviewed by ISC, with a coverage which dates to the start of the 20<sup>th</sup> century ([ISC, 2022](#)). In this bulletin, event magnitude scales vary between time periods and agencies. For the selected geographical area, it contains 671 events (out of 1512 compiled events) spanning between 1903 and 2022. However, hypocentral depths of some events are not recorded. In that respect, events recorded in the ISC bulletin are prioritised after the USGS catalogue.

#### 2.5.1.4 DGSM catalogue

The DGSM, an agency under MEMD, is mandated with the responsibility of monitoring and recording earthquakes in Uganda. Earthquake datasets obtained are recorded in the  $M_s$  scale and span from 1970 to 2022. A total of 842 events are recorded within and around Uganda. However, these include small-magnitude ( $M_s < 4.0$ ) events that are ignored in subsequent analyses. Thus, only 250 events with  $M_s \geq 4.0$  are considered. The hypocentral depths of all events are recorded in this catalogue ([DGSM, 2022](#)). The agency recommended ISC reviewed bulletin ([ISC, 2022](#)) as a reliable record for events that occurred before 1970. Accordingly, the DGSM catalogue is given fourth priority during duplicate identification and removal.

#### 2.5.1.5 GEM global historical earthquake archive

This archive is a collection of reviewed global historical events, which generally comprises of 825 large magnitude earthquakes that occurred between 1000 and 1903 ([Albini et al., 2013](#)). Due to the plausible lack of historical records in SSA, additional events are obtained from the reappraisal of major African earthquakes between 1900 and 1930 ([Ambraseys and Adams, 1991](#)). In total, both of these compilations contained only 2 events within Uganda and around

its immediate environs. In the process of merging the catalogue for Uganda, all events compiled from the GEM global historical earthquake archive are used directly without prioritisation.

#### 2.5.1.6 Compilations from Literature

A summary of previous earthquakes in Uganda and its vicinity between 1912 and 1973 was compiled from published studies (e.g., [Fairhead and Girdler, 1971](#); [Fairhead and Stuart, 1982](#); [Gutenberg and Richter, 1941](#); [Rothé, 1969](#) and [Sutton and Berg, 1958](#)). Out of the 1512 events, 134 are obtained from this compilation ([Maasha, 1975](#)). Although earthquake magnitudes were harmonised to the  $m_b$  scale, the depths of some events were unfortunately not recorded. Hence, this dataset is least prioritised when generating the final earthquake catalogue for Uganda.

### 2.5.2 Duplicate finding and catalogue merging

Since the Uganda earthquake catalogue used in this work is compiled from several databases, it is important to identify and remove duplicate events before the catalogue refinement process. This is because different bulletins have their own versions of the origin time, location, accuracy of measurement, and magnitude scales etc. After merging catalogues from different sources, earthquakes falling within a prescribed temporal and spatial window are assumed to represent the same seismic event. Different studies have attempted to define time and space windows for duplicate removal. For instance [Jones et al. \(2000\)](#) proposed that two events may be considered duplicates if they differ by less than 100 km and 16 seconds in space and time respectively. However, [Jónasson et al. \(2021\)](#) discovered that the suggested window was too strict and rather proposed 320 km and 16 seconds. The most appropriate window should be decided based on the seismic network, geology and seismo-tectonics of the region in question.

In this regard, a more representative pilot study by GEM and *AfricaArray* ([Poggi et al., 2017](#)) indicated relative uncertainties between agencies recording and reporting events in SSA. The study noted that larger windows gave erroneous results by misrepresenting earthquakes in an aftershock sequence as duplicates. Accordingly, best results were obtained with a space and time windows of  $0.5^\circ$  (approximately 55.5 km) and 120 seconds respectively. Since Uganda lies within SSA, it is likely that the country's geology and seismo-tectonics are similar. Therefore, this study adopts the same windows to identify and remove duplicate events. Employing these windows gives 768 duplicate events (out of 1512). The final updated earthquake catalogue consists of 744 major events starting from the twentieth century.

### 2.5.3 Homogenisation

Following catalogue merging and removal of duplicate seismic events, the magnitude of events is harmonised to the  $M_w$  scale. Due to lack of calibration data for Uganda, this study prioritises

more credible globally proposed magnitude conversion equations. A summary of the list of agencies and their respective conversion equations, largely adopted from [Poggi et al. \(2017\)](#), is presented in Table 2.1.

**Table 2.1** Agencies and their corresponding moment magnitude conversion equations

| Agency <sup>‡</sup> | $M_w$ conversion rule        | Range           | References                                                                          |
|---------------------|------------------------------|-----------------|-------------------------------------------------------------------------------------|
| ISC                 | $0.616M_s + 2.369$           | $M_s < 6.0$     | <a href="#">Weatherill et al. (2016)</a>                                            |
|                     | $0.994M_s + 0.1$             | $M_s \geq 6.0$  |                                                                                     |
|                     | $1.084m_b - 0.142$           | $m_b < 6.5$     |                                                                                     |
| NEIC                | $0.723M_s + 1.798$           | $M_s < 6.5$     | Assumed 1:1 scaling and arbitrary uncertainty (0.3)                                 |
|                     | $1.005M_s - 0.026$           | $M_s \geq 6.5$  |                                                                                     |
|                     | $1.159m_b - 0.659$           | $m_b < 6.5$     |                                                                                     |
| PRE                 | $M_L$                        | $M_L < 6.0$     | <a href="#">Edwards et al. (2010)</a>                                               |
| BUL                 | $M_{blg}$                    | $M_{blg} < 6.0$ |                                                                                     |
| TZB, ETP, AAE       | $1.02 + 0.47M_L + 0.05M_L^2$ | $M_L < 5.0$     |                                                                                     |
| PAS                 | $0.616(M_s - 0.2) + 2.369$   | $M_s > 6.0$     | ISC- $M_s$ corrected, as suggested in <a href="#">Engdahl and Villaseñor (2002)</a> |
|                     | $0.994(M_s - 0.2) + 0.1$     | $M_s < 6.0$     |                                                                                     |

<sup>‡</sup> Acronyms defining agencies are taken from the ISC website (Contributing agencies ([isc.ac.uk](http://isc.ac.uk)), accessed on 21 June 2022). For prioritization, agencies are sorted in decreasing order.

In addition, Fig 2.3a shows the distribution of seismicity over time for all events in the merged, homogenised, but non-declustered earthquake catalogue for Uganda. Event distribution is not uniform over the investigated period as there are more events reported after 1957, especially for lower magnitudes. This can be attributed to the contribution from seismic monitoring stations like the Lwiro network established in the 1950s. According to [DGSM \(2022\)](#), the installation of several seismic networks (e.g., Entebbe station in 1991, Hoima and Kilembe in 1992, Dundu in 1995, and Kyahi station in 1999) is partly responsible for the recent increase in reporting of earthquakes (especially small magnitude events) within and around Uganda.

#### 2.5.4 Declustering

The sequence of earthquakes often features numerous aftershocks and foreshocks which are related to the mainshocks. In as much as these correlated events are not necessarily irrelevant in seismic hazard and risk assessments ([Boyd, 2012](#)), it is vital to decluster seismicity data through a systematic identification of earthquake clusters before estimating mean occurrence rates. Several algorithms (e.g., [Gardner and Knopoff, 1974](#); [Reasenber, 1985](#); [Knopoff, 2000](#) and [Bustos, 2009](#)) have been developed to apply fixed distance and time windows for finding correlated events using magnitude bins of each mainshock. The HMTK ([Weatherill, 2014](#)) is used to run the original [Gardner and Knopoff \(1974\)](#) algorithm; together with the subsequent

modifications by Grünthal ([van Stiphout et al., 2012](#)) and [Uhrhammer \(1986\)](#) described in Eqs. (2.1), (2.2) and (2.3) respectively.

$$d = 10^{0.1238M+0.983} \quad t = \begin{cases} 10^{0.032M+2.7389} & \text{if } M \geq 6.5 \\ 10^{0.5409M-0.547} & \text{else} \end{cases} \quad (2.1)$$

$$d = e^{1.77+(0.037+1.02M)^2} \quad t = \begin{cases} e^{-3.95+(0.62+17.32M)^2} & \text{if } M \geq 6.5 \\ 10^{2.8+0.024M} & \text{else} \end{cases} \quad (2.2)$$

$$d = e^{-1.024+0.804M} \quad t = e^{-2.87+1.235M} \quad (2.3)$$

where  $d$  is the distance window (in km),  $t$  is the time window (in days), and  $M$  is the earthquake size (preferably in the moment magnitude scale).

For each assumed earthquake mainshock, fixed distance and time windows required to isolate and remove correlated/clustered events from the sorted catalogue are calculated using Eqs. (2.1-2.3). Additionally, the [Knopoff \(2000\)](#) procedure provides window parameters for events ranging in magnitude between 4.2 and 6.0. Following tendencies of time and distance windows from [Gardner and Knopoff \(1974\)](#), [Bustos \(2009\)](#) modified the [Knopoff \(2000\)](#) procedure by extrapolating the spatial and temporal windows for events with magnitude greater than 6.0. Subsequently, a code ([MATLAB, 2021b](#)) is developed to run the modified [Knopoff \(2000\)](#) algorithm extended by [Bustos \(2009\)](#).

The number of mainshocks and dependent events in the refined catalogue according to each algorithm is listed in Table 2.2. For instance, the declustered catalogue consists of 543 events out of the original 744 (approximately 27 % removal of dependent events) in the range of  $4.1 \leq M_w \leq 7.2$  following the modified [Knopoff \(2000\)](#) algorithm. The results show that other declustering algorithms remove more events due to larger windows. Therefore, as a conservative approach for estimating seismicity rates of occurrence, the declustered catalogue based on modified [Knopoff \(2000\)](#) algorithm is adopted in subsequent analyses.

A comparison between cumulative distribution of earthquakes before and after removal of dependent events for all  $M_w \geq 4$  events that occurred between 1903 and 2022 is shown in Fig 2.3b. The plot shows that the number of events in the declustered catalogue is less than those in the non-declustered data by approximately 27 %. This plot is similar to the analysis done by [Poggi et al. \(2017\)](#); although more earthquake events were removed in their work since the original [Gardner and Knopoff \(1974\)](#) declustering algorithm was employed, notwithstanding the much wider area (encompassing the entire sub-Saharan Africa) comprising many more earthquake records.

**Table 2.2** Summary of non-Poissonian events removed using various algorithms

| Algorithm                  | Mainshocks | Events removed | Percentage of events removed (%) | Clusters |
|----------------------------|------------|----------------|----------------------------------|----------|
| Gardner and Knopoff (1974) | 365        | 379            | 50.54                            | 101      |
| van Stiphout et al. (2012) | 309        | 435            | 58.13                            | 98       |
| Uhrhammer (1986)           | 511        | 233            | 30.76                            | 70       |
| Musson (1999)              | 485        | 259            | 34.28                            | 76       |
| Modified Knopoff (2000)    | 543        | 201            | 27.02                            | 99       |

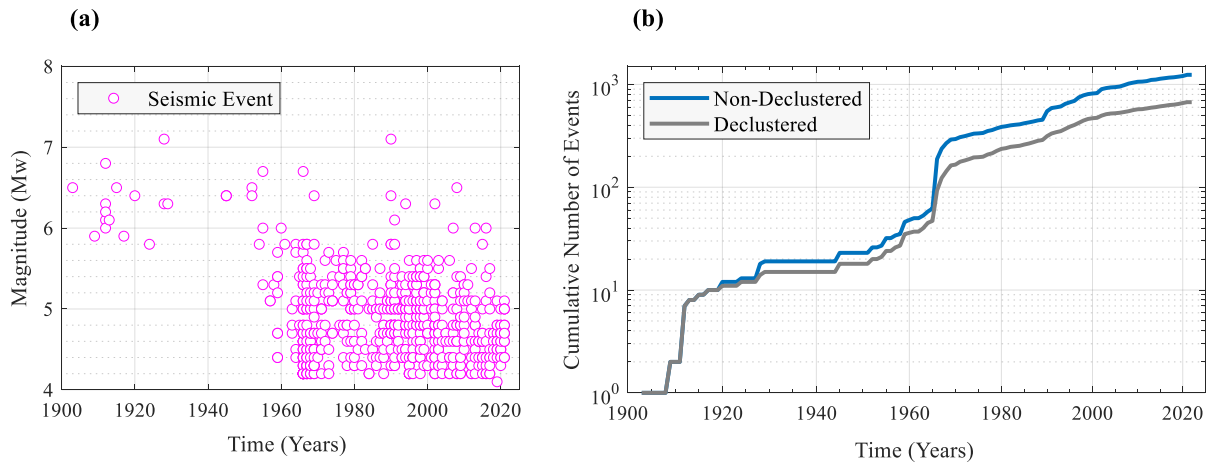


**Fig 2.3 (a)** Distribution of seismicity over time for the events in the homogenised, non-declustered earthquake catalogue for Uganda; and **(b)** Comparison between cumulative distribution of earthquakes before and after fore-/aftershock cluster removal

### 2.5.5 Completeness Analyses

Earthquake catalogue completeness procedures (e.g., [Alamilla et al., 2015](#); [Hafiez, 2015](#) and [Stepp, 1972](#)) characteristically involve identifying magnitude thresholds for which significant departures from the expected occurrence rates are observed. For each magnitude level, the catalogue completeness periods may start at different points in time. Whilst large magnitude events are often complete from earlier dates in time, small magnitude earthquakes tend to be complete for recent periods ([Sianko et al., 2020](#)). In undertaking completeness analysis for the Uganda catalogue, [Stepp \(1972\)](#) procedure is first implemented using the HMTK ([Weatherill, 2014](#)). However, this algorithm gives erroneous results for large magnitudes, possibly because of sparse and largely irregular data coverage. Subsequently, completeness magnitude ( $M_c$ ) values are determined statistically using maximum curvature ([Wiemer and Wyss, 2000](#)) and  $b$ -value stability ([Cao and Gao, 2002](#)) methods; in combination with a bootstrapping mechanism ([Michael, 1987](#)) to cater for uncertainties. Although the use of day-to-night ratio of earthquake frequency method suggested by [Rydelek and Sacks \(1989\)](#) could have been a suitable alterna-

tive, previous studies (e.g., [Di Giacomo et al., 2015](#)) employed non-parametric and straightforward techniques like the maximum curvature method of [Wiemer and Wyss \(2000\)](#) which gives statistically robust estimates of the  $M_c$  values ([Mignan and Woessner, 2012](#)).

The Uganda catalogue is eventually divided into six periods (1900-1929, 1930-1959, 1960-1964, 1965-1969, 1970-1979, and 1980-2022) after subsequent adjustments based on network coverage and station spacing. Next, the [ZMAP \(2022\)](#) code of [Wiemer \(2001\)](#) is used to evaluate completeness thresholds and results plotted as shown in Fig 2.4. While the *red* lines indicate completeness magnitudes and periods, the *yellow* shaded area marks the incomplete dataset which is excluded from further analysis. Although deciding the completeness period for different magnitudes can be very subjective, it is concluded herein that the Uganda catalogue is complete for:  $M_w \geq 4.5$  from 1980,  $M_w \geq 4.8$  from 1970,  $M_w \geq 4.9$  from 1965,  $M_w \geq 5.3$  from 1960,  $M_w \geq 5.6$  from 1930 and  $M_w \geq 6.0$  from 1900. The completeness thresholds are in good agreement with the fact that for higher magnitudes, the completeness periods start from earlier dates while smaller magnitude events are often complete for recent time periods.

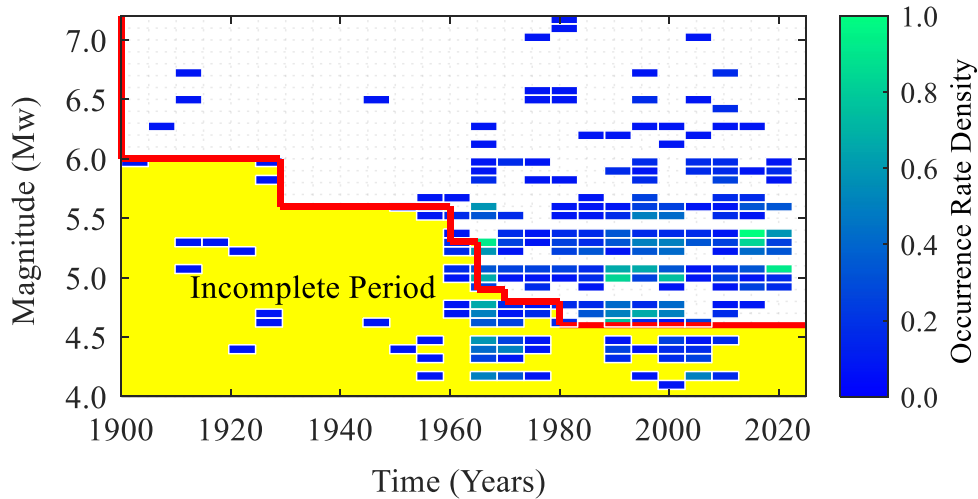


**Fig 2.4** Magnitude-time-density plot of the Uganda catalogue, with normalised rates computed for a 0.1 magnitude bin and a fixed time window of 5 years

## 2.6 Seismic source characterisation

Seismic source characterisation involves identifying and defining all possible rupture scenarios that could produce ground shaking within the model coverage area. Using fault characteristics, observed seismicity and geo-tectonic setting, a rupture scenario is mainly characterised by earthquake magnitudes and their epicentral locations, in addition to its likelihood of occurrence ([Bommer, 2022](#)). This section discusses the steps taken to characterise earthquake sources.

### 2.6.1 Zonation

Whilst there are many legitimate zonation modelling approaches, a typical strategy involves preparing the earthquake catalogue, dividing the region of interest into tectonic domains, choosing and defining source geometries and typologies, and assigning activity rates to each source zone (Baker et al., 2021; Vilanova et al., 2014). Herein, a mixed approach that accounts for observed seismicity and geo-tectonic characteristics of Uganda is adopted; principally assuming that each zone has reasonably uniform seismicity and zonation is in harmony with regional geo-tectonics. The methodological framework of this approach involves assessing a suitable scale and degree of stationarity, completeness thresholds, and credibly ranking physical criteria used to delineate ASZs. The application of this zonation strategy subsequently splits the study area into 13 ASZs. In addition to the fault system and epicentral location of major earthquakes within and around Uganda, the area source zonation model used in the MC-based PSHA is shown in Fig 2.5. The fault system shown in Fig 2.5 is obtained from the global homogenised database developed by the GEM Foundation (Styron and Pagani, 2020).

ASZs of similar geology and tectonic settings are subsequently categorised into four gross sources. Zones 1-5 are grouped to constitute the WRS category; zones 9, 10 and 12 are combined to form the RFB category stretching across to Speke Gulf and Nyanza rifts via Lake Victoria basin; the third gross source group consists of zones 8 and 13, representing the Eastern Rift System (ERS) category; and zones 6, 7 and 11 constitute the Congo-Uganda-Tanzania (CUT) craton. This approach is necessary for determining occurrence rates since certain zones recorded very few events which would not give reliable estimates of seismicity parameters.

#### 2.6.1.1 Category A: Western Rift System (WRS)

Within the study region, the WRS exhibits the largest rate of earthquake occurrence, although with limited volcanism. The northern part (Zone 2) is characterised by a series of faults which form part of the rift striking in the north-south direction (Ebinger, 1989; Twesigomwe, 1997). The WRS category includes the Albertine rift and is bounded between the south-southwest and north-northeast Lake Albert basin, east-west trending River Nile, and north-south trending Nile rift. Also, the Rwenzori mountain block is characterised by the Virunga volcanoes linked with a transverse fracture zone along the western rift axis (Kampunzu et al., 1986; Maasha, 1975).

The WRS is dominated by relatively strong seismic events which spread throughout the lithosphere and many large magnitude events have occurred within the lower crust, with hypocentral depths between 30 and 40 km (Yang and Chen, 2010). For selected fault sections along the WRS, the variation of earthquake hypocentral depths with time is presented in Fig 2.6a-d. Along the Albertine rift, the largest events (7.0  $M_w$  and 6.4  $M_w$ ) strike deeper in the lithosphere

(35 km and 32 km respectively) as shown in Fig 2.6a-b. Whereas hypocentral depths of larger earthquake ( $M_w > 4.6$ ) fall within 21 km, events less than 4.6  $M_w$  have occurred beyond 21 km depth along the Rwenzori rift as seen in Fig 2.6c-d. This observation is consistent with findings from previous studies (e.g., Brazier et al., 2005; Craig et al., 2011 and Nyblade and Langston, 1995).

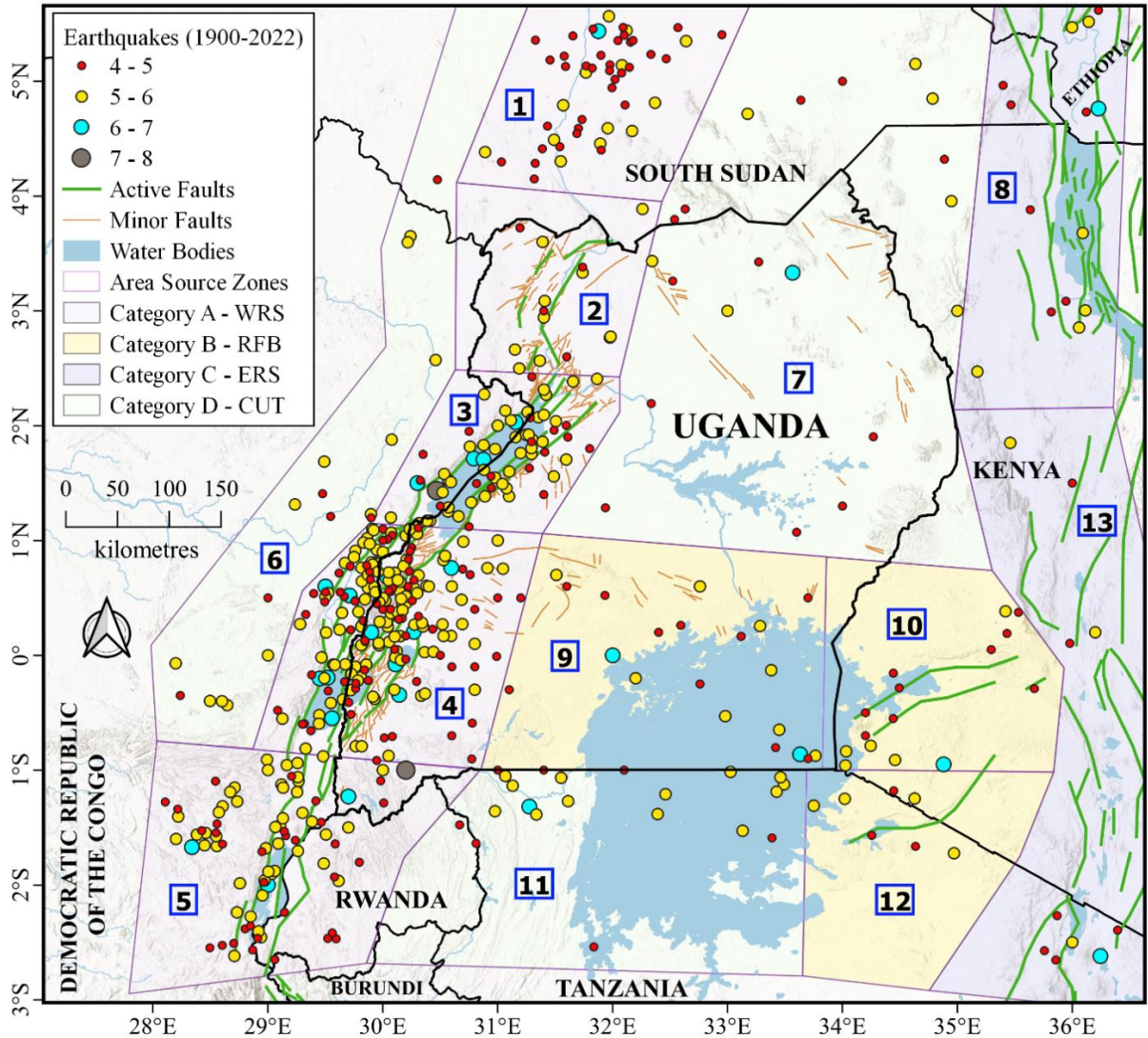


**Fig 2.5** Earthquake epicentres, active and minor fault systems, and area source zonation model used to perform the MC-based PSHA for Uganda

On the other hand, larger hypocentral depth values are computed for more recent earthquakes. This is partly attributed to the recent increase in the number of earthquake recording instruments from which more accurate hypocentral depth solutions are obtained. The variation of focal depth solutions across a horizontal section through fault lines is plotted for two example cross-sections along the WRS. Whilst Fig 2.7a shows depth variation through the Rwenzori rift, a similar variation across the Albertine rift is presented in Fig 2.7b. It can be seen that earthquakes with epicentres closer to the faults (green lines) generally occur at greater depths

compared with those further from the faults; although a few exceptions are observed. In delineating ASZs falling within the WRS, consideration is given to the observed seismicity, existing focal mechanism and fault orientation data (Macgregor, 2015). Therefore, the WRS consists of five ASZs (shown as Zones 1, 2, 3, 4, and 5 in Fig 2.5) covering various segments of the western branch of the EARS.

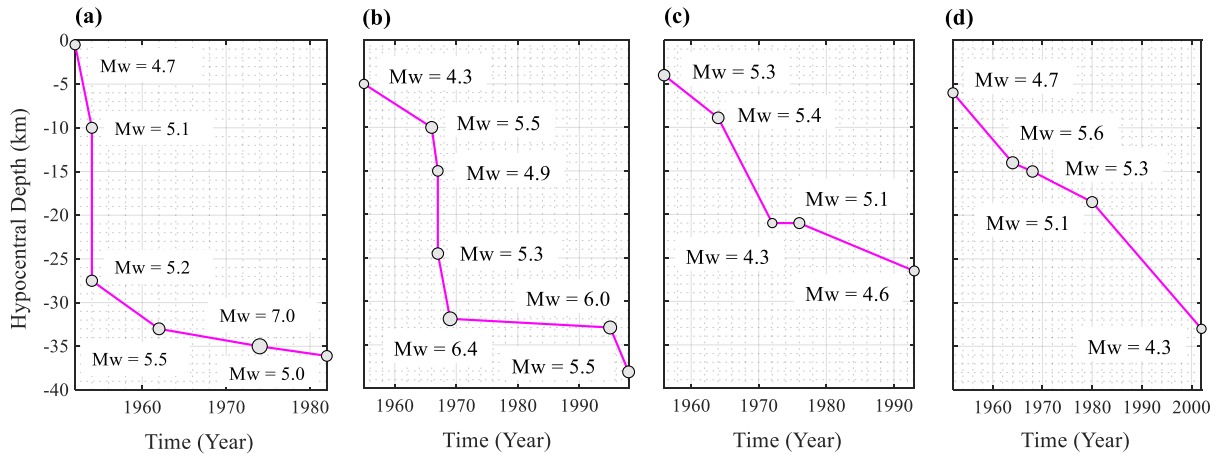


**Fig 2.6** Cross-sections through specific example faults along the two arms of the western rift system in source category A: **(a)** Left arm of the Albertine rift; **(b)** Right arm of the Albertine rift; **(c)** Left arm of the Rwenzori rift; **(d)** Right arm of the Rwenzori rift

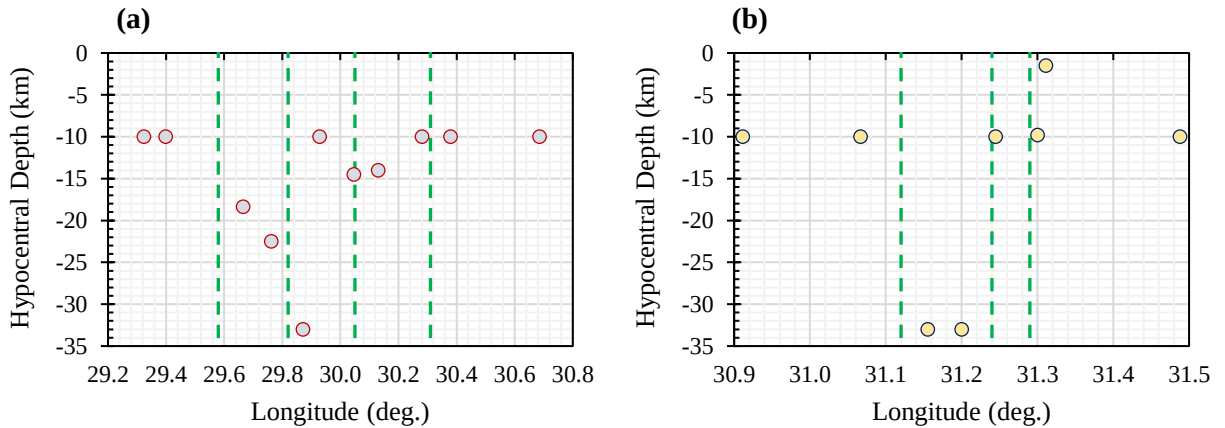


**Fig 2.7** Variation of hypocentral depths across horizontal cross-sections through selected active faults (green lines) in the Western Rift System: **(a)** Rwenzori rift (Zone 4), and **(b)** Albertine rift (Zone 3)

#### 2.6.1.2 Category B: Rwenzori Fold Belt (RFB)

This category encompasses Nyanza, Speke and Utimbere rifts as well as the connected Katonga faults. It is characterised by Tertiary and Quaternary faults which strike parallel to the Katonga rupture faulting zone; thus, capable of producing earthquakes of moderate intensity (Hartnady et al., 1992). The RFB is dominated by stable zones of seismicity originating from Tanzania

and its geo-tectonic environment is largely stable (Furman et al., 2004). Geophysical evidence shows that the lithosphere is 150-200 km below the Precambrian basement and ground shaking levels are possibly lower compared to the surrounding active rift zones (Petit and Ebinger, 2000; Saria et al., 2014). This source category contains three ASZs (shown as Zones 9, 10 and 12 in Fig 2.5) whose boundaries are predominantly delineated based on seismicity.

#### 2.6.1.3 Category C: Eastern Rift System (ERS)

The ERS is bounded by major faults that form the main parts of the eastern arm of EARS and comprises two source zones, shown as Zones 8 and 13 in Fig 2.5, starting from Turkana basin and running southwards along the Victoria microplate. The ERS is characterised by extensive grid faulting, geothermal and volcanic activity (Baker et al., 1972; Chorowicz, 2005; Dawson, 1992; Yang and Chen, 2010). Moreover, Twesigomwe (1997) indicated that the ERS comprises a diffusion fault which links its southern and northern segments. Since the ERS has few records of seismicity, geo-tectonics are mainly considered in its zonation. Further consideration is given to the zone's physical location as it lies between the Ethiopian plateau and Kenyan dome.

#### 2.6.1.4 Category D: Congo-Uganda-Tanzania (CUT) craton

This source category is intersected by the Precambrian Aswa shear zone, which is largely stable and inactive. The geology of the CUT craton mainly comprises high-grade Metamorphic rocks and Archean granitic green stones. Although the zone mainly exhibits inactive tectonic features, some earthquake events have been recorded especially around Lake Victoria (Mavonga and Durrheim, 2009; Poggi et al., 2017; Twesigomwe, 1997). This source category contains three ASZs (shown as Zones 6, 7, and 11 in Fig 2.5) whose borders are principally delineated based on geological features and micro-plate boundaries.

### 2.6.2 Focal depth distribution

Although hypocentral depths of some events are unknown, a reasonable statistical analysis based on the available samples is considered sufficient. In addition to events whose hypocentral depths have been explicitly assigned a priori, earthquakes of unrecorded focal depth solutions are excluded from this analysis. The hypocentral depth histogram presented in Fig 2.8a and magnitude-depth density plot shown in Fig 2.8b indicate that most events occur between 10 and 15 km, with very few occurring up to a maximum depth of 45 km. Moreover, larger magnitude events ( $M_w > 6.5$ ) mostly occur at depths greater than 10 km. This is consistent with previous studies (e.g., Rykounov et al., 1972; Shudofsky, 1985; Tanaka, 1983 and Tongue et al., 1994) which indicate that most earthquakes in East Africa occur at shallow depths of less than 25 km. In addition, the distribution of hypocentral depths of earthquakes falling within the four source categories is shown in Fig 2.9a-d. While many earthquakes are reported at depths

raising to 40 km, it can be observed that the largest contribution ranges between the depths of 0 and 10 km across all source groups. Because of its seismically active nature, it is obvious that seismic source category A (WRS) recorded the highest number of events contributing to focal depth solutions. Notably, the least contribution of event depths falls between 20 and 30 km across all source categories.

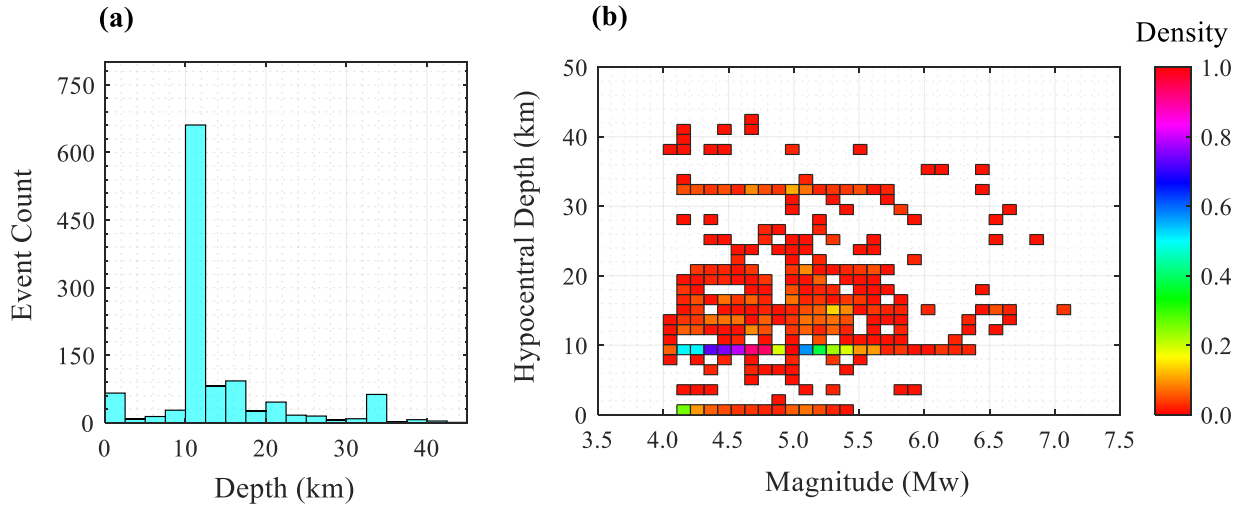


**Fig 2.8** Hypocentral depth distribution plots for the Uganda earthquake catalogue showing: **(a)** Event hypocentral depth count **(b)** Magnitude-depth density

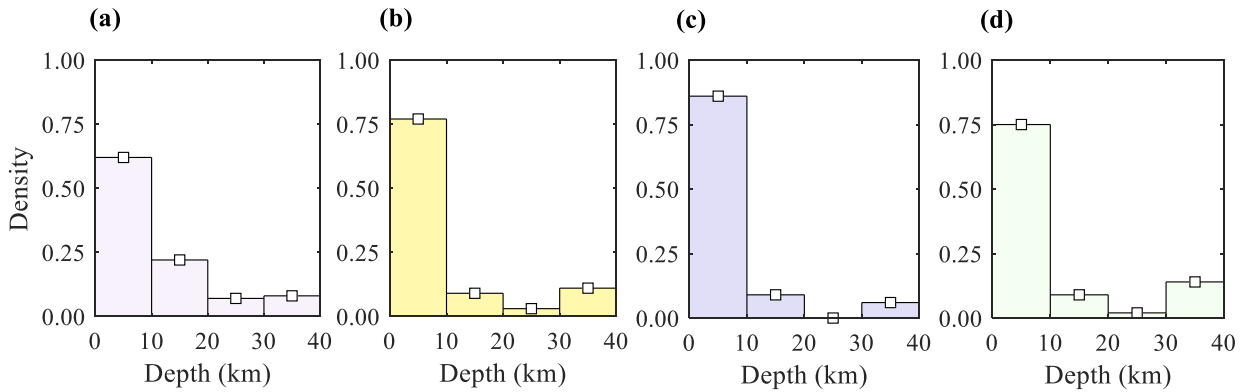


**Fig 2.9** Distribution of hypocentral depth solutions of earthquakes falling within the four seismic source categories defined in the zonation: **(a)** Category A (WRS) – 442 events, **(b)** Category B (RFB) – 35 events, **(c)** Category C (ERS) – 35 events, and **(d)** Category D (CUT craton) – 56 events

### 2.6.3 Seismicity analysis

#### 2.6.3.1 Magnitude-frequency distribution

The seismicity of a region, modelled with parameters (*a*- and *b*-values which are defined within the Gutenberg-Richter recurrence law) reflecting the characteristics of ASZs, describes the relationship between the frequency of occurrence and magnitude of earthquakes (Gutenberg and

Richter, 1944; Ishimoto, 1939). There are several approaches (e.g., Aki, 1965; Bender, 1983 and Kijko and Smit, 2012) which can be used to define the seismicity of a given region.

In this work, earthquake recurrence parameters and their associated standard deviations are estimated using the Weichert (1980) algorithm. This approach is a maximum likelihood method in which different periods of completeness for different magnitude thresholds are considered. Furthermore, the algorithm implicitly makes assumptions regarding stationarity of events for all periods, thereby considered efficient and unbiased for most applications (Felzer, 2008). In its subsequent application, Gutenberg-Richter recurrence parameters are firstly determined for the entire catalogue; and then, independently for each seismic source category because of the limited records available, especially for certain ASZs. The  $a$ -values (shown in Table 2.3) for each ASZ are estimated by imposing the initially calibrated  $b$ -values. The plots showing recurrence parameters for the four source categories are presented in Fig 2.10a-d.

**Table 2.3** Seismicity parameters for ASZs used in MC-based PSHA for Uganda

| Category      | ASZ | $M_{min}$ | $M_{max}$ | $a$ -value | $b$ -value | $\sigma(b)$ |
|---------------|-----|-----------|-----------|------------|------------|-------------|
| A. WRS        | 1   | 4.0       | 6.7       | 3.080      | 0.96       | 0.038       |
|               | 2   | 4.0       | 6.4       | 7.937      |            |             |
|               | 3   | 4.0       | 7.6       | 3.056      |            |             |
|               | 4   | 4.0       | 7.2       | 3.645      |            |             |
|               | 5   | 4.0       | 7.7       | 3.216      |            |             |
| B. RFB        | 9   | 4.0       | 7.0       | 1.721      | 0.86       | 0.139       |
|               | 10  | 4.0       | 7.0       | 2.276      |            |             |
|               | 12  | 4.0       | 6.1       | 4.576      |            |             |
| C. ERS        | 8   | 4.0       | 6.7       | 2.935      | 0.79       | 0.215       |
|               | 13  | 4.0       | 7.0       | 2.107      |            |             |
| D. CUT craton | 6   | 4.0       | 6.2       | 1.683      | 0.67       | 0.123       |
|               | 7   | 4.0       | 7.0       | 2.466      |            |             |
|               | 11  | 4.0       | 6.6       | 1.978      |            |             |

### 2.6.3.2 Maximum magnitudes

Approximation of the maximum magnitude ( $M_{max}$ ) for use in PSHA is a complicated, and often contentious process that is guided by geology and seismo-tectonic information of the seismic source of interest (Weatherill, 2014). A truncated Gutenberg and Richter (1944) model and/or other non-parametric methods based on observed seismicity are normally used to estimate the largest potential earthquakes for regional seismicity representing each areal source. Subsequently, Kijko (2004) made various assumptions and suggested three models (fixed  $b$ -value, uncertain  $b$ -value, and non-parametric Gaussian) for estimating  $M_{max}$ . Many statistical methods and Bayesian approaches are well-suited for estimating the largest potential earthquake for regional data representing areal sources (Baker et al., 2021). However, because of the lack of information relating to Uganda's seismogenic depth potential and active fault characteristics (e.g., rupture lengths, rupture widths and slip rates), it is challenging to estimate maximum magnitudes using source-scaling relationships. Consequently,  $M_{max}$  values (shown in Table 2.3

and Fig 2.10a-d) are arbitrarily determined by adding a conservative increment of 0.5 magnitude units to the maximum observed magnitude for each ASZ.

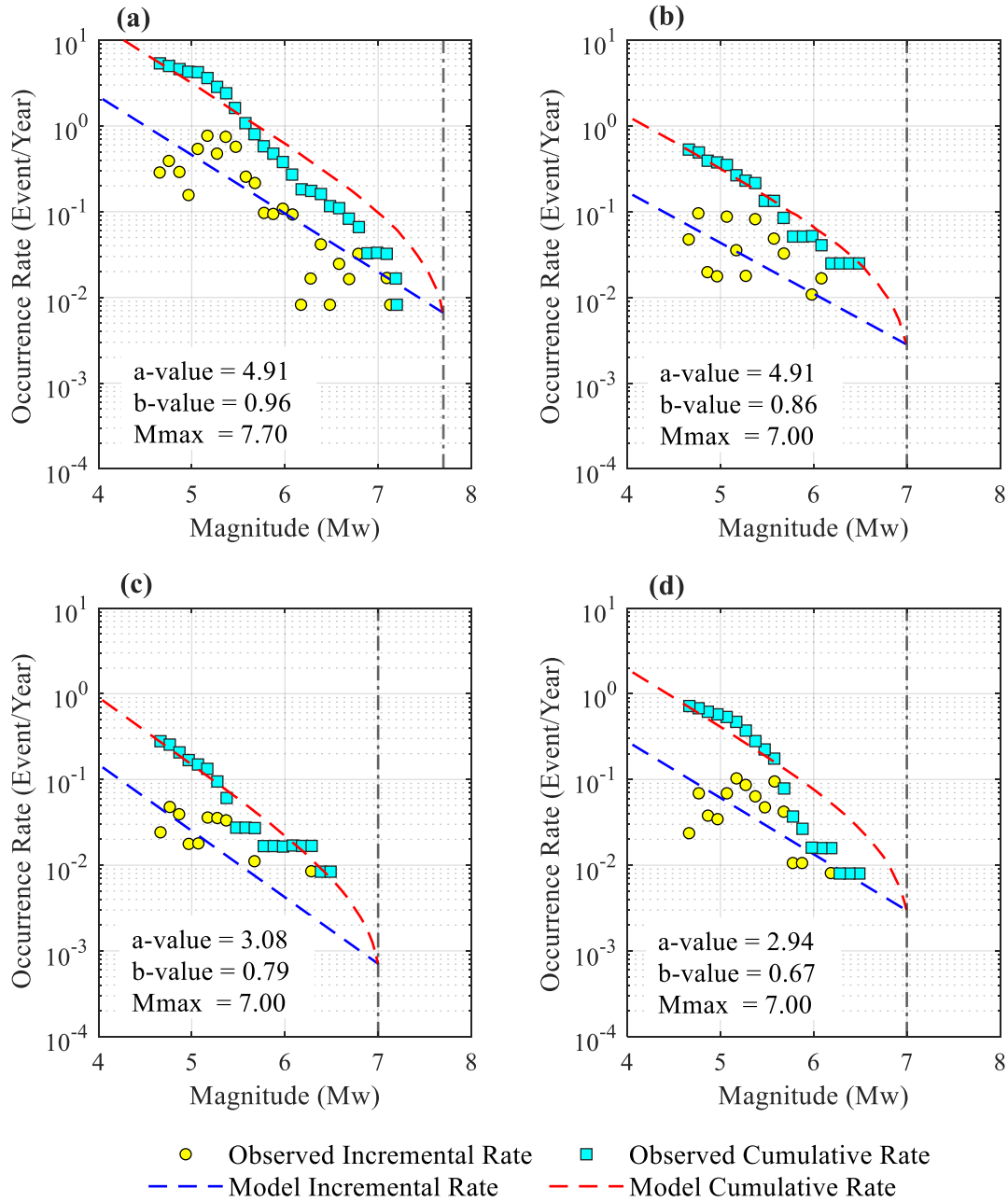


**Fig 2.10** Gutenberg-Richter magnitude occurrence relationships for each of the four tectonic categories or groups: **(a)** Category A (WRS); **(b)** Category B (RFB); **(c)** Category C (ERS); and **(d)** Category D (CUT) craton or the Precambrian basement of Uganda

## 2.7 Ground motion characterisation for Uganda

A comprehensive PSHA requires suitable models for predicting the probability distribution of ground motion intensities by considering all possible rupture scenarios (Baker et al., 2021; Kramer, 1996). Empirical GMPEs which are specifically developed for the region of interest

should preferably be used in hazard calculations. Unfortunately, the substantial lack of reliable GMPEs for Uganda and the adjacent areas may be attributed to the absence of sufficient strong ground motion data (Bwambale et al., 2015; Poggi et al., 2017). Accordingly, Twesigomwe (1997) used a semi-theoretical approach to develop a GMPE (Eq. 2.4) by calibrating earthquake data and assuming a range of standard deviations as suggested by Krinitzsky et al. (1988):

$$\ln PGA = 2.832 + 0.886M_s - \ln R - 0.0027R + \ln(\varepsilon) \quad (2.4)$$

where  $PGA$  is the peak ground acceleration (in g),  $M_s$  is the surface-wave magnitude,  $R$  is the epicentral distance (in km), and  $\varepsilon$  is the normally distributed error.

Furthermore, highlighting strong ground motion data gaps for the region, Mavonga (2007a) used small magnitude earthquake data to simulate strong motions of large magnitude earthquakes, and derived a GMPE (Eq. 2.5) for events  $\geq 7.0 M_w$  and occurring in Kivu province:

$$\ln PGA = 0.152 + 1.43M_w - 1.3 \ln R \quad (2.5)$$

where  $M_w$  is moment magnitude. However, seismic hazard estimates obtained using the GMPE suggested by Mavonga (2007a) may not be highly reliable because their derivation was not calibrated against actual strong ground motion data for the Kivu province.

Conversely, Pankow and Pechmann (2006) used existing strong motion records to adopt an extensional tectonic regime relationship described in Eq. (2.6). In this GMPE, the parameter  $\Gamma$  represents the site class; in which rock sites (e.g., as shown in Fig 2.11) with soil depths less than 5 km,  $\Gamma = 0$  and  $\Gamma = 1$  for alternative site conditions (Douglas, 2021).

$$\log PGA = 0.237 + 0.229(M_w - 6) - 1.052 \log D + 0.174\Gamma \quad (2.6)$$

where,  $D = \sqrt{r_{jb}^2 + h^2}$  in which  $r_{jb}$  is the Joyner-Boore distance, and  $h = 7.27$  km.

In a hazard study of the Albertine region, these three GMPEs presented in Eqs. (2.4), (2.5), and (2.6) were compared and significant variations in the predicted PGA values were noted (Bwambale et al., 2015). The study observed that the GMPE proposed by Pankow and Pechmann (2006) gives more realistic predictions, possibly because it is derived based on strong ground motion records. In another study, Poggi et al. (2017) employed the simple functionalities embedded in the Ground Motion Toolkit (GMTK) (Weatherill et al., 2014) to select four GMPEs developed based on strong ground motion data. Although these equations are not specifically developed for SSA, they were adopted because of similar seismo-tectonic settings. In their study, Poggi et al. (2017) selected two GMPEs proposed by Akkar et al. (2014) and Chiou and Youngs (2014) for regions of active shallow crust; whilst ground motion responses

in stable continental tectonic regions were predicted using the two GMPEs derived by [Pezeshk et al. \(2011\)](#) and [Atkinson and Boore \(2006\)](#). In this work, all four GMPEs are adopted, and a logic-tree (Fig 2.12) approach is used to assign weights depending on the likelihood of each clustered tectonic type.

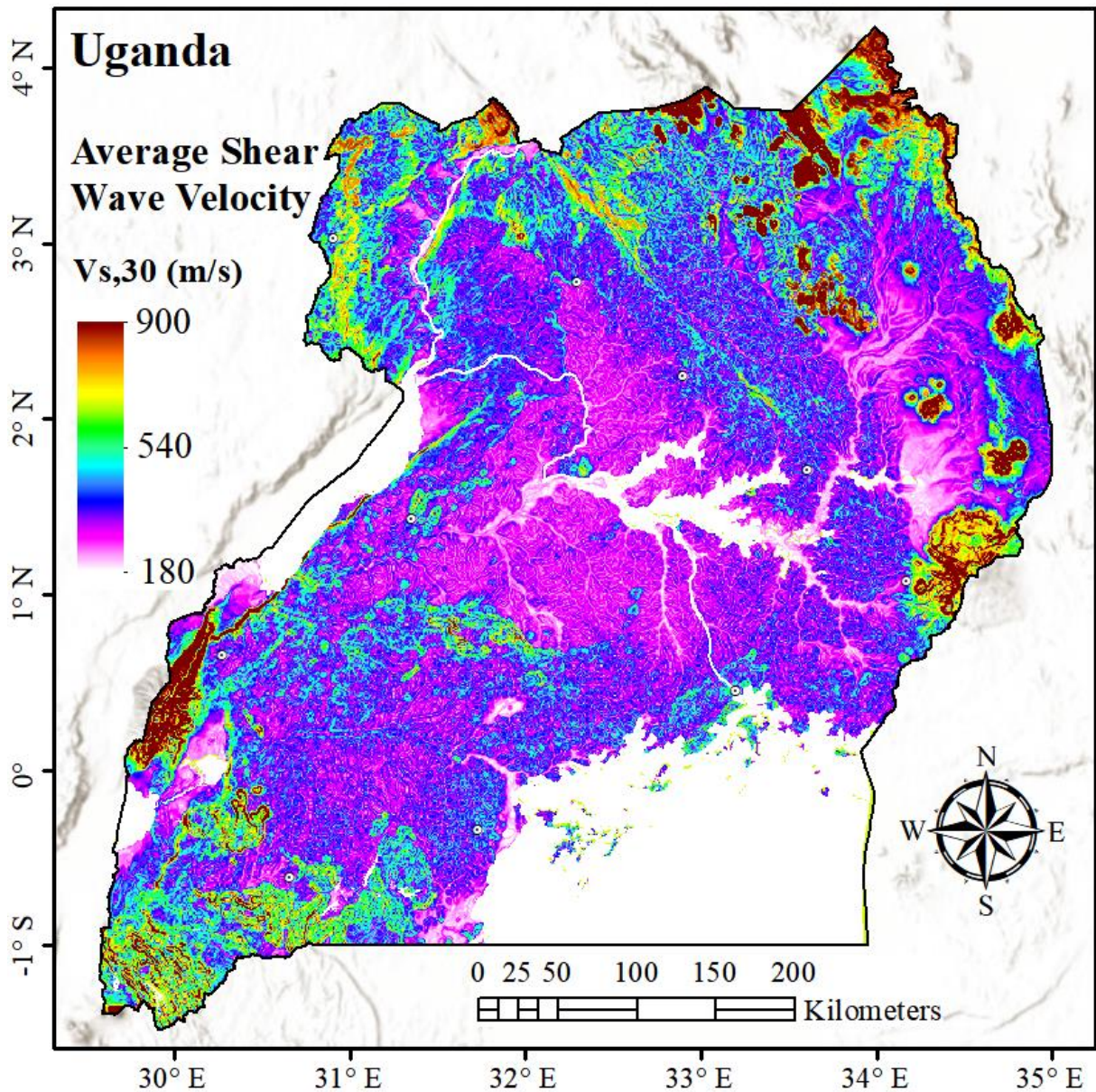


**Fig 2.11** Reference map showing the average shear-wave velocity in the upper 30 m of soil, used to characterise site conditions in MC-based PSHA for Uganda ([Allen and Wald, 2007](#))

This approach allows for the determination of confidence intervals of the predicted ground motion intensity ([Bommer et al., 2005](#); [Scherbaum et al., 2005](#)), in addition to offering a realistic assessment of any drawbacks. Consequently, a logic-tree is implemented to minimise epistemic uncertainty associated with the present hazard model. An additional branching level is incorporated to cater for uncertainties that may arise when defining  $M_{max}$ . The number of

logic tree parameters can be reduced by use of a MC-based PSHA since source zone geometries and characteristic magnitudes are initially randomized when generating synthetic catalogues (Sianko et al., 2020).

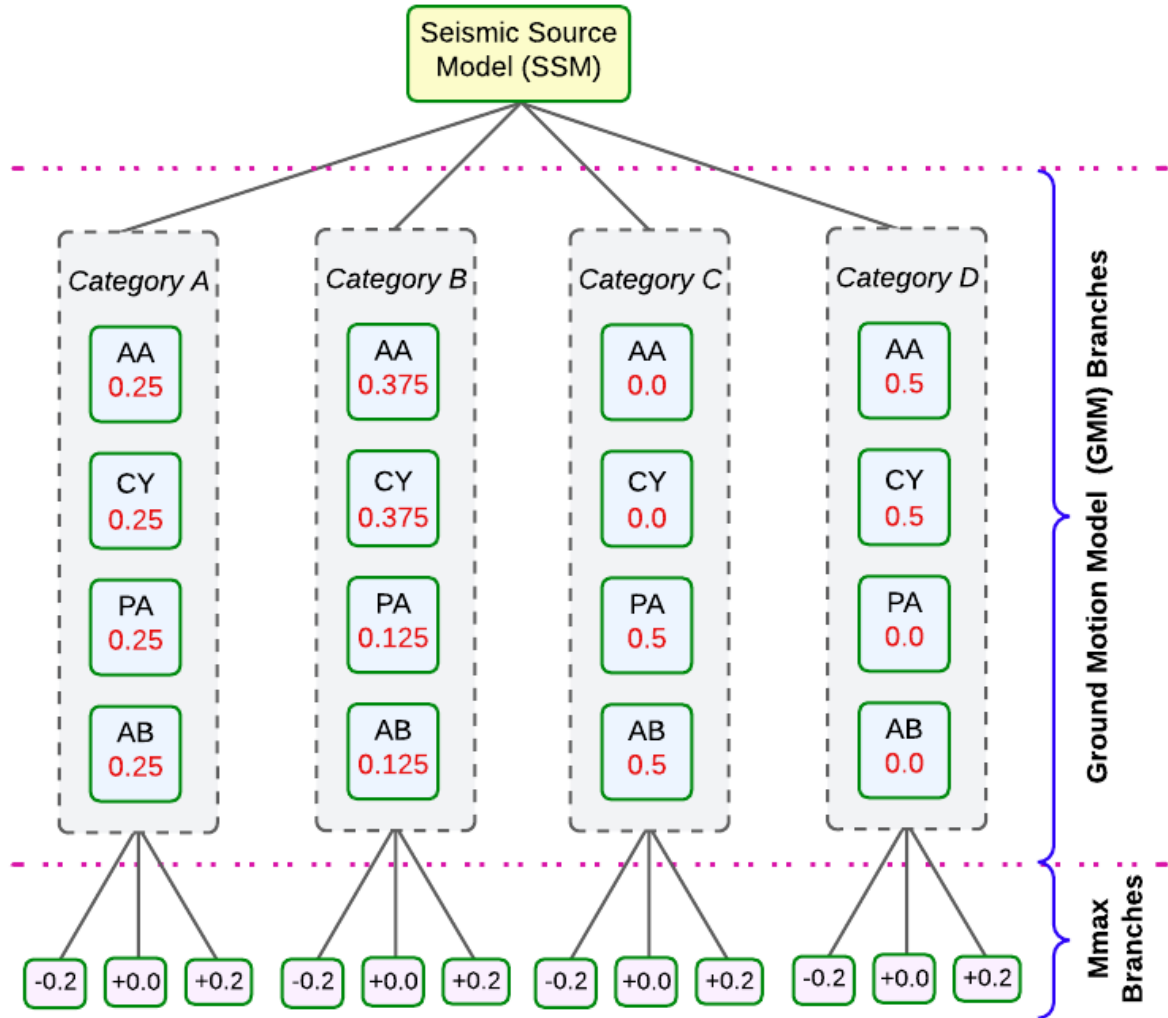


**Fig 2.12** Schematic diagram showing the logic tree implemented in stochastic event-based PSHA for Uganda. Four GMPEs are used: AA – Akkar et al. (2014), CY – Chiou and Youngs (2014), PA – Pezeshk et al. (2011), and AB – Atkinson and Boore (2006) and their weights (*in red*) assigned

## 2.8 MC-based PSHA results

As described in Section 2.6.1, the investigation area comprises of a mesh spacing of 2.5 km (with a total of 16637 sites) including the buffer zone. The upper 30-metre average shear-wave velocity reference data mapped in Fig 2.11 is obtained from USGS database (Allen and Wald, 2007) and values range between 180 and 900 m/s. As defined in Eurocode 8-1 (CEN, 2004), these values mostly correspond to stiff-soil conditions. In addition to site-specific hazard maps, bedrock hazard maps are derived for free rock conditions, with a fixed 30-metre average shear-wave velocity reference of 760 m/s assumed for each site of the investigation mesh.

Within a 50-year investigation time, the target ground motion intensity for calculation considers 5 % damped RSA to estimate the POE of 10 and 2 %, corresponding to 475- and 2475-year return periods respectively. These periods are chosen as standard return periods with the possible aim of incorporating results into the national seismic design code (US 319:2003) (UNBS, 2003). Moreover, longer periods are avoided due to lack of historical records which would affect calibration rates for large magnitude events. Ground response values are computed for intensity measure types and levels of PGA and spectral acceleration (SA) at spectral periods (T) of 0.05, 0.1, 0.5, 1.0, and 2.0 seconds; with a truncation level of  $\pm 3$  applied to the distribution of ground motion. The calculation output includes mean hazard curves, mean and percentile (0.15, 0.5 and 0.85) Uniform Hazard Spectra (UHS), and disaggregation plots at some major Ugandan cities. In addition to the hazard maps produced in terms of PGA and SA, seismic response spectra for two example sites (Mbarara and Fort Portal cities) located in western Uganda are proposed in accordance to Eurocode 8-1 (CEN, 2004), and compared with the spectra generated following the Uganda seismic code of practice for structural designs (US 319:2003) (UNBS, 2003).

### 2.8.1 Seismic hazard curves and Uniform hazard spectra

#### 2.8.1.1 Mean hazard curves

In this work, mean hazard curves are computed for major cities in Uganda where earthquake risk assessment is thought necessary. Mean hazard curves for different spectral periods, presented in Fig 2.13, are derived based on bedrock conditions (considering a fixed 30-metre average shear-wave velocity reference of 760 m/s) at selected major regional cities. Although the concurrence of GMPEs for stable continental and active shallow crustal conditions could influence various ground motion likelihoods differently, the hazard curves seem to adequately quantify the distribution of intensity measure levels and their associated rates of exceedance.

#### 2.8.1.2 Uniform hazard spectra (UHS)

Bedrock site conditions are used to compute representative mean and percentile UHS for eight major regional cities in Uganda. The mean and percentile UHS for a 10 % POE in 50 years (corresponding to a 475-year return period) for eight selected cities across the country are shown in Fig 2.14.

#### 2.8.1.3 Comparison with previous predictions

Mean hazard curve, derived in terms of PGA, obtained for bedrock soil condition in Kampala is compared with the previous pilot study by the GEM and *AfricaArray* (Poggi et al. 2017) as depicted in Fig 2.15a. While Poggi et al. (2017) estimated a PGA of 0.045 g for a 10 % POE in 50 years (a 475-year return period), the present model predicts a PGA of 0.027 g over the

same return period. In general, differences in hazard levels range between 30 and 40 % across various annual rates of exceedance. Similarly, mean UHS computed for a 10 % POE in 50 years in Kampala is compared with the previous regional estimates and results plotted as shown in Fig 2.15b. It can be seen that at a period of 0.1 s, the present model estimates a SA of 0.065 g whereas [Poggi et al. \(2017\)](#) predicted a higher value of 0.095 g. Differences in hazard results can be attributed to the fact that the model developed by [Poggi et al. \(2017\)](#) assumed a lower fixed 30-metre average shear-wave velocity reference of 600 m/s, as opposed to bedrock conditions which are considered in the present study.

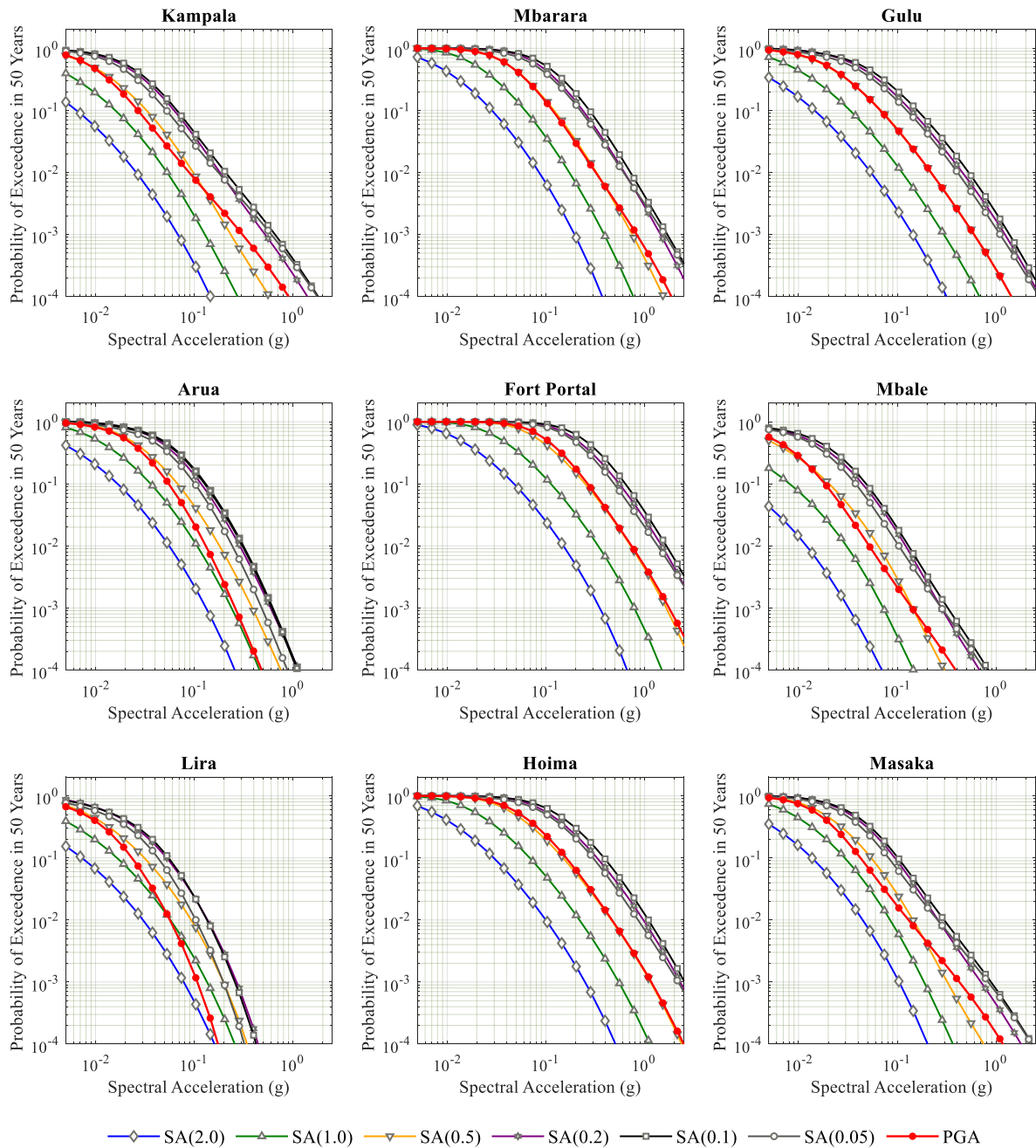


**Fig 2.13** Mean hazard curves calculated at various spectral periods and derived based on bedrock site conditions representing nine major cities in Uganda

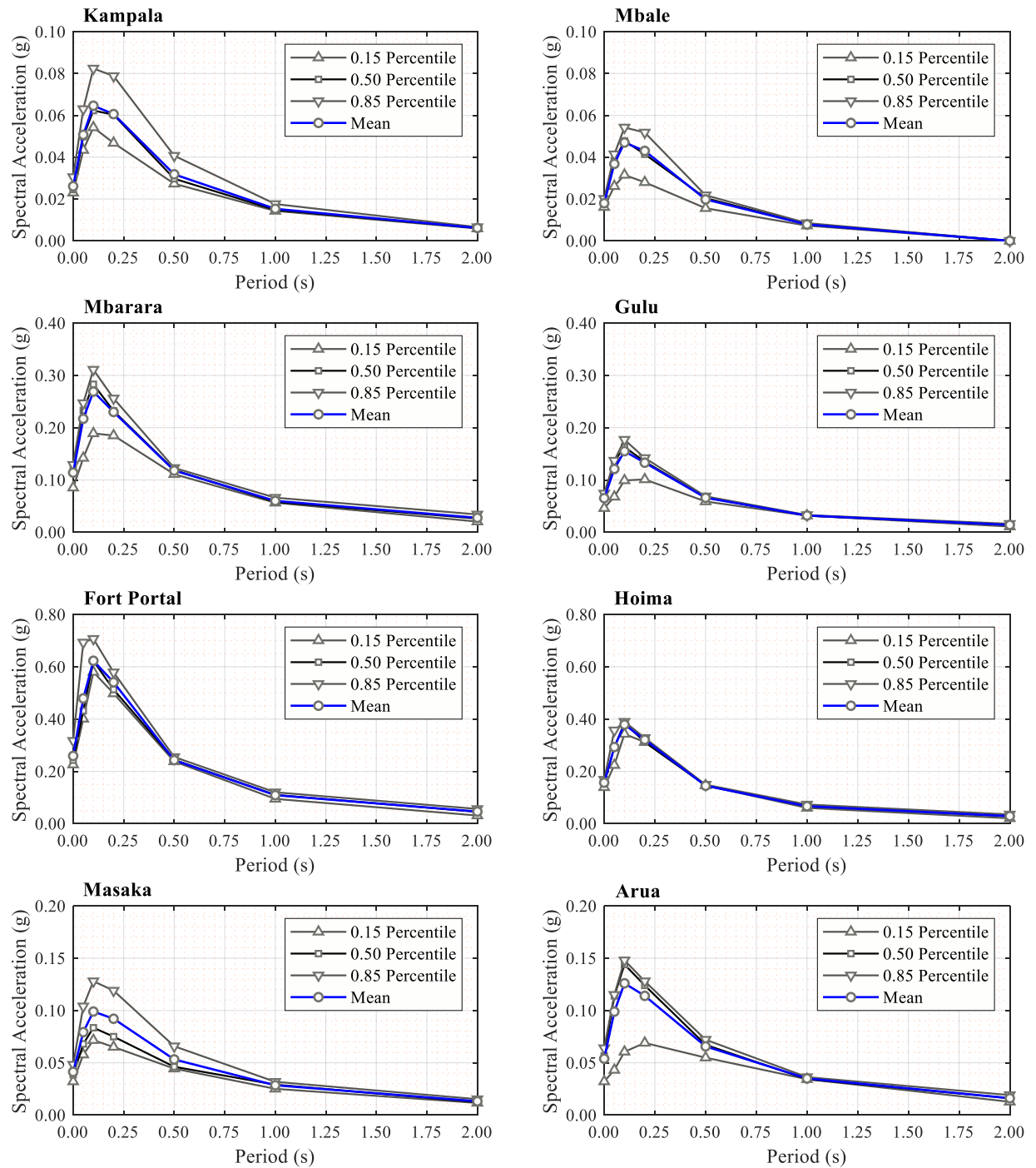


**Fig 2.14** Mean and percentile Uniform Hazard Spectra (UHS) based on bedrock site conditions and computed for 10 % POE in 50 years (475-year return period) for eight regional cities in Uganda

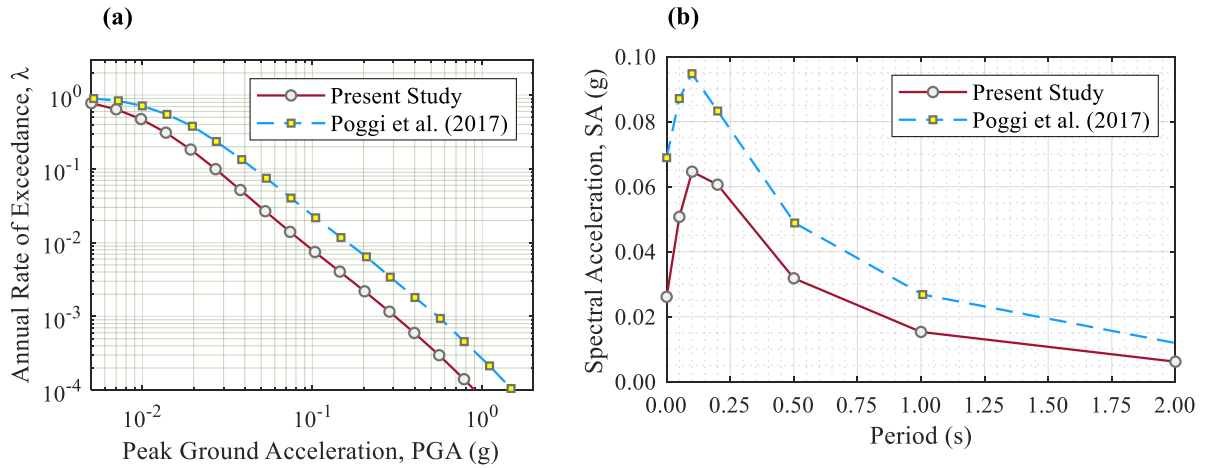


**Fig 2.15** Comparison of hazard results obtained in this work for an example site located in Kampala with those derived in the previous study by Poggi et al. (2017): (a) mean hazard curve in terms of PGA, and (b) mean uniform hazard spectra computed for a 10 % POE in 50 years

## 2.8.2 Earthquake hazard maps

### 2.8.2.1 Hazard maps in terms of peak ground acceleration (PGA)

Using refined grids, seismic hazard maps are produced for the entire country. Fig 2.16a-b shows the site-dependent hazard maps produced in terms of PGA for 10 and 2 % exceedance probabilities, both in 50 years. As expected, the Albertine, Rwenzori and Upper Kivu regions (Zones 3 and 4 in Fig 2.5) can reach a maximum PGA of 0.34 and 0.5 g in 475- and 2475-year return periods respectively, whereas the rest of the country has relatively lower accelerations. In addition, bedrock hazard maps showing PGA predictions corresponding to a 475- and 2475-year return periods are presented in Fig 2.17a-b. Within a 50-year investigation time, maximum bedrock PGAs of 0.27 and 0.5 g are predicted for 10 and 2 % exceedance probabilities respectively.

Considering a 10 % POE in 50 years, the site-dependent hazard model (Fig 2.16a) predicts a maximum PGA of 0.34 g within Fort Portal city. For the same city, the bedrock hazard model (Fig 2.17a) estimates PGA values raising to 0.255 g. Although similar soil/rock conditions may prevail throughout a city, site-dependent hazard estimates may be different due to changing local site conditions. Subsequently, this work considers bedrock hazard predictions to be more representative. Given recent population growth, urbanisation and increased economic activity that led to the creation of regional cities like Fort Portal and Hoima, the overall risk has significantly increased.

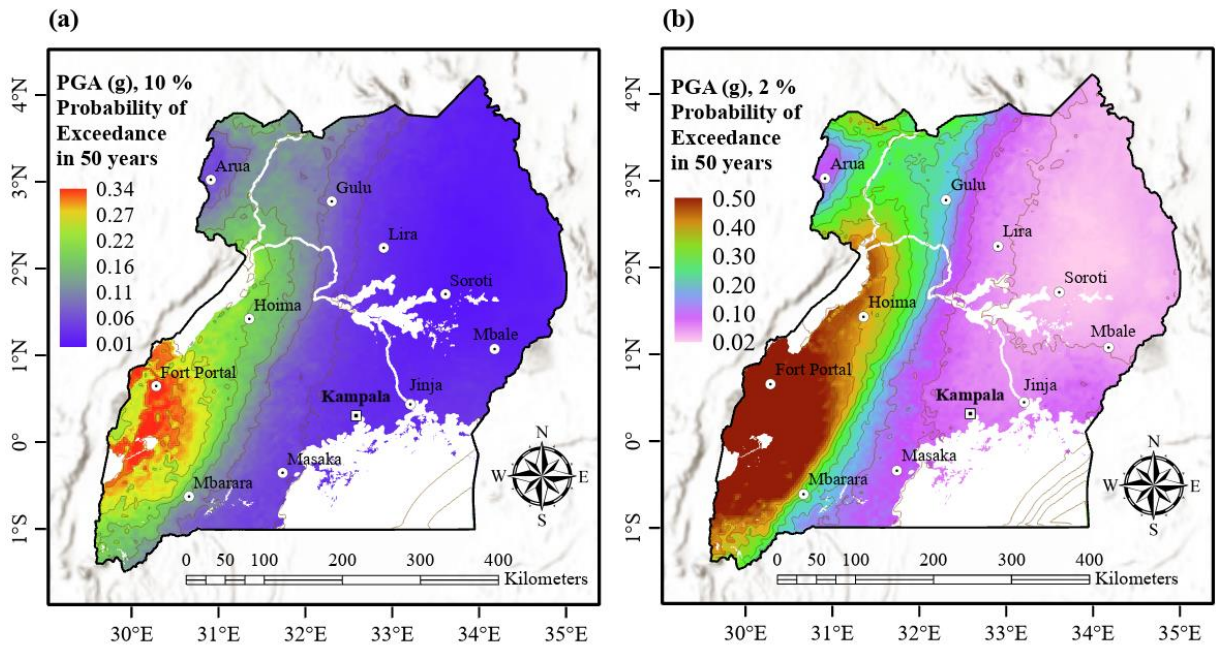


**Fig 2.16** Site-dependent seismic hazard maps of Uganda investigated over 50 years, in terms of PGA (g) and computed for: **(a)** 10 % POE (475-year return period), and **(b)** 2 % POE (2475-year return period). The contour lines are imposed on the maps at 0.05 g contour interval

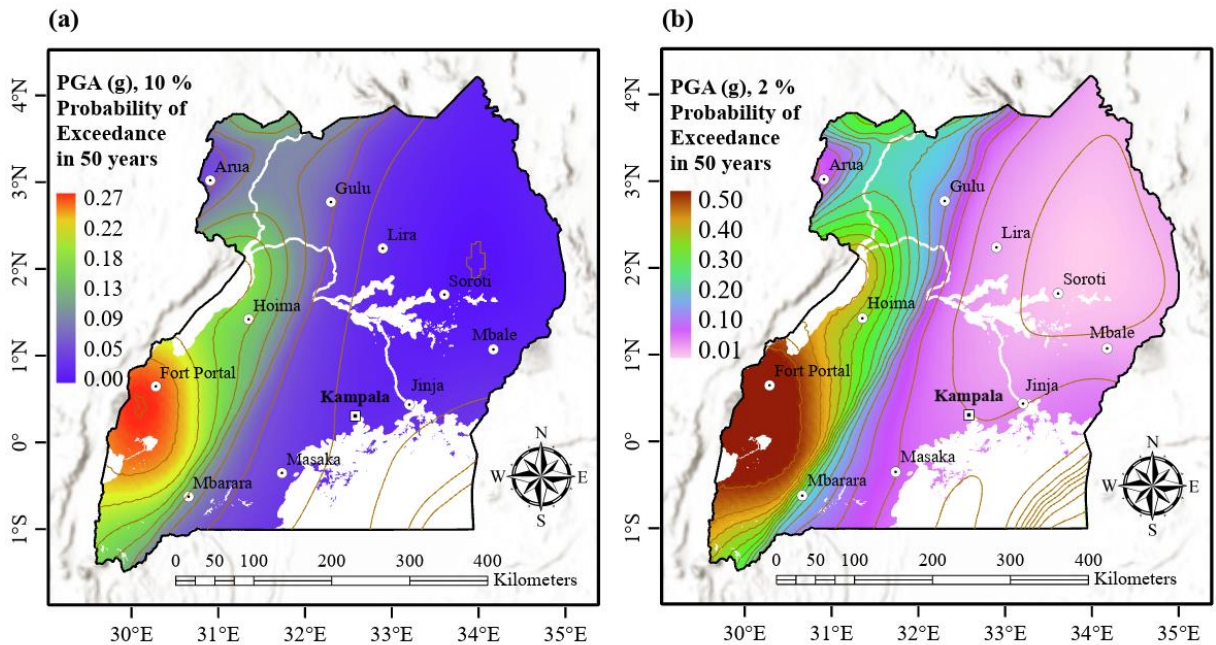


**Fig 2.17** Bedrock earthquake hazard maps of Uganda investigated in terms of PGA (g) and computed for: **(a)** 475-year return period (10 % POE in 50 years), and **(b)** 2475-year return period (2 % POE in 50 years). The contour lines are imposed on the maps at 0.03 g contour interval

### 2.8.2.2 Hazard maps in terms of spectral acceleration (SA)

For engineering applications, such as definition of seismic action in building codes, hazard maps are normally produced in terms of SA at various spectral periods. For instance, Fig 2.18a-d and Fig 2.19a-d respectively show site-specific and bedrock earthquake hazard maps in terms of SA (g) at various spectral periods,  $T$  (s) that are computed for 10 % POE in 50 years.

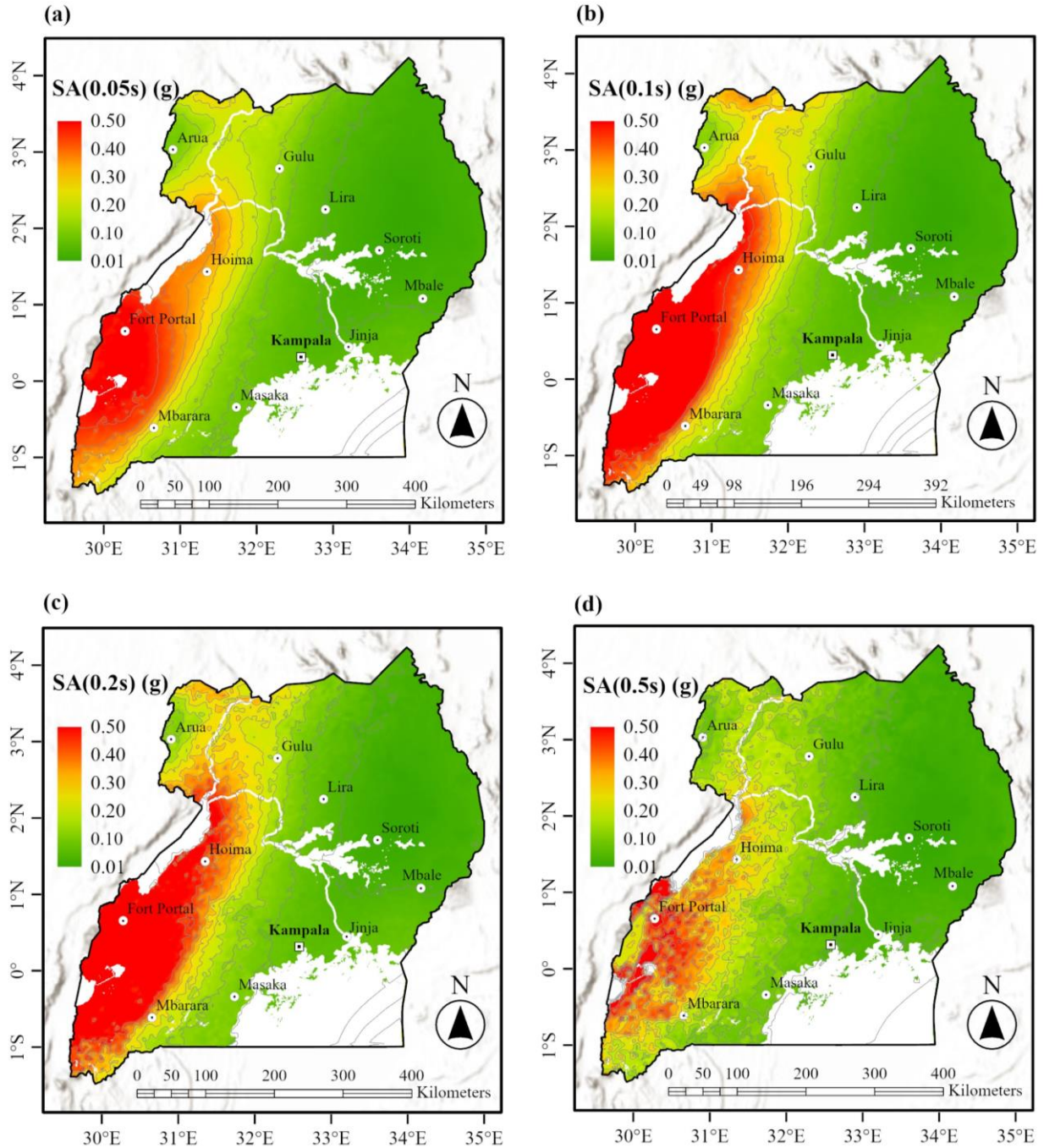


**Fig 2.18** Site-specific seismic hazard maps of Uganda in terms of spectral acceleration SA (g), computed for 10 % probability of exceedance in 50 years (475 year return period) and at various spectral periods  $T$  (s): **(a)** SA( $T = 0.05$  s), **(b)** SA( $T = 0.1$  s), **(c)** SA( $T = 0.2$  s), and **(d)** SA( $T = 0.5$  s). The contour lines are imposed on the maps at 0.05 g contour interval

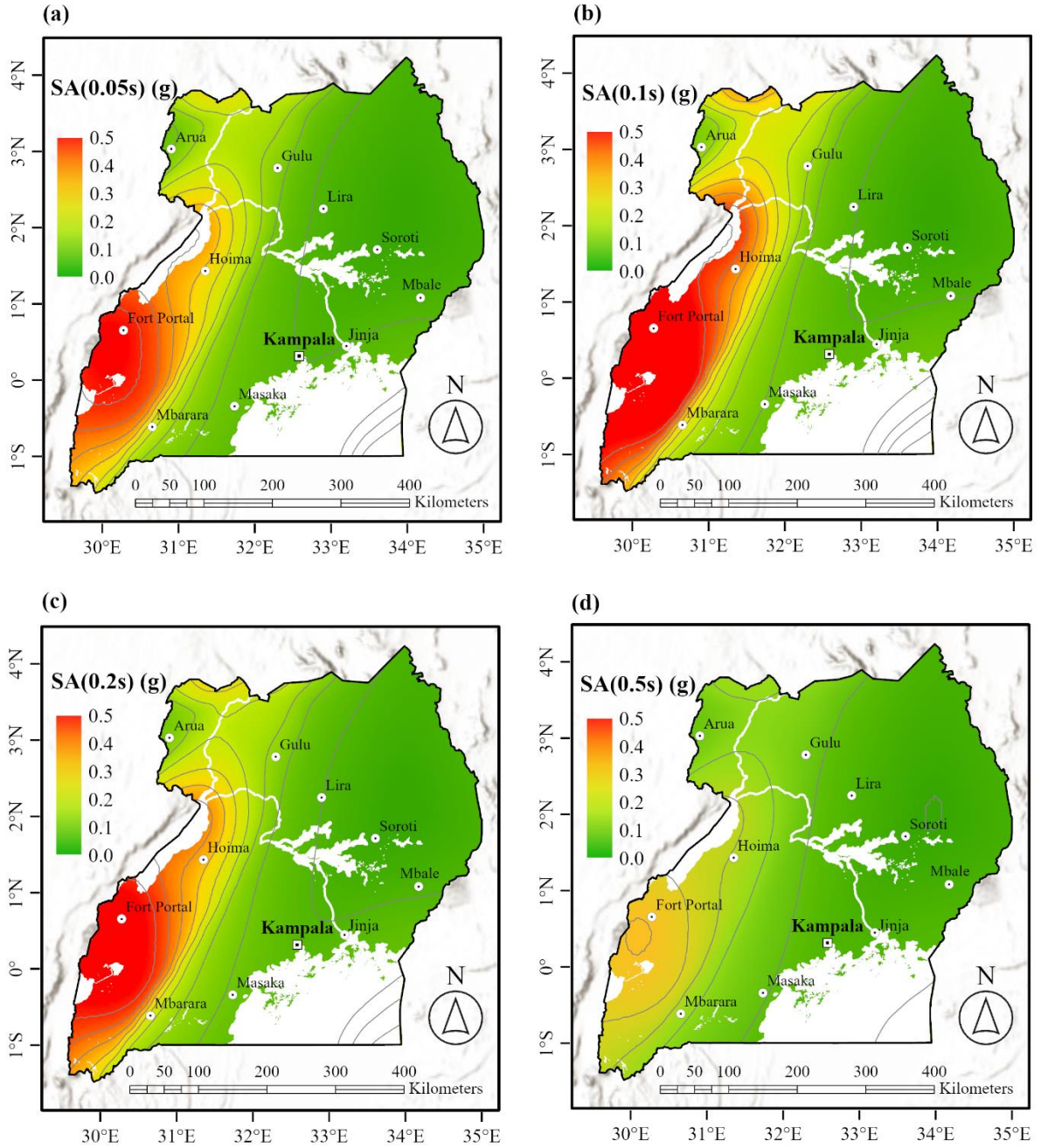


**Fig 2.19** Bedrock earthquake hazard maps of Uganda in terms of spectral acceleration SA (g), computed for 10 % probability of exceedance in 50 years (475 year return period) and at different spectral periods  $T$  (s): **(a)** SA( $T = 0.05$  s), **(b)** SA( $T = 0.1$  s), **(c)** SA( $T = 0.2$  s), and **(d)** SA( $T = 0.5$  s). The contour lines are imposed on the maps at 0.05 g contour interval

### 2.8.3 Deaggregation

On completion of PSHA computations, a fundamental task is to identify the design earthquake at a particular site of interest through the process of earthquake disaggregation (Baker et al., 2021; Bazzurro and Allin Cornell, 1999; McGuire, 1995). In this procedure, all seismic events producing a given target hazard level for a given return period are extracted. The short-term

and long-term seismic disaggregation plots are shown in Fig 2.20a-c and Fig 2.21a-c respectively. These plots show the contribution of sources, with different magnitude-distance measurements, to the PGA overall bedrock hazard at specific sites in Uganda's hazard-prone cities.

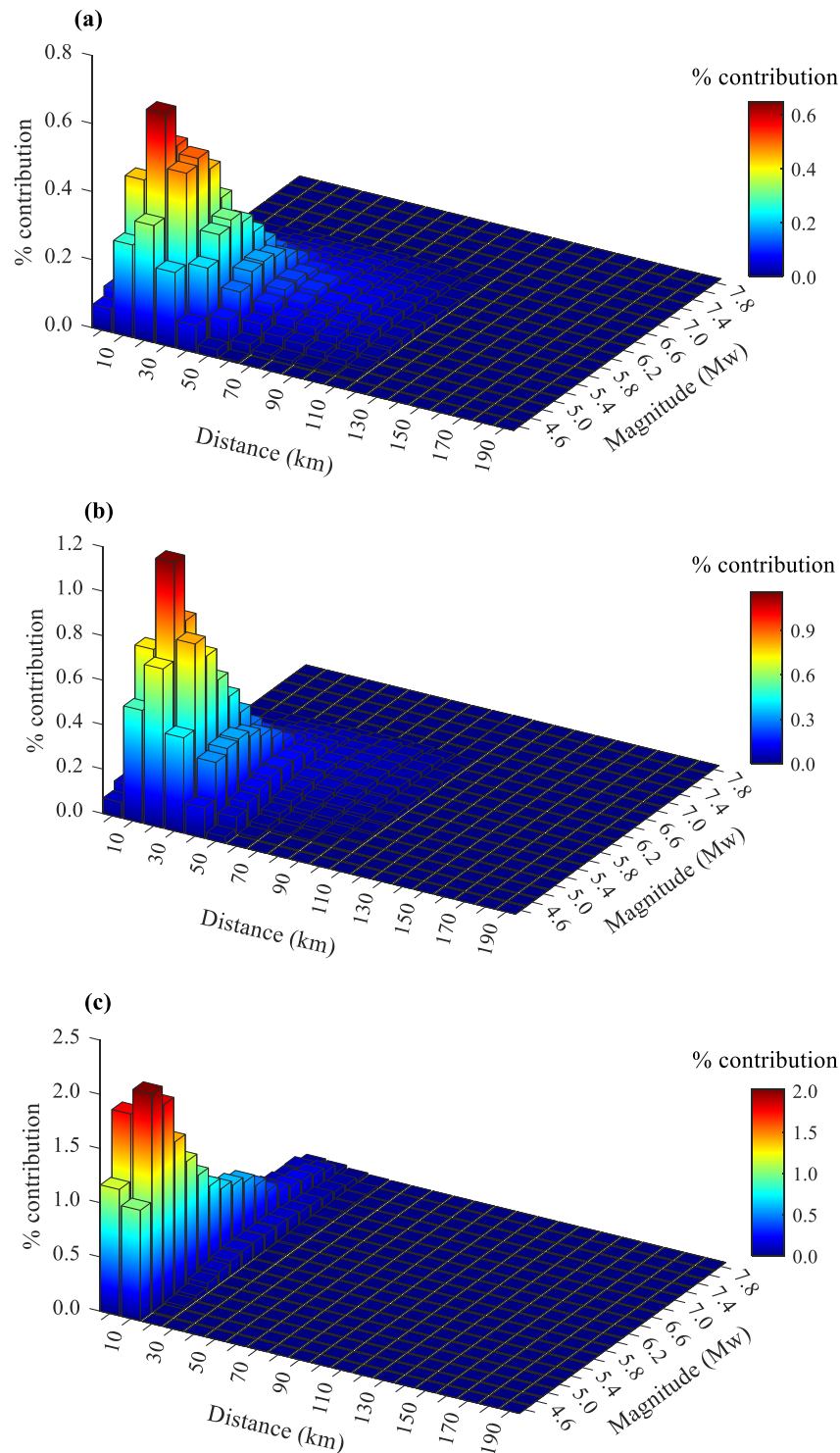


**Fig 2.20** Short-term earthquake disaggregation plots showing the contribution of sources, with different magnitude ( $M_w$ ) – distance (km) measurements, to the PGA overall bedrock hazard for a 10 % POE in 50 years (475-year return period); at specific locations in three major regional cities of Uganda: **(a)** Kampala, **(b)** Masaka, and **(c)** Fort Portal (high hazard region in western Uganda)

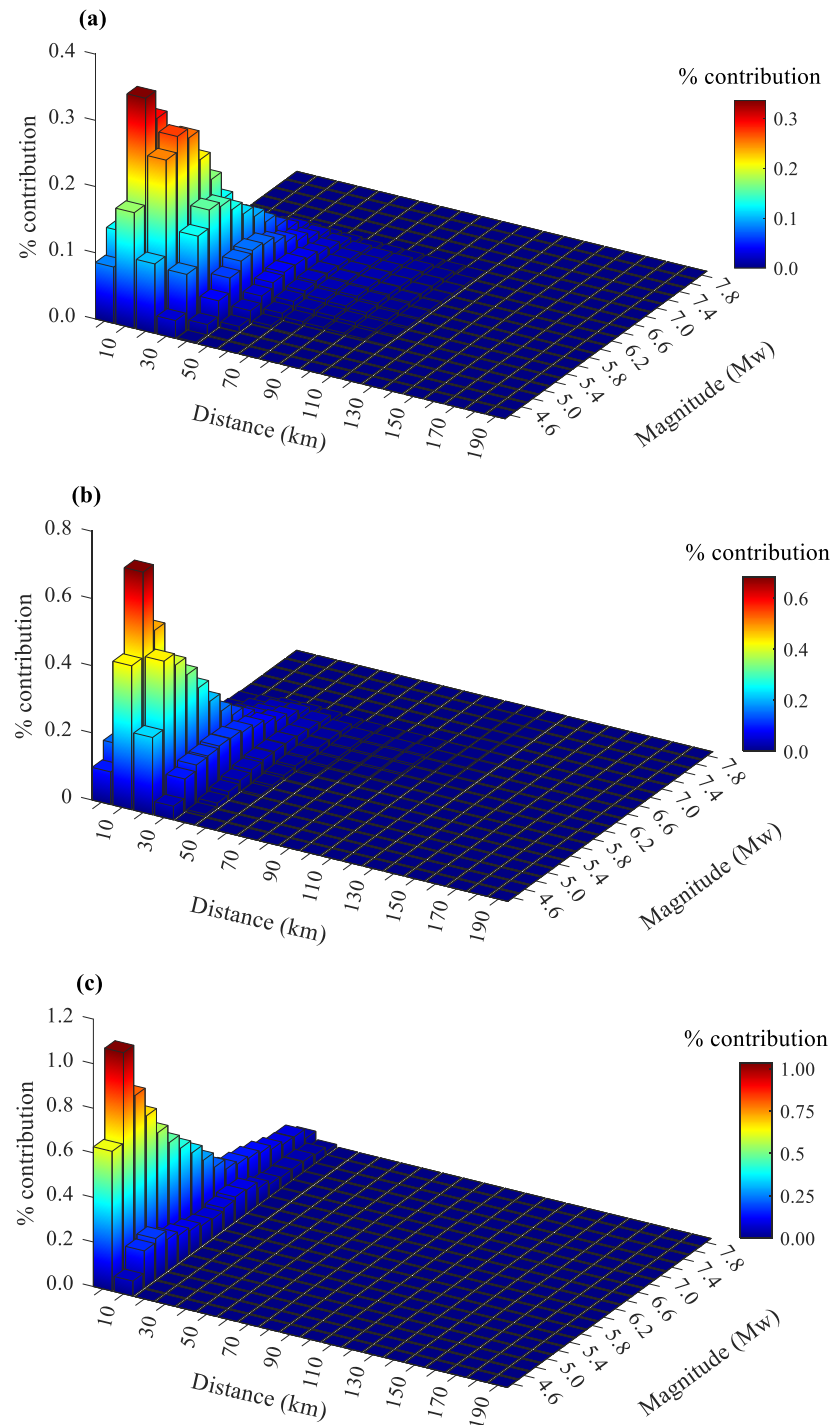


**Fig 2.21** Long-term earthquake disaggregation plots showing the contribution of sources, with different magnitude ( $M_w$ ) – distance (km) measurements, to the PGA overall bedrock hazard for a 2 % POE in 50 years (2475-year return period); at specific locations in three major regional cities of Uganda: **(a)** Kampala, **(b)** Masaka, and **(c)** Fort Portal (high hazard region in western Uganda)

#### 2.8.4 Seismic response spectra

In accordance with the provisions of Eurocode 8-1 (CEN, 2004), typical elastic acceleration response spectra are developed for two example cities (Mbarara and Fort Portal). Based on the

magnitudes of earthquakes generated from seismic sources, Type 1 (high seismicity) spectrum is assumed for both cities. Considering the parameters and stratigraphic profiles defined in Eurocode 8-1 (CEN, 2004), the sites are classified as Type A (rock) ground. Over a 475-year return period, reference bedrock PGA values of 0.122 and 0.255 g are considered for Mbarara and Fort Portal respectively (Fig 2.17a), and a damping ratio of 5 % is assumed herein. For application in design of ductile structures, inelastic behaviour is explicitly taken into account by the behaviour factor derived in accordance to Eurocode 8-1 (CEN, 2004). Considering the high seismic vulnerability of buildings across Uganda, low ductility class (DCL) is selected for two example sites and a behaviour factor of 1.5 is used to subsequently derive design response spectra for sites situated in Mbarara and Fort Portal. In addition to spectral displacements, the corresponding elastic and design spectral pseudo-accelerations representing seismic action in the horizontal direction in selected sites at Mbarara and Fort Portal are respectively presented in Fig 2.22a and Fig 2.22b.

As subsequently shown in Fig 2.23a-b, the design pseudo-acceleration spectra derived according to Eurocode 8-1 (CEN, 2004) are compared with design spectra computed based on the Uganda seismic code of practice for structural designs (US 319:2003) developed by UNBS (2003). According to the structural performance classes and importance factors described in US 319:2003 (UNBS, 2003), minimal ductility in buildings of minor importance is assumed. Depending on the local ground accelerations defined in US 319:2003 (UNBS, 2003), Mbarara and Fort Portal cities fall within Zone 1. However, the present study indicates that whereas Fort Portal is correctly located in Zone 1, the PGA map presented in Fig 2.17a shows that Mbarara has lower PGA values than those given in US 319:2003 (UNBS, 2003) and therefore Mbarara should fall within Zone 2.

Based on the provisions of US 319:2003 (UNBS, 2003), a comparison of design spectra for Mbarara (shown in Fig 2.23a) indicates that the ordinates of design spectrum obtained by considering Zone 2 conditions match Eurocode 8-1 (CEN, 2004) design pseudo-acceleration spectrum better than when Zone 1 conditions are assumed. Hence, there is need to update the current seismic zones and zoning factors described in US 319:2003 (UNBS, 2003) based on more accurate local ground accelerations derived in the present study. Additionally, the shape of the elastic response spectrum described in US 319:2003 (UNBS, 2003) should be aligned to modern seismic design codes, such as Eurocode 8-1 (CEN, 2004), which explicitly consider the magnitude of earthquakes that contribute most to seismic hazard. On the other hand, design spectral pseudo-accelerations in Fort Portal city, generated according to Eurocode 8-1 (CEN, 2004), closely match the ordinates obtained following US 319:2003 (UNBS, 2003) as shown in Fig 2.23b. Although several assumptions are made to define behaviour factors considered in US 319:2003 (UNBS, 2003), the design spectra derived according to Eurocode 8-1 (CEN,

2004) generally predict lower spectral accelerations compared with the design spectra computed using US 319:2003 (UNBS, 2003).

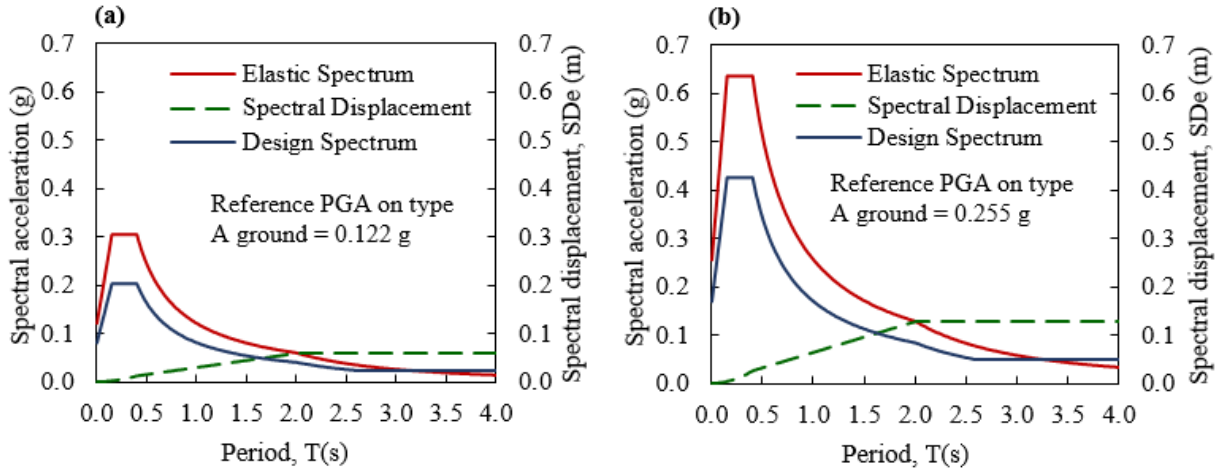


**Fig 2.22** Elastic spectral pseudo-acceleration, spectral displacement and design pseudo-acceleration response spectrum derived based on Eurocode 8-1 (CEN, 2004). High seismicity spectrum is assumed for typical structures of low ductility class (DCL) with a 5 % damping ratio and in type A (rock) ground for two selected sites located in: **(a)** Mbarara city, and **(b)** Fort Portal city.

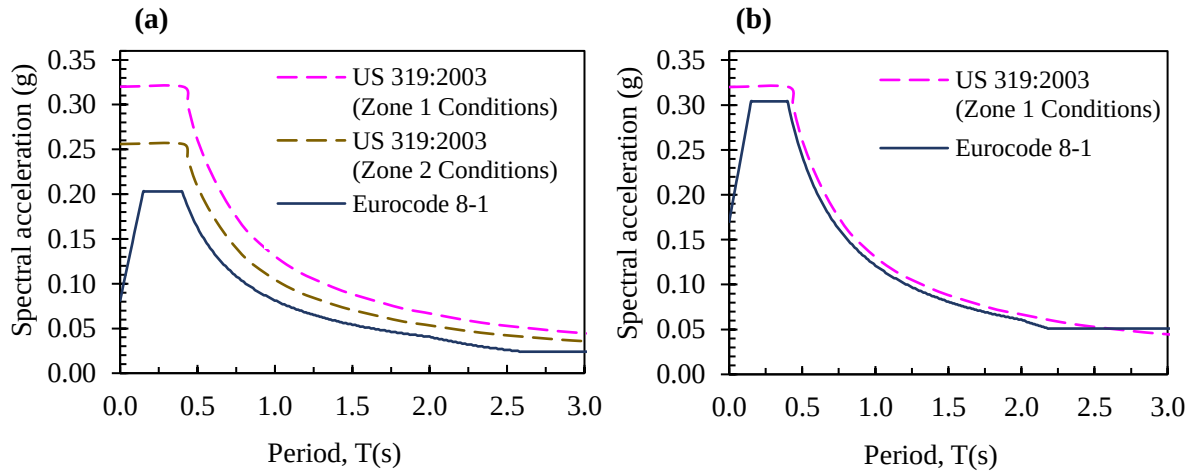


**Fig 2.23** Comparison of design pseudo-acceleration spectra derived according to Eurocode 8-1 (CEN, 2004) with the design spectra based on US 319:2003 (UNBS, 2003), for two selected example sites located in: **(a)** Mbarara city, and **(b)** Fort Portal city

## 2.9 Discussion

Despite the limited pool of seismic hazard studies conducted for Uganda, the MC-based PSHA model developed herein is largely consistent with previous regional studies, reviewed in Section 2.2. Considering the bedrock hazard map representing a 10 % POE in 50 years (see Fig 2.17a), comparison of the findings with those of previous studies confirms that the country is prone to seismic hazard of varying degrees. To begin with the north-western part of Uganda,

the PGA observed around Arua city is in the range of 0.03 to 0.09 g and this value closely matches the predictions from previous works like the GSHAP model (Midzi et al., 1999). The level of ground shaking increases further southwards, where for instance PGA values between 0.135 and 0.165 g can be expected in the Albertine region. Particularly, Hoima city can expect a PGA raising to 0.15 g. Although this value is consistent with the prediction by Bwambale et al. (2015) who reported a PGA of 0.152 g along the Albertine graben, it is contrary to the GEM and *AfricaArray* pilot study (Poggi et al., 2017) which reported a higher PGA value of 0.2 g. Even though these values are still moderately low, greater accelerations are observed further south towards the Rwenzori and Kigezi regions.

As depicted in Fig 2.17a, the largest PGA across the country is observed along the Rwenzori rift downwards through the Lakes George and Edward. Within this region, Fort Portal city can expect a maximum acceleration ranging between 0.24 and 0.27 g over a 475-year return period. This finding is similar to the predictions from previous projects (e.g., Cheriberi and Yee, 2022; Midzi et al., 1999; Poggi et al., 2017 and Twesigomwe, 1997) which conclusively indicate that this region is exposed to the highest risk. However, accelerations tend to decrease further downwards (south-western Uganda); for instance, the seismic hazard model proposed in this work predicts a PGA in the range of 0.09 to 0.15 g around Mbarara city. It is noted, in Fig 2.17a, that ground accelerations generally decrease as one moves away from Uganda's western border. In general, the other parts of the country are prone to relatively lower seismic hazard, except for a few major cities like Gulu and Masaka where ground acceleration between 0.05 and 0.08 g can be expected. Regions around the other major provincial cities like Kampala, Lira and Mbale cities can experience low PGA values less than 0.03 g. In overall, Fig 2.17a-b shows that high hazard regions (e.g., Fort Portal city) can expect PGA values increasing to 0.27 g and 0.5 g over 475- and 2475-year return periods respectively. Compared with the GEM and *AfricaArray* pilot study of Poggi et al. (2017) which predicted PGA values in excess of 0.3 g over a 475-year return period, the present model estimates lower accelerations with a maximum PGA of 0.27 g over the same return period (Fig 2.17a). This can be attributed to the fact that whereas bedrock conditions are adopted in the present study, Poggi et al. (2017) assumed a lower fixed 30-metre average shear-wave velocity reference of 600 m/s.

Mean and percentile UHS for major Ugandan cities shown in Fig 2.14 indicate that a maximum mean SA of 0.623 g at a period of 0.1 second can be expected in Fort Portal. For the same spectral period, many of the other cities can expect mean SAs less than 0.1 g, except Arua, Gulu, Mbarara and Hoima cities, where mean SAs of 0.126 g, 0.155 g, 0.269 g and 0.379 g are predicted, respectively. On the other hand, short-term bedrock earthquake disaggregation results shown in Fig 2.20a-c show that corresponding design PGAs in Kampala, Masaka and Fort Portal cities are most likely to be produced by a modal earthquake of 4.6  $M_w$  striking at

approximate distances of 20, 15 and 10 km respectively. In addition, long-term disaggregation plots presented in Fig 2.21a-c indicate that a modal earthquake of 4.6  $M_w$  striking within 5, 10 and 15 km respectively correspond to the design PGAs in Fort Portal, Masaka and Kampala. Such information may not only be used as input parameters for assessing secondary hazards due to earthquakes, but also relevant in the selection of appropriate time-history earthquake records necessary for dynamic analysis of structures located in earthquake-prone regions.

Although the hazard model for Uganda presented herein broadly agrees with previous national and regional assessments, the major challenge however is the lack of strong ground motion data required to determine GMPEs for the region. The model developed in this work relies on GMPEs developed for regions of similar seismo-tectonics. Yet, predicting seismic hazard using locally calibrated GMPEs would generally give more representative results. This study, therefore, recommends that potentially hazardous sites be monitored by installing new stations to record strong ground movement, as a prerequisite for deriving suitable GMPEs. This will not only aid the development of seismic response models, but also become a precursor to microzonation and hazard investigations in scenario cities across Uganda. Further challenges were faced in completeness analysis of earthquake catalogues largely due to data deficiencies, especially historical records. Therefore, the DGSM under MEMD should aim to strengthen the seismic networks within the region.

## 2.10 Conclusions

This paper presents a novel stochastic event-based PSHA model for Uganda based on a fault-oriented spatially distributed seismicity approach. An updated earthquake catalogue for the region is compiled and merged from various credible sources prior to the refinement process. Seismic source zones are delineated based on past regional seismicity, geology and seismo-tectonic environment. The zonation is preceded by employing a maximum likelihood algorithm to estimate earthquake recurrence parameters. Notwithstanding the non-existence of GMPEs specifically developed based on actual strong ground motion data for the region, a logic-tree approach is implemented to predict ground motion response using four selected GMPEs developed for regions of similar geology and seismo-tectonics. Mean hazard curves, UHS and disaggregation are derived for some major cities in Uganda. In addition to hazard maps produced in terms of PGA for 10 and 2 % POE in 50 years, spectral acceleration maps at spectral periods of 0.05, 0.1, 0.2, and 0.5 seconds are computed for a 475-year return period. Furthermore, the design spectral pseudo-accelerations representing seismic actions in the horizontal direction are developed for two example sites in Mbarara and Fort Portal cities. The findings, which are largely consistent with previous regional studies, confirm that western Uganda is exposed to the highest level of seismicity. For example, Rwenzori and Kigezi regions can expect PGA

values between 0.24 and 0.27 g, with an estimated maximum value raising to 0.255 g in Fort Portal city over a 475-year return period. Except for Hoima and Mbarara cities where maximum PGA values ranging between 0.09 and 0.165 g are predicted, the rest of the country's territory is prone to PGA values below 0.09 g. The seismic hazard assessment framework presented in this work can reliably be used as a starting point for the update and continuous improvement of a more robust seismic design code as a step toward a more resilient built environment owing to reduced earthquake-related losses across the country.

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# CHAPTER 3

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## CO-SEISMIC AND RAINFALL TRIGGERED LANDSLIDE HAZARD SUSCEPTIBILITY FOR UGANDA DERIVED USING FUZZY LOGIC AND GEOSPATIAL MODELLING TECHNIQUES

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### Abstract

Uganda has suffered from many damaging landslides like the 1966 Rwenzori, 1994 Kisomoro and 2010 Bududa. Despite escalating landslide risks exacerbated by rapid deforestation, urbanization and population growth coupled with a substandard building stock, comprehensive national co-seismic and rainfall-induced landslide hazard and risk maps for Uganda do not exist. This study therefore aims to conduct landslide hazard assessment and zonation for Uganda using a geospatial-based fuzzy logic methodology. In this methodology, landslide frequency ratios obtained for the 1966 Toro and 1994 Kisomoro earthquakes are assigned to the stochastic event-based probabilistic seismic hazard map derived using OpenQuake-engine. The available co-seismic and rainfall-induced landslide inventory datasets are used to derive the distribution of landslide frequency ratios based on geology, topographic slope position index, slope aspect, slope angle, distance from streams, and proximity to major active faults. The spatial distribution of fuzzy membership functions obtained from frequency ratios are overlaid and aggregated to produce landslide susceptibility maps showing relative probabilities of landslide occurrences across Uganda. Results indicate that the highest overall landslide hazard susceptibility is expected in areas comprising highly weathered outcropping rocks of precambrian granites, dominantly metasedimentary, and granulites and gneisses geologies within 40 km from major active faults; where the bedrock peak ground acceleration  $\geq 0.1$  g, topographic position index  $\geq 3.8$ , slope gradient  $\geq 10$  degrees, and the distance from streams  $\leq 1.25$  km. These findings can inform Uganda's directorate of disaster preparedness and management towards pioneering the development of co-seismic landslide risk mitigation measures for the country.

**Keywords** Uganda; landslide inventory; landslide conditioning factors; fuzzy logic; GIS-based modelling; stochastic event-based modelling; landslide zonation and susceptibility mapping.

### 3.1 Introduction

Over the past few decades, Uganda has experienced an increasing frequency of landslide events due to the escalating rates of deforestation, urbanisation and population growth. Landslides in

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Uganda, which have mostly occurred in the mountainous areas (Nakileza and Nedala, 2020), have resulted in numerous deaths, injuries and damage to the ecosystem, services and infrastructure (Masaba et al. 2017). Uganda's National Planning Authority reported in its development plan that landslide occurrences between 1933 and 2012 were responsible for approximately 14 % of the country's natural-hazard-induced disaster related deaths (Akeru 2012), with over 4 % of the population grossly affected due to past landslides (Doocy et al. 2013; Kato and Mutonyi 2011; Vlaeminck et al. 2016). Nationally, over 250 people are annually exposed to landslide risk, with a long term mean annual fatality estimate of 20 persons; and according to Uganda's recent disaster risk profile, the expected average annual damage to the building stock falls in excess of US\$ 850000, in addition to US\$ 200000 estimated as the combined average cost of damage to education centres and healthcare facilities each year (WorldBank 2019).

Various previous studies indicate that landslides across Uganda are largely induced by rainfall and earthquakes (Knapen et al. 2006; Nefeslioglu et al. 2011). In general, rainfall-triggered landslides have been observed around Mount Elgon in Eastern Uganda (see Fig 3.3). In March 2010, a rainfall-induced landslide occurred in Bududa district in eastern Uganda and killed at least 388 people, with more than 8500 lives affected (Broeckx et al. 2019; Mugagga et al. 2012; Wanasolo 2012). Moreover, earthquake-induced secondary effects such as landslides can considerably aggravate the overall damages, injuries and loss of lives (Chousianitis et al. 2016). Within Uganda's territory, regions surrounding the Rwenzori Mountains in western Uganda (see Fig 3.3) are exposed to earthquake-triggered landslides due to their tectonic environment, seismicity, topography, geomorphology and geology (Jacobs et al. 2016). For example, the 1966 Toro and 1994 Kisomoro earthquakes with surface wave magnitude ( $M_s$ ) of 6.6 and 6.2, respectively, triggered numerous co-seismic landslides in Bundibugyo, Kasese, Kabarole and Bunyangabu districts of western Uganda (Sykes 1967; UNESCO 1966; USGS 2010). Except for Kampala capital city and its immediate environs (see Fig 3.2b), these regions comprise some of the most populated areas of Uganda.

Landslide hazard and risk analyses typically encompass the utilization of suitable methods to assess complex geo-physical processes. Several methods proposed in literature have been used to assess landslide susceptibility, inventory mapping, hazard prediction and evaluation of the associated landslide risks (Aleotti and Chowdhury 1999). To begin with, different approaches have been categorised on the basis of assessment area units. Although the assessment area units may be automatically derived from overlays of each landslide parameter map (Ives and Bovis 1978), regular grids of identical size and shape (Anbalagan and Singh 1996; Carrara 1983) and/or individual hillslopes and other morphological units (Carrara et al. 1992; Kienholz 1978) can alternatively be adopted. In contrast, landslide assessment procedures can be categorised into (1) relative hazard, (2) absolute hazard, and (3) monitored landslide hazard.

Although relative landslide hazard assessments provide useful insights, absolute landslide hazard assessment can be performed by employing statistical or empirical methods from which hazard curves relating to landslide conditioning parameters are derived in either a deterministic or probabilistic manner. On the other hand, monitored landslide hazard assessment involve the subjective comparison of deformations with pre-determined thresholds based on expert judgement ([Hartlen and Viberg, 1988](#)).

On a broader perspective, landslide hazard assessment can be categorised to consist of qualitative and quantitative approaches. Previous studies (e.g., [Bughi et al. 1996](#); [Carrara and Merenda 1976](#); [Fenti et al. 1979](#); [Gupta and Anbalagan 1997](#); [Hearn 1995](#); [Ives and Messerli 1981](#); [Rupke et al. 1988](#); [Soeters and Van Westen 1996](#)) utilized qualitative techniques to assess landslides. Conversely, quantitative landslide assessment techniques essentially involve the interpretation of empirical data to evaluate both triggering (causative) and conditioning (preparatory) factors associated with landslides. Whereas the temporal distribution of slope movement is governed by the triggering factors (e.g., rainfall, earthquakes, volcanic eruptions, human activity, and rapid snowmelt), landslide conditioning parameters such as geology, topography, hydrology, environmental and meteorological aspects are linked with the spatial distribution of landslide occurrences ([Hervás and Bobrowsky 2009](#)). To conduct a quantitative landslide susceptibility assessment statistical, geotechnical and/or neural network analyses can be employed.

In statistical analysis, weighted values are attributed to several landslide conditioning factors and the spatial distribution of landslides compared with each factor considered in the analysis, either in a bivariate or multivariate manner ([Aleotti and Chowdhury 1999](#); [Baeza and Corominas 1996](#); [Clerici and Dall'Olio 1995](#); [Leroi 1996](#); [Wieczorek et al. 1996](#)). Regarding geotechnical approaches, either a deterministic framework which involves quantifying the soil properties and calculating the factor of safety ([Aleotti and Chowdhury 1999](#); [Chowdhury and Bertoldi 1977](#)) or probabilistic methods that further account for the magnitude-time variability of undrained shear strength, angle of internal friction and cohesion ([Chowdhury 1984](#); [Nguyen and Chowdhury 1984](#)) can be applied. On the other hand, neural networks (black box model) suggested by [Lees \(1996\)](#) can be used for landslide hazard assessment. The application and further descriptions of quantitative methods for landslide hazard assessment can be found in literature (e.g., [Aleotti et al. 1998](#); [Bortolami et al. 1994](#); [Carrara 1983](#); [Choubey et al. 1992](#); [Kingsbury et al. 1992](#); [Meherota et al. 1994](#)).

The upsurge in human and economic losses due to previous landslides across Uganda has prompted several studies over recent decades. [Knapen et al. \(2006\)](#) used statistical methods to investigate rainfall-induced landslides in the densely populated Manjiya County located at

the foot slopes of Mount Elgon. The results indicated dominant landslides on steep concave slopes of northeast orientation. Besides, landslides along such slopes were exacerbated by human interferences like deforestation, unsuitable agricultural practices and foundation excavations along unstable hillslopes (Kitutu et al. 2009; Kitutu et al. 2011). In another study characterizing the physical properties and occurrence of major rainfall-triggered landslides on the slopes of Mount Elgon, Mugagga et al. (2012) indicated that the soils are inherently prone to landslides, even without human intervention. Likewise, Bamutaze (2019) analysed 286 georeferenced rainfall-induced landslides from which the catchment area around Mount Elgon was delineated, and morphometric and terrain attributes extracted from a 33-metre digital elevation model (DEM). Results showed the highest landslide frequency along middle segments at predominantly 1500-1900 metres above sea level (m.a.s.l) and 10-30° gradients.

In their study of the upper Manafwa catchment located in eastern Uganda, Nakileza and Nedala (2020) used landslide inventory data, field surveys and a 30-metre DEM to characterise and statistically determine frequency ratios for the most dominant topographic factors responsible for landslides in the area. The spatial distribution of landslides revealed that mid to upper slope positions (altitude ranging 1500-1800 m.a.s.l) of moderately steep gradients between 15 and 20° were most susceptible to landslides. Moreover, it was noted that human encroachment onto critical slopes often triggered shallow and deep landslides (Broeckx et al. 2019). In another study, Jacobs et al. (2017) assessed the characteristics and spatial distribution of both rainfall- and earthquake-triggered landslides covering a catchment area of 114 km<sup>2</sup> around the Rwenzori Mountains. The results showed the highest concentration of both rainfall-induced and co-seismic landslides on slope gradients of 10-15° and 25-30° along the lowlands (< 1500 m.a.s.l) and highlands (1500-5109 m.a.s.l) respectively. Nseka et al. (2019) relied on field surveys and a 10-metre DEM to statistically evaluate the topographic parameters inducing landslides in Kigezi region of south-western Uganda. The results revealed dominant occurrences in zones where slope gradients range between 25° and 35°.

Despite the vast spatial distribution of landslides across Uganda, many previous studies, except the attempt by Musinguzi and Asiimwe (2014), have only focused on landslide occurrences in the most critical struck regions of the country. Moreover, these previous studies have largely focused on Uganda's susceptibility to rainfall-triggered slope failures, without accounting for earthquake-induced landslides which struck the country's mountainous regions. Yet, the categorisation and discrimination of regions threatened by earthquake-induced landslides (e.g., using the GIS-based spatial multi-criteria approach) is paramount towards building community resilience (Karpouza et al. 2021). This study, therefore, aims to conduct a holistic landslide susceptibility assessment and a comprehensive relative hazard zonation for Uganda. Using the *OpenQuake*-engine (Pagani et al. 2014), a fault-oriented spatially smoothed seismicity

technique (Pagani et al. 2023; Weatherill, 2014) is employed to model earthquake characteristics. A subsequent assessment of rainfall and earthquake-triggered landslides across Uganda is then performed using a fuzzy logic approach that is implemented in *ArcGIS* (Raines et al. 2010) environment. Predominant landslide conditioning factors (e.g., topography, lithology and hydrology) are analysed in conjunction with rainfall and earthquake triggering factors to produce a comprehensive relative landslide susceptibility map for Uganda.

### 3.2 Fuzzy logic method for landslide hazard assessment

Fuzzy logic approach, initially introduced by Zadeh (1965), can be used to assess the likelihood of landslides in an area by assuming that the factors responsible for inducing past landslides can reliably be used as indicators for triggering future events occurring within the same region (Anbalagan et al. 2015; Lee and Talib 2005; Tangestani 2004). As opposed to alternative methods of landslide susceptibility assessment, the GIS-based fuzzy logic approach is employed for regions with scarce landslide inventory. For instance Gorsevski et al. (2003), Kanungo et al. (2009), Kayastha (2012), Tangestani (2004) and Kritikos et al. (2015) employed the fuzzy logic approach to predict the distribution of landslides in various global catchments. This procedure involves determining landslide frequency ratios, deriving semi-data driven fuzzy memberships and fuzzy maps for the different conditioning factors, and implementing the fuzzy overlay tools to produce landslide susceptibility maps. The schematic diagram illustrating the sequential workflow of fuzzy logic approach implemented in *ArcGIS* (Raines et al. 2010) environment is presented in Fig 3.1.

Herein, a statistical bivariate method (Aleotti and Chowdhury 1999; Leroi 1996) is used to calculate the spatial relationship between the location of landslides and landslide conditioning (geology, topographic slope position index, slope aspect, slope angle, distance from streams and proximity to active faults) as well as triggering factors (earthquakes). The frequency ratio ( $FR_i$ ) is defined as the ratio of the frequency of landslides within a specific conditioning and/or triggering factor class  $i$  to the relative frequency of all observed landslide pixels across the study area (Lee and Pradhan 2007; Lee and Sambath 2006; Yilmaz 2009). This is expressed as:

$$FR_i = \frac{N_{(P)i} / N_{(P)}}{N_{(LP)} / N_T} \quad (3.1)$$

where  $N_{(P)i}$  is the number of observed landslide pixels (unit area) in a landslide factor category  $i$ ,  $N_{(P)}$  is the total number of pixels in the selected factor category  $i$ ,  $N_{(LP)}$  is the total number of observed landslide pixels in the region of interest, and  $N_T$  is the total number of pixels in the entire study area. The approach defined in Eq. (3.1) is adopted because landslide scars obtained are captured as raster images which support pixel counts in *ArcGIS* (Raines et al. 2010).

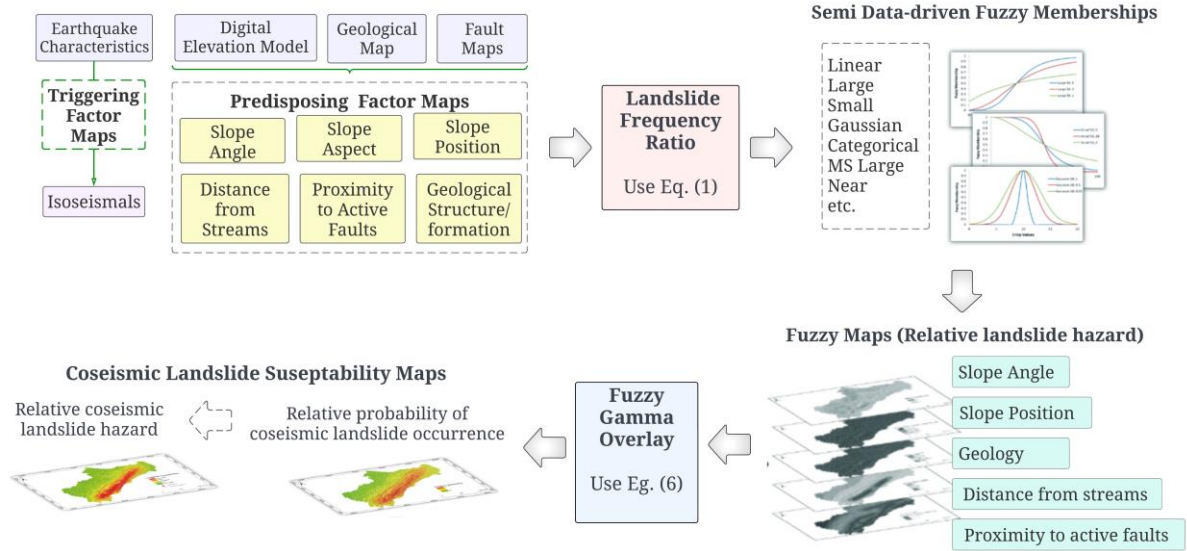


**Fig 3.1** Schematic illustration of the GIS-based fuzzy logic method employed to produce co-seismic and rainfall-induced landslide susceptibility maps for Uganda.

Following the determination of landslide frequency ratios for each landslide parameter, the fuzzy membership functions (e.g., *Linear*, *Large*, *Small*, *Gaussian*, *Categorical*, *MS Large*, and *Near*) available in the fuzzy membership tool embedded in *ArcGIS* (Raines et al. 2010) are implemented to produce fuzzy maps; prior to the application of fuzzy overlay operators used to generate membership functions and landslide conditioning parameter maps for the various landslide conditioning factors (Bonham-Carter 1994; Wang et al. 2009). Landslide conditioning parameter maps are then aggregated and their spatial distribution overlaid to produce the final fuzzy sets describing the relative co-seismic landslide hazard susceptibility for the region in question (Dubois and Prade 1985; Kayastha 2012; Zimmermann 2012). The fuzzy algebraic OR, fuzzy algebraic AND, fuzzy PRODUCT, fuzzy SUM, and fuzzy GAMMA are defined as follows:

$$\text{Fuzzy OR} \quad \mu(x) = \max(\mu_i) \quad (3.2)$$

$$\text{Fuzzy AND} \quad \mu(x) = \min(\mu_i) \quad (3.3)$$

$$\text{Fuzzy SUM} \quad \mu(x) = 1 - \prod_{i=1}^n (1 - \mu_i) \quad (3.4)$$

$$\text{Fuzzy PRODUCT} \quad \mu(x) = \prod_{i=1}^n \mu_i \quad (3.5)$$

$$\text{Fuzzy GAMMA} \quad \mu(x) = \left[ 1 - \prod_{i=1}^n (1 - \mu_i) \right]^\gamma \times \left[ \prod_{i=1}^n \mu_i \right]^{1-\gamma} \quad (6)$$

where  $\mu(x)$  is the combined membership function,  $\mu_i$  is the fuzzy membership function for the  $i^{th}$  fuzzy overlay map, and the parameter  $\gamma$  is chosen in the range of 0 and 1. The  $\gamma$ -value establishes the effect of large  $\mu_i$  values (fuzzy membership functions favouring the occurrence of landslides) compared to small  $\mu_i$  values (fuzzy membership functions discouraging landslide

occurrence). Therefore, at known landslide locations like in Bududa and Manafwa districts located around Mount Elgon in eastern Uganda, it is expected that the optimal value of  $\gamma$  will predict high hazard levels (Kritikos et al. 2015).

### 3.3 Case study area: Uganda

Uganda is a Sub-Saharan African country which lies along the equator between latitude: 1° S and 4° N, and longitude: 30° E and 35° E, as shown in Fig 3.2a. The country has a total area of 241550 km<sup>2</sup>, of which 41027 km<sup>2</sup> (approximately 17 %) is open inland water. Majority of the country's territory receives mean annual rainfall between 1000 and 1500 mm. An average annual population growth rate of 3.19 % has been recorded over the past few years and as at June 2022, Uganda's population stood at over 44.2 million (UBoS 2022). The landlocked East African country sits at an estimated average altitude of 900 m.a.s.l and comprises a diverse geography of lakes, mountains and volcanos. The first elevation data compiled between 1962 and 1970 is obtained locally from National Forest Authority and merged with the 30-metre Shuttle Radar Topography Mission (RCMRD 2022; USGS 2022a) as depicted in Fig 3.2b. The major areas that are largely prone to rainfall-induced and co-seismic landslides include:

1. The Rwenzori Mountains, situated along the equator crossing the western arm of the East African Rift System (EARS) shown in Fig 3.3, are amongst the country's most remarkable highlands. Mount Rwenzori is a peninsular raising to a maximum of 5109 m.a.s.l and it comprises an active seismo-tectonic setting (Koehn et al. 2010), gneisses geology (Bauer et al. 2012), ecology (Eggermont et al. 2009), glaciers (Taylor et al. 2009) and long-term soil erosion processes (Roller et al. 2012). Because of its geomorphology, regions around the Rwenzori Mountains have over the past experienced landslides of varying degrees. For instance, the densely populated districts of Kasese and Bundibugyo registered many human and economic losses due to previous landslides. However, limited scientific information is published regarding co-seismic landslides; except the studies conducted by Mavonga (2007), Eggermont et al. (2009) and Jacobs et al. (2017).
2. Mount Elgon, located in Eastern Uganda (see Fig 3.3), is Uganda's most landslide-prone area. It is an extinct volcanic shield with a maximum elevation of 4321 m.a.s.l and predominantly characterized by weathering and intense precipitation along its steep cliffs (Knapen et al. 2006; Scott 1998). Partly due to its fertile soils, the human population of the area is quite high; with settlements spread on crests, hillslopes and valleys. This has led to increased losses during previous rainfall-induced landslides and rockfalls along the lower flanks of the volcano, especially in Bududa district (Broeckx et al. 2019; Knapen et al. 2006). Descriptions of the geology, soils, land use and biodiversity of Mount Elgon can be found in literature (e.g., Simonetti and Bell 1995; Sassen et al. 2013; Van Eynde et al. 2017; Kitutu et al. 2009; Mugagga et al. 2012).

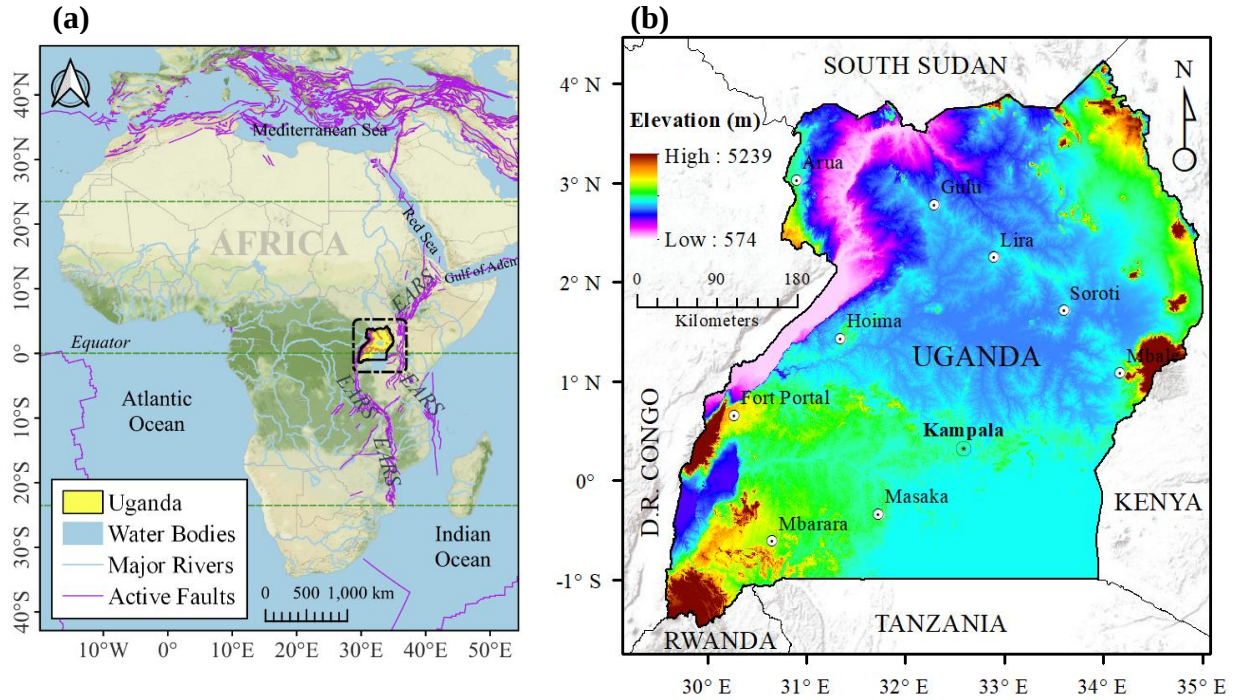


**Fig 3.2 (a)** Uganda's geographical location between the two arms of the East African Rift System, superimposed on the African continent; and **(b)** Map of the study area showing regional cities and the 30-metre Shuttle Radar Topography Mission digital elevation model

### 3.4 Landslide and earthquake datasets for Uganda

#### 3.4.1 Landslide locations and pixel distribution

The landslide locations showing the spatial distribution of both rainfall-induced and co-seismic landslide scars are acquired from National Aeronautics and Space Administration satellite repository ([NASA 2022](#)). Additional information on earthquake-triggered landslides is obtained from the US Geological Survey database ([USGS 2022b](#)). Datasets relating to the landslide scars obtained are captured as raster images which support pixel counts; and as such, landslide pixel data is obtained from the World Bank and the Global Facility for Disaster Reduction and Recovery databases ([WorldBank and GFDRR 2022](#)). Whereas the data showing the geographical location of landslide scars is used to map the spatial distribution of both rainfall-induced and co-seismic landslides, information regarding landslide pixels provides a means for determining the landslide frequency ratios using a statistical bivariate method defined in Eq. (3.1). Subsequently, overall landslide scars are mapped on co-seismic and rainfall-induced landslide pixels as portrayed in Fig 3.3, and the major active fault system indicated is taken from the Global Earthquake Model foundation database ([Styron and Pagani 2020](#)). It is observed that the mountainous parts of the country, especially Elgon and Rwenzori mountains, have experienced the largest concentrations of landslide clusters. The concentration of landslides in these regions is partly due to unstable landscapes, in particular slope positions ([Regmi et al. 2014](#)).

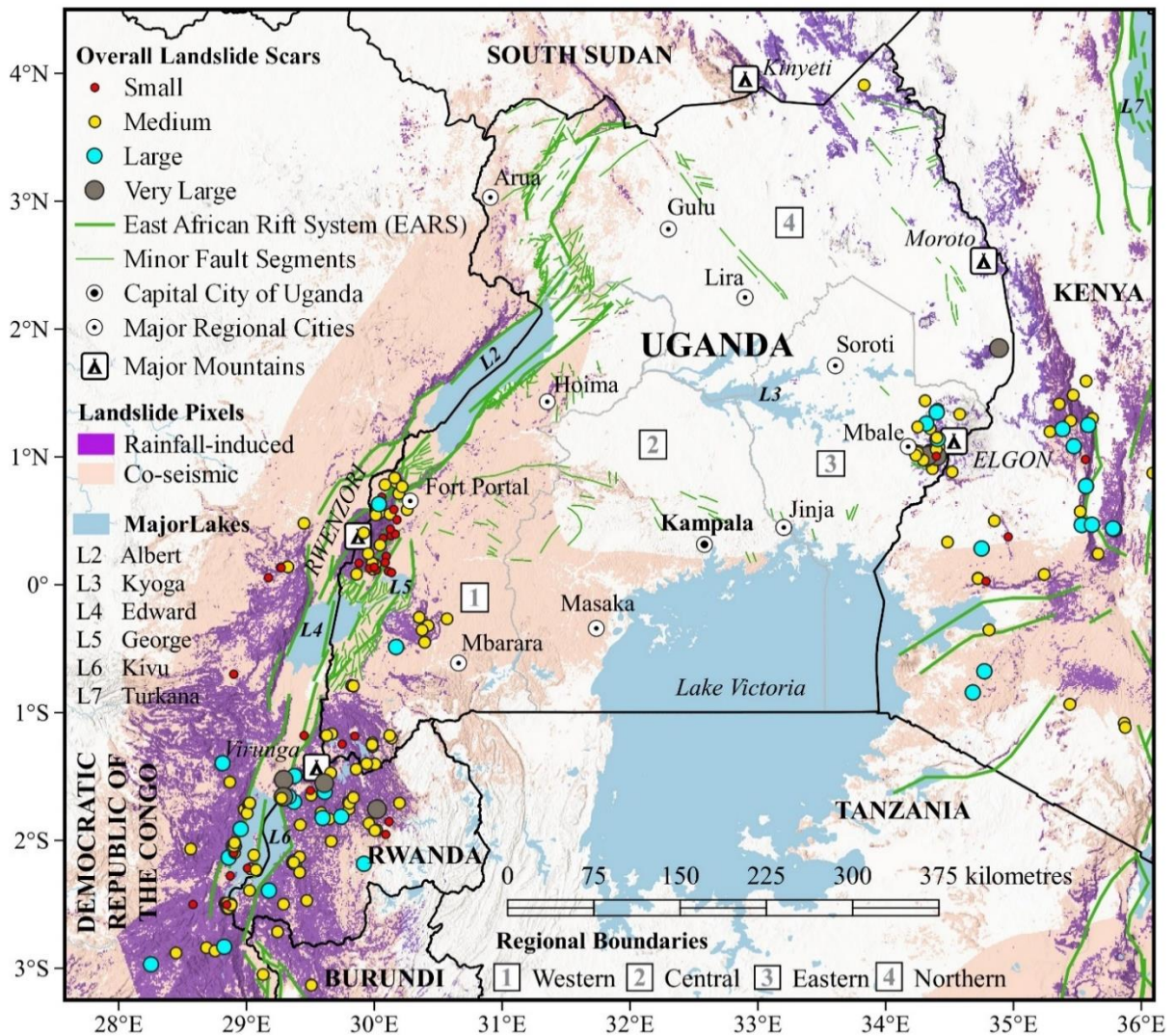


**Fig 3.3** Co-seismic and rainfall-induced landslide pixels (areas); relative to the major regional cities, active and minor fault systems, mountains and locations of known landslide scars which occurred in Uganda and around its neighbouring countries between 1933 and 2018

### 3.4.2 Earthquake characteristics

Landslide frequency ratios and fuzzy membership functions are derived for two major events: 5<sup>th</sup> February 1994 Kisomoro (6.2  $M_s$ ) and 20<sup>th</sup> March 1966 Toro (6.6  $M_s$ ) earthquakes which struck the Rwenzori region in western Uganda at hypocentral depths of 14.2 and 29.3 km, respectively (Jacobs et al. 2017; Marano et al. 2010; Tanyaş et al. 2017). These events triggered extensive landslides around their epicentres. For instance, 0.1-1.0 km<sup>2</sup> of the relatively low-populated remote countryside was exposed to landslides in the aftermath of the 1966 Toro event (USGS 2022b). Considering that recordings for a given earthquake event are available at a number of sites, knowledge of various ground-motion fields can be used whilst incorporating their spatial correlation to constrain shaking intensity for sites neighbouring the recording stations (Crowley et al., 2008). Spatial correlation model (e.g. Esposito and Iervolino 2012; Goda

and Hong 2008; Jayaram and Baker 2009; Wang and Takada 2005) can be used to obtain inter-event and intra-event residuals at each site when modelling ground-motion fields for scenario earthquakes (Erdik 2021). The inclusion of the spatial correlation of ground motion intensities into the earthquake risk analysis can result in more representative estimates (Weatherill et al. 2015).

However, the spatial correlation in ground-motion intensities across Uganda is not considered in the present study. Using a logic-tree approach, ground motion prediction equations (GMPEs) proposed by Akkar et al. (2014), Chiou and Youngs (2014), Pezeshk et al. (2011) and Atkinson and Boore (2006) are used to generate peak ground acceleration (PGA) isoseismals shown in Fig 3.4a-b. Whereas isoseismals are produced for the two scenario earthquakes, landslide hazard is incorporated into an existing MC-based PSHA model for Uganda. In this work, landslide hazard analysis is incorporated into an existing seismic hazard model for Uganda. The 30-metre average shear wave velocity and site-specific hazard maps for a 475-year return period are shown in Fig 3.5a-b, in addition to seismic hazard maps on reference rock site conditions for 475-year and 2475-year return periods shown in Fig 3.6a-b, respectively. Information on the existing stochastic event-based probabilistic seismic hazard analysis for Uganda can be found in the literature by Olenk et al. (2024).

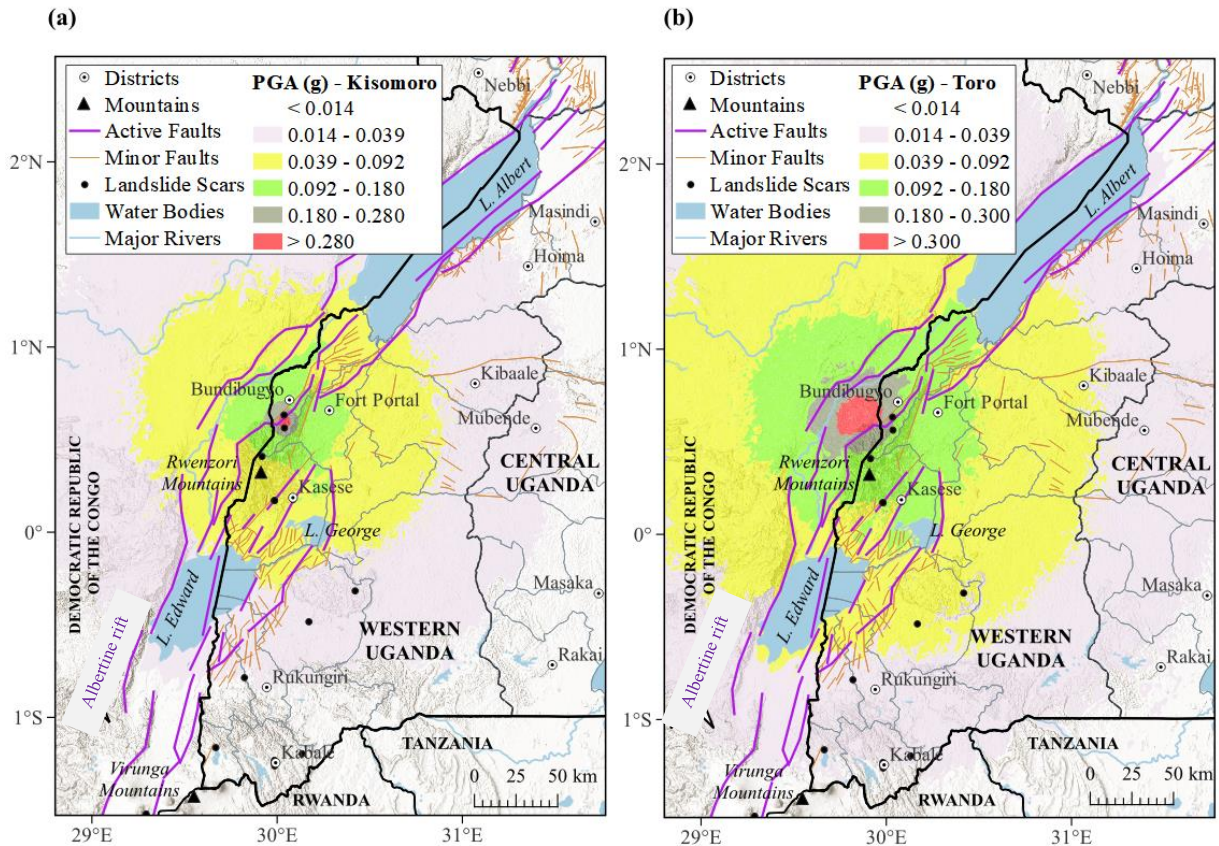


**Fig 3.4** Seismic hazard maps in terms of peak ground acceleration (PGA [g]) for *scenario* earthquakes: **(a)** the 5 February 1994 Kisomoro (6.2  $M_s$ ), and **(b)** the 20 March 1966 Toro (6.6  $M_s$ )

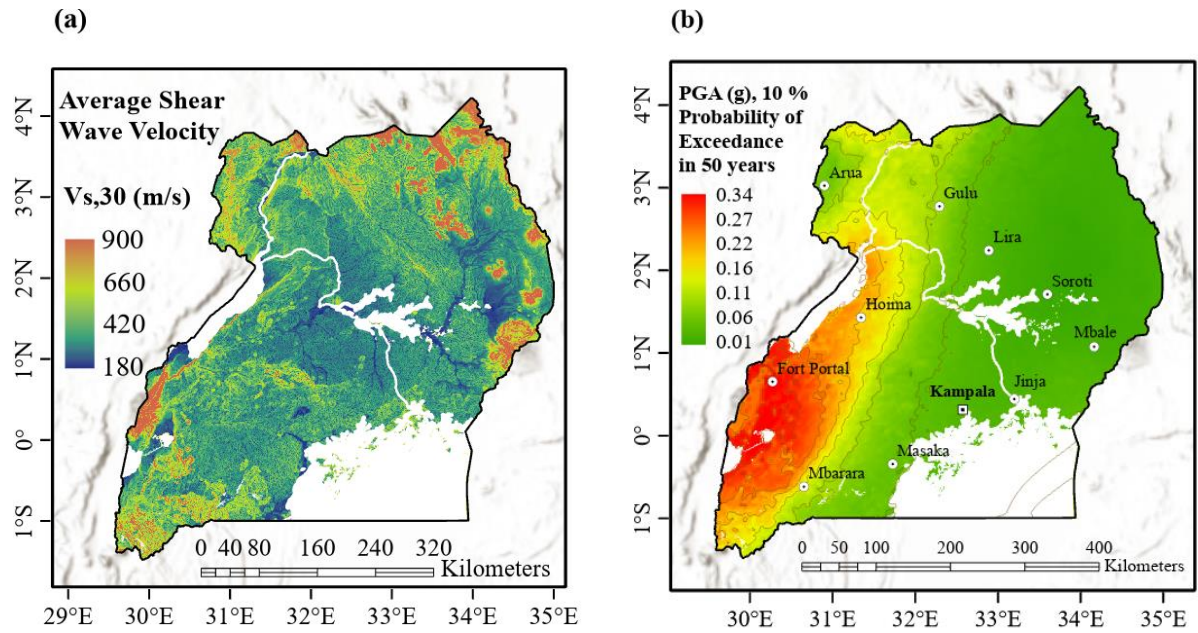


**Fig 3.5 (a)** 30-metre average shear-wave velocity reference map of Uganda, and **(b)** site-specific seismic hazard map in terms of PGA (g), with contour lines imposed at 0.05 g interval and presented for a 475-year return period (Oleng et al. 2024).

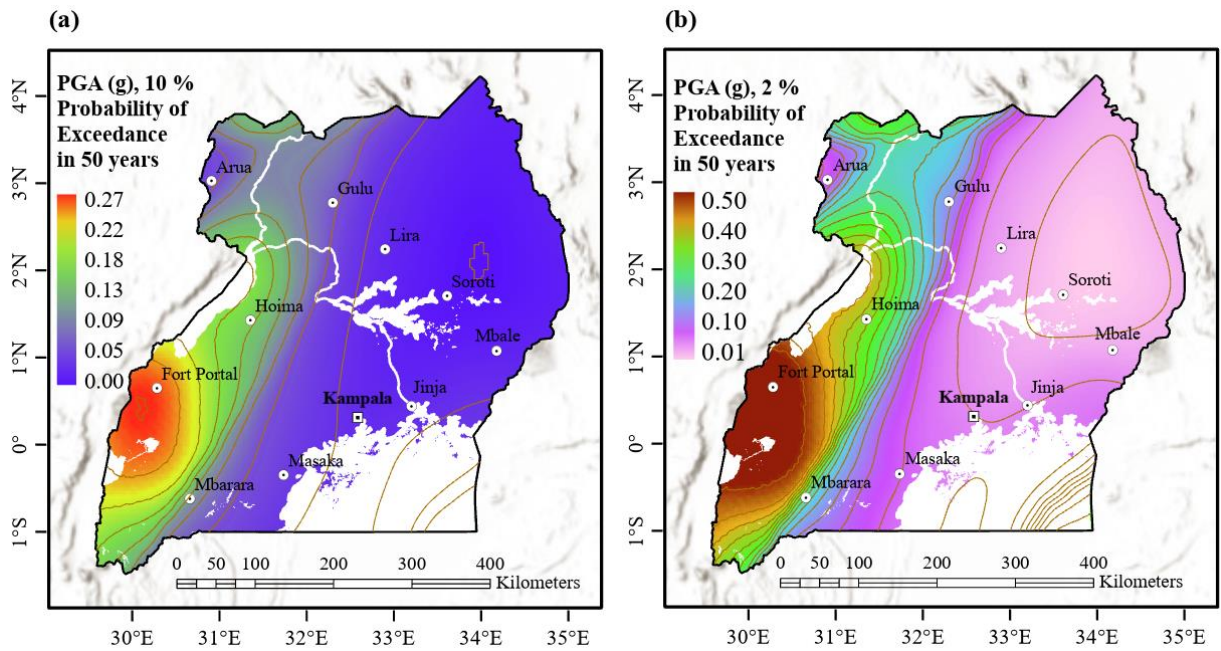


**Fig 3.6** Seismic hazard maps on reference rock site conditions derived in terms of PGA (g), with contours imposed at 0.03 g interval, for: **(a)** 475-year return period, and **(b)** 2475-year return period (Oleng et al. 2024)

### 3.5 Landslide inventory analysis and model design

Historical landslide inventories can be used to represent future landslide susceptibility for a given region. However, many countries in the global south lack accurate and complete datasets

relating to landslide susceptibility and inventories (Xu 2015). That notwithstanding, meaningful quantitative landslide hazard analyses are often performed based on triggering and conditioning parameters. Whereas co-seismic landslides are triggered based on the resulting effects of strong ground motion on a rock mass, the intrinsic characteristics that render a slope susceptible to failure are largely responsible for initiation of rainfall-induced landslides (Glade and Crozier 2005; Kritikos et al. 2015; Nakileza and Nedala 2020). It is worth noting that although rainfall-induced landslides are largely associated with the topographic factors, the influence of climate change can substantially exacerbate the impact of natural-hazard-induced disasters.

Based on the morphometric conditions underpinning the spatial and temporal dynamics of landslide hazards across Uganda, identified in previous studies (e.g., Bamutaze 2019; Kitutu et al. 2009; Knapen et al. 2006; Mugagga et al. 2012 and Nakileza and Nedala, 2020), the major landslide triggering parameters considered in this work include rainfall and earthquakes; which are modelled together lithology (geology, tectonics and topography) and hydrologic conditioning factors. These factors combine with the triggering factor to generate landslide hazard. The following sub-sections explain how the selected triggering and conditioning factors are designed and incorporated herein.

### 3.5.1 Triggering factors

Co-seismic landslides are often initiated when a rock/soil mass is subjected to strong ground motion, commonly quantified directly in terms of peak ground acceleration (PGA) or expressed indirectly in terms of the Modified Mercalli Intensity (MMI) scale (Baker et al. 2021; Kramer 1996; Kritikos et al. 2015). In this study, two earthquakes (1966 Toro and 1994 Kisomoro events) whose ground motion responses are shown in Fig 3.4a-b are considered. In addition to the standard groupings of the MMI scale, frequency ratios are evaluated in terms of the following PGA (g) ranges: < 0.014, 0.014-0.039, 0.039-0.092, 0.092-0.18, 0.18-0.28, and 0.28-0.36.

### 3.5.2 Conditioning parameters

#### 3.5.2.1 Geology

Extensive variations on the geological timescale of Uganda has been recorded for over three billion years (Maasha 1975; Westerhof et al. 2014). The simplified geological map of Uganda presented in Fig 3.7a shows that the country largely comprises of Precambrian basement that is dominantly granulites and gneisses, metasedimentary, metavolcanics and granites. The other parts comprise Tertiary-Quaternary unconsolidated sedimentary geology. Along with Palaeozoic-Mesozoic sediments, across the country lies the volcanic region around the western and eastern borders. Another geo-tectonic structure is the Aswar shear zone which is broadly stable and seismically inactive; except at its northern end where it intercepts the East African Rift

System (Fairhead and Stuart 1982; Furman et al. 2006; Karp et al. 2012; McDougall and Brown 2009; Muwanga et al. 2001; Schlüter 2008; Sykes and Landisman 1964; Westerhof et al. 2014).

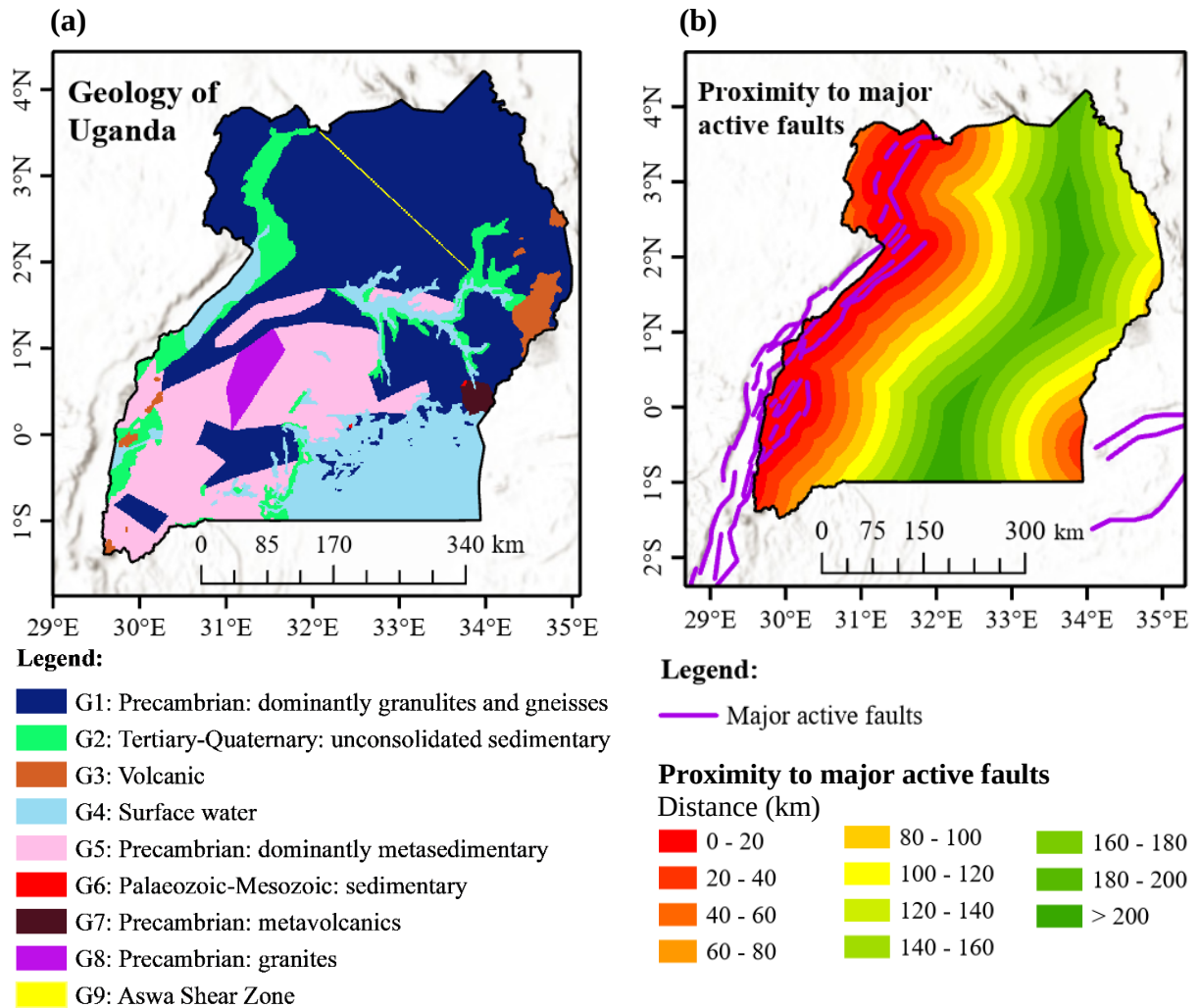


**Fig 3.7** Landslide conditioning factor maps of Uganda showing the inventory model characterisation for: **(a)** generalised geological formations, and **(b)** proximity to active faults

### 3.5.2.2 Proximity to the major active faults

Owing to various soil/rock weakening mechanisms like fault slip, geochemical alterations, and groundwater infiltration (Korup 2004; Warr and Cox 2001), the release of seismic energy along active faults may substantially reduce material strengths within a few kilometres of the lithosphere (Brune 2001; Dramis and Sorriso-Valvo 1994; Kellogg 2001; Kramer 1996). Due to the considerable loss of material strength, the regions closer to active faults are more vulnerable to earthquake-triggered landslides (Petley 2012). While taking into account the minimum distance between faults and the maximum distance at which landslide scars are mapped, a class size of 20 km is used to group distances from active faults in Uganda as shown in Fig 3.7b. It is obvious that areas near the western boarder are much closer to the East African Rift System

compared with the rest of the country, except for the eastern boundary which lies within a few kilometres from the eastern or Gregory arm of the East African Rift System.

### 3.5.2.3 Topographic slope position

Various hillslope types (e.g., valleys, mid-slopes and ridges) respond differently to earthquake-induced ground shaking (Athanasopoulos et al. 1999; Davis and West 1973; Havenith et al. 2003; Spudich et al. 1996). This is because of the localised increase in the amplitude of ground motion due to seismic wave propagation through the Earth's crust (Lee et al. 2009; Meunier et al. 2008; Wald and Allen 2007). This work utilises the Topographic Position Index (TPI), defined by Weiss (2001), to classify the land formation (morphology) across Uganda into discrete categories based on relative slope positions. Within a predetermined neighbourhood, for instance a 10-15 cell size (300-500 m for small-scale TPI) and a 62-67 cell size (1.86-2.1 km for large-scale TPI), the TPI essentially measures the difference between the elevation of a given central point and the mean altitude of the surrounding grid cells. This is expressed as follows:

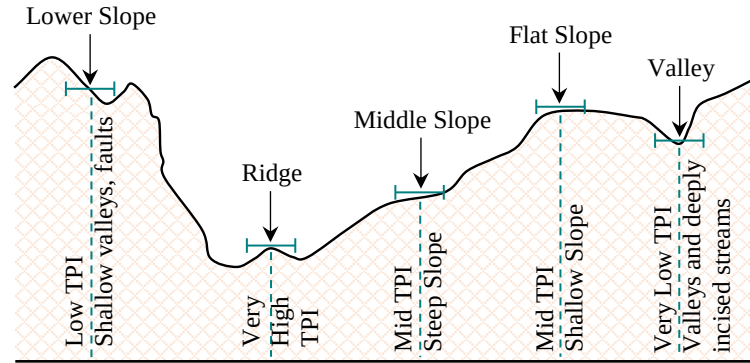
$$TPI = Z_o - \frac{\sum_{n=1}^N Z_n}{N} \quad (3.7)$$

where  $Z_o$  and  $Z_n$  respectively denote elevation at the central point and altitude of surrounding cells within a local window, and  $N$  is the total number of surrounding points employed in the evaluation. Positive TPI values indicate that the point under consideration is located at a higher altitude than its average surroundings, and vice versa. It is worth noting that whilst large-scale TPI values largely reveal major landscape units, smaller morphological features such as minor ridges and valleys are highlighted for small-scale TPI values (Drăguț and Blaschke 2006; Jenness 2006; Weiss 2001). In this regard, small-scale predetermined neighbourhood of a 300-metre grid/cell radius is considered herein and Uganda's landscape is subsequently categorised into 6 classes: valley, lower slope, flat slope, middle slope, upper slope and ridge (Jenness et al. 2013). According to Bufalini et al. (2021), the morphological categories shown in Fig 3.8 are defined based on the range of TPI values shown in Table 3.1.

**Table 3.4** Topographic position index (TPI) values corresponding to the various morphological features describing land form classes adopted for characterising slope positions across Uganda

| Morphological classes                                         | Range of TPI values |             |
|---------------------------------------------------------------|---------------------|-------------|
|                                                               | Lower limit         | Upper limit |
| Valley (U-shaped valley/Spread water), deeply incised streams | -63.5               | -13.3       |
| Lower slope, shallow valleys, faults                          | -13.3               | -4.3        |
| Flat slope                                                    | -4.3                | 3.8         |
| Middle slope                                                  | 3.8                 | 13.8        |
| Upper slope, small hills                                      | 13.8                | 28.8        |
| Mountain tops, high ridges                                    | 28.83               | 64.5        |

**Fig 3.8** Slope position classification obtained from topographic position index and slope (Weiss, 2001) used to generate the 6 topographic slope position classes used in this study



Following the slope position map shown in Fig 3.9a, majority of Uganda's territory consist of lower slopes, with the western and eastern boundaries predominantly comprising flat and middle slopes. Whereas the Albertine rift and West Nile block are mainly composed of valleys, upper slopes and ridges are largely observed around Uganda's mountainous regions.

#### 3.5.2.4 Slope aspect

In landslide hazard zonation, slope orientation with respect to the North may be considered as a vital parameter (Kanungo et al. 2009; Nagarajan et al. 1998; Saha et al. 2002). This is because the effect of soil moisture content, air dryness and solar heating are determined by the slope aspect influence (Capitani et al. 2013; Celtek 2021; Yalcin 2008). It is worth noting that due to its triggering effect on precipitation, slope aspect is often evaluated in combination with other factors considered in this study (Ahmed 2015; Ayalew and Yamagishi 2005; Pachauri and Pant 1992). Moreover, the influence of slope aspect on vegetation cover and moisture retention can affect material shear strengths, and possibly initiate slope failure (Silalahi et al. 2019). Slope aspect can be classified in several ways depending on the purpose at hand (Bourenane et al. 2015; Caniani et al. 2008; Tangestani 2004). In this study, the slope aspect map shown in Fig 3.9b is generated for 8 classes: north ( $0-22.5^\circ$ ,  $337.5-360^\circ$ ), northeast ( $22.5-67.5^\circ$ ), east ( $67.5-112.5^\circ$ ), southeast ( $112.5-157.5^\circ$ ), south ( $157.5-202.5^\circ$ ), southwest ( $202.5-247.5^\circ$ ), west ( $247.5-292.5^\circ$ ) and northwest ( $292.5-337.5^\circ$ ).

#### 3.5.2.5 Slope angle

Landslide incidences are substantially affected by slope angle, which is considered as a critical topographic parameter in the initiation of slope failures (Dahal et al. 2009; Gupta et al. 2008; Jibson et al. 2000; Kanungo et al. 2006). Steeper slopes are more susceptible to failure due to their greater vertical components of gravity which result in increased shear stresses within the soil (Kritikos et al. 2015). Hence, it is anticipated that steeper slopes subjected to significant ground motion will experience more landslides compared to gentle slopes. Accordingly, slope angles for the study region are categorized into 10 slope classes of  $5^\circ$  increments up to  $50^\circ$ , and a further class  $> 50^\circ$  as shown in Fig 3.9c. It is seen that most parts of the country generally lie

within slope angles  $< 15^\circ$ , except for the highland regions around Mount Elgon and Rwenzori ranges (see Fig 3.3) where greater slopes angles are observed.

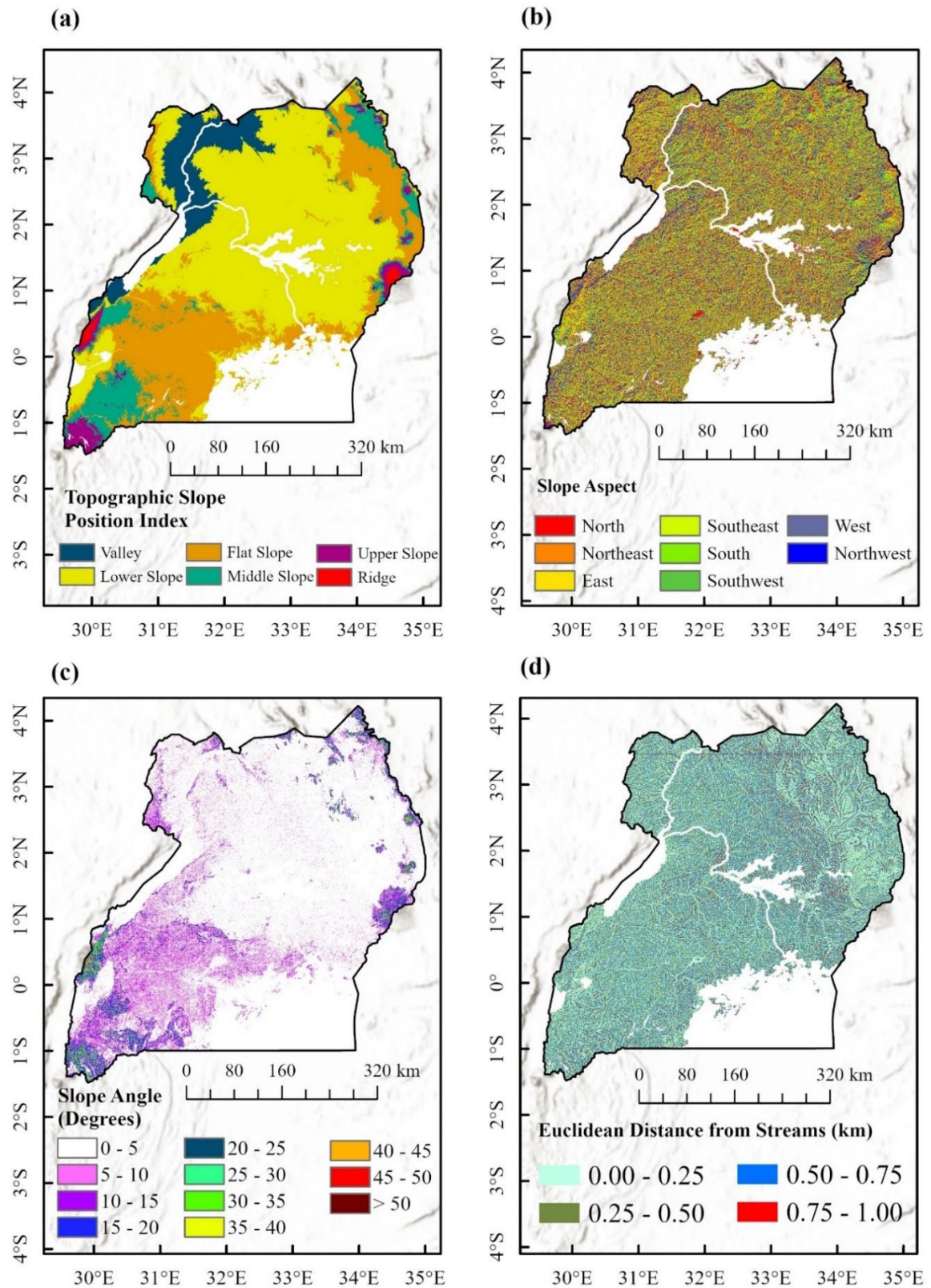


**Fig 3.9** Landslide conditioning parameter maps of Uganda, represented in terms of: (a) topographic slope position index, (b) slope aspect, (c), slope angle, and (d) distance from streams

### 3.5.2.6 Distance from streams

Hydrological processes are significant in landscape evolution and as such various landslide hazard studies have incorporated distance from drainage networks amongst the critical conditioning factors (Bathrellos et al. 2021; Larsen and Montgomery, 2012; Snyder et al. 2000; Whipple, 2004). The inclusion of hydrology not only takes into account the undercutting stream flow and terrain modification, but also stream channel and gulley erosion. These localised processes can progressively lead to the removal of horizontal restraints, thereby increasing shear stresses in the soil; a phenomenon which may eventually lead to induction of slope instability in the event of an earthquake (Dai et al. 2011; Donati and Turrini, 2002; He and Beighley, 2008; Korup, 2004; Van Westen et al. 2003b). Based on the density of Uganda's drainage network, distances from streams are grouped into the following 8 classes: 0-0.25, 0.25-0.50, 0.50-0.75, 0.75-1.00, 1.00-1.25, and > 1.25 km. The map shown in Fig 3.9d indicates the distribution of landslide pixels with regard to their proximity to natural stream networks.

## 3.6 Results

### 3.6.1 Landslide frequency ratio

Landslide frequency ratios for the 1966 Toro and 1994 Kisomoro events, whose characteristics are described in Section 3.4.2, are computed and plotted against landslide conditioning parameter classes in terms of MMI and PGA as shown in Fig 3.10a-b. Similarly, the distribution of landslide frequency ratios and the normalised overall relative landslide areas corresponding to the most relevant landslide conditioning factors described in Section 3.5.2 are presented in Fig 3.11a-f. For each landslide conditioning parameter, normalised relative areas shown Fig 3.11a-f. indicate the dominant landslide regions based on each conditioning factor class.

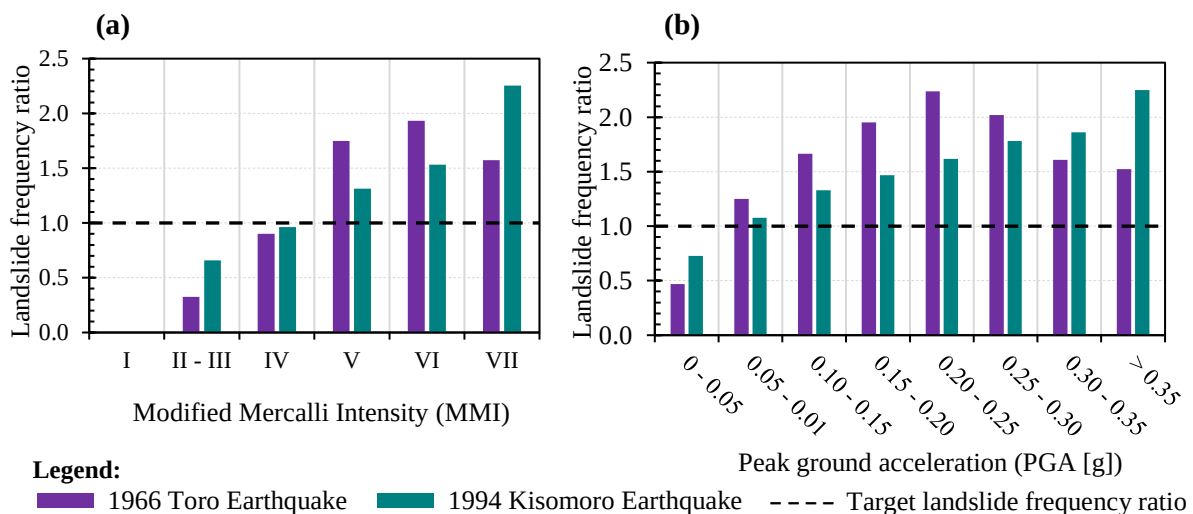
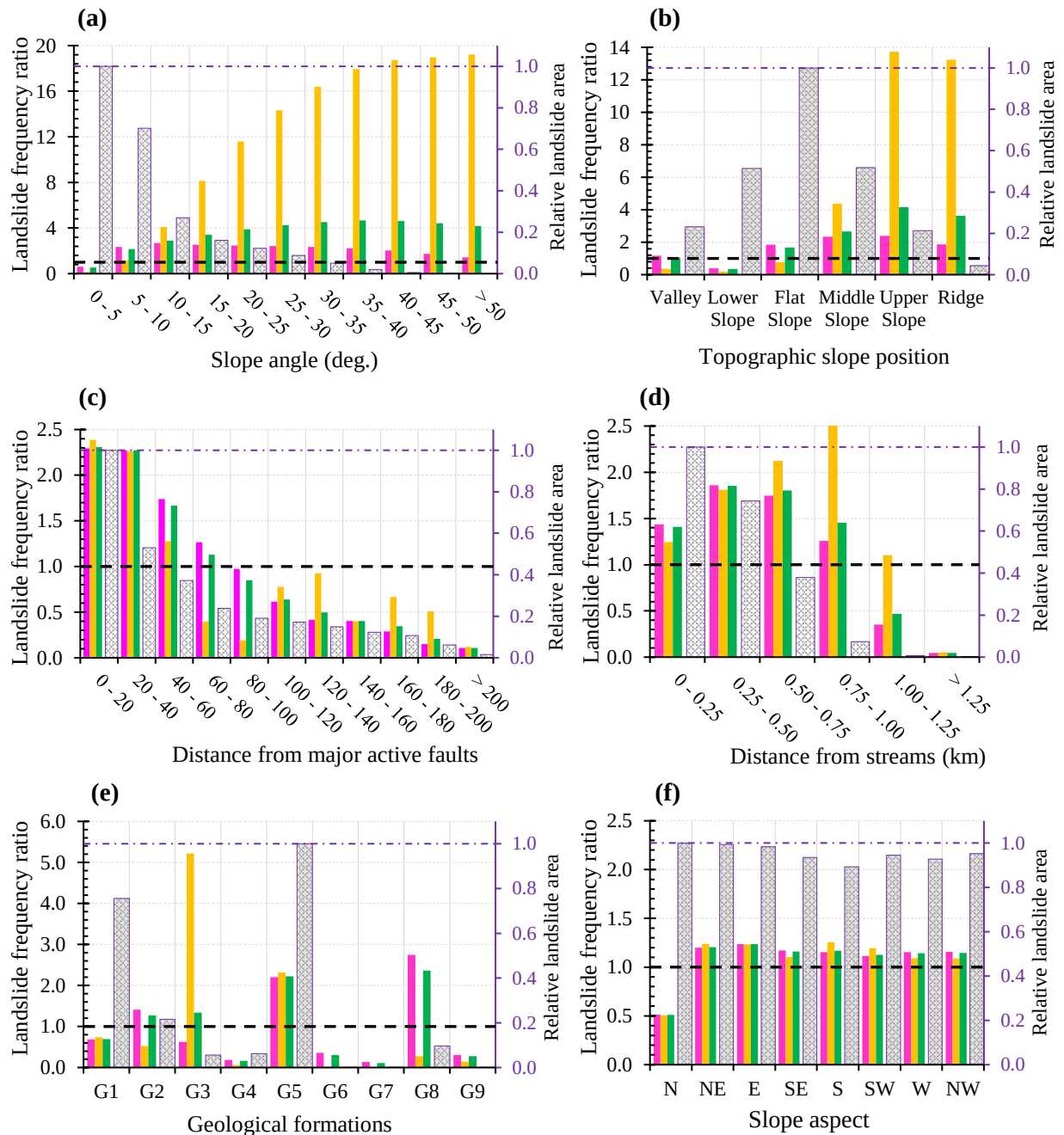


**Fig 3.10** Landslide frequency ratio for the 1966 Toro and 1994 Kisomoro earthquakes assessed in terms of: **(a)** Modified Mercalli Intensity (MMI) scale, and **(b)** Peak ground acceleration (PGA [g])

**Legend:**

- Co-seismic landslide frequency ratios
- Rainfall-induced landslide frequency ratios
- Overall landslide frequency ratios
- Normalised total relative landslide areas

*Slope Aspect* N: North, NE: Northeast, E: East, SE: Southeast, S: South, SW: Southwest, W: West, and NW: Northwest; *Geological formation* G1: Precambrian dominantly granulites and gneisses, G2: Tertiary-Quaternary unconsolidated sedimentary, G3: Volcanic, G4: Surface water, G5: Precambrian dominantly metasedimentary, G6: Palaeozoic-Mesozoic sedimentary, G7: Precambrian metavolcanics, G8: Precambrian granites, and G9: Aswa Shear Zone. The dotted dashed black lines denote a target landslide frequency ratio of 1

**Fig 3.11** Landslide frequency ratios obtained from co-seismic, rainfall-induced, and both co-seismic and rainfall-triggered landslide pixels, for landslide conditioning factors: **(a)** slope angle, **(b)** slope position, **(c)** proximity to active faults, **(d)** distance from streams, **(e)** geological formations, and **(f)** slope aspect.

### 3.6.2 Comparison of landslide frequency ratios

Landslide frequency ratios covering the upper Manafwa catchment, stretching across Bududa district in Eastern Uganda, are compared with the findings of [Nakileza and Nedala \(2020\)](#) who characterized the morphometric conditions underpinning the spatial and temporal dynamics of landslide hazards along the volcanics of Mount Elgon following the study by [Bamutaze \(2019\)](#). The comparison based on slope angle (shown in Fig 3.12a) indicates that except for slope angles less than 5°, the present study generally estimates approximately 10-60 % higher landslide frequency ratios across all gradients. Although both studies utilised similar elevation models at 30 m resolution, the differences can be attributed to the fact that whilst [Nakileza and Nedala \(2020\)](#) ignored landslide scars previously reported in Namisindwa and Bududa ([DesInventar, 2020](#)), the present study incorporates all landslide scars located in the entire Manafwa catchment. Furthermore, Fig 3.12b shows that the landslide frequency ratios for slope aspect estimated in the present study agree well with the predictions of [Nakileza and Nedala \(2020\)](#).

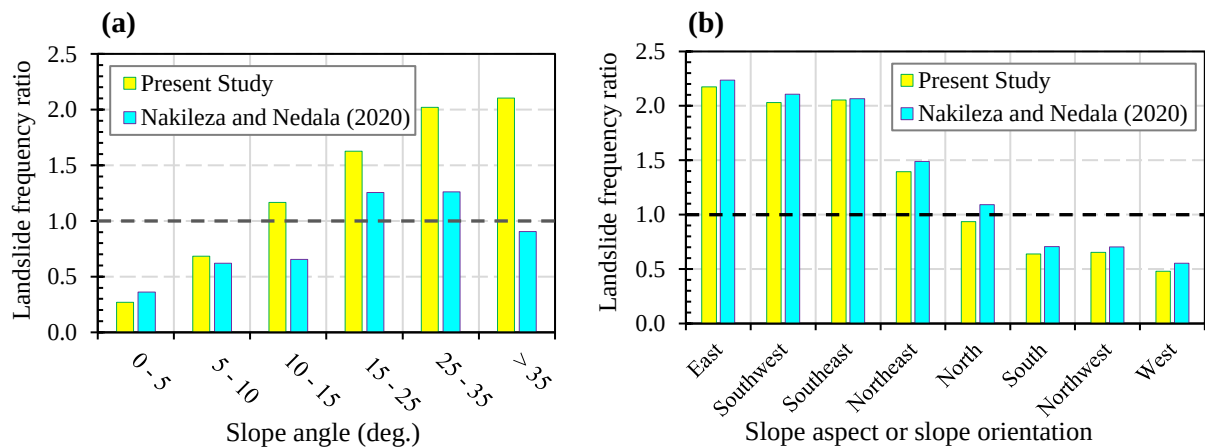


**Fig 3.12** Overall landslide frequency ratios covering the upper Manafwa catchment across Bududa district compared with the study by [Nakileza and Nedala \(2020\)](#), derived for: **(a)** slope angle, **(b)** slope aspect

On the other hand, the spatial distribution of landslide scars and the isoseismals of the two scenario earthquakes which extensively triggered landslides in Bundibugyo, Kasese, Bunyangabu, Kabarole and Ntoroko districts of western Uganda is mapped in Fig 3.13a. It is seen that majority of landslides occurred along the active fault segments located in Bundibugyo and Kasese. Moreover, many medium-size landslides mapped within 2 km of active faults were possibly triggered by earthquakes in the region. Landslide frequency ratios derived from both rainfall-triggered and earthquake-induced landslide pixels are compared with frequency ratios determined by considering co-seismic landslide pixels only. The landslide frequency ratios corresponding to slope angles and slope position (Fig 3.13b-c) indicate that co-seismic landslide pixels contribute significantly to the overall landslide hazard in these regions. As further

indicated in Fig 3.13d, Precambrian dominantly granulites and gneisses, Volcanic and Tertiary-Quaternary unconsolidated sedimentary geological formations are predominantly more susceptible to earthquake-triggered landslides.

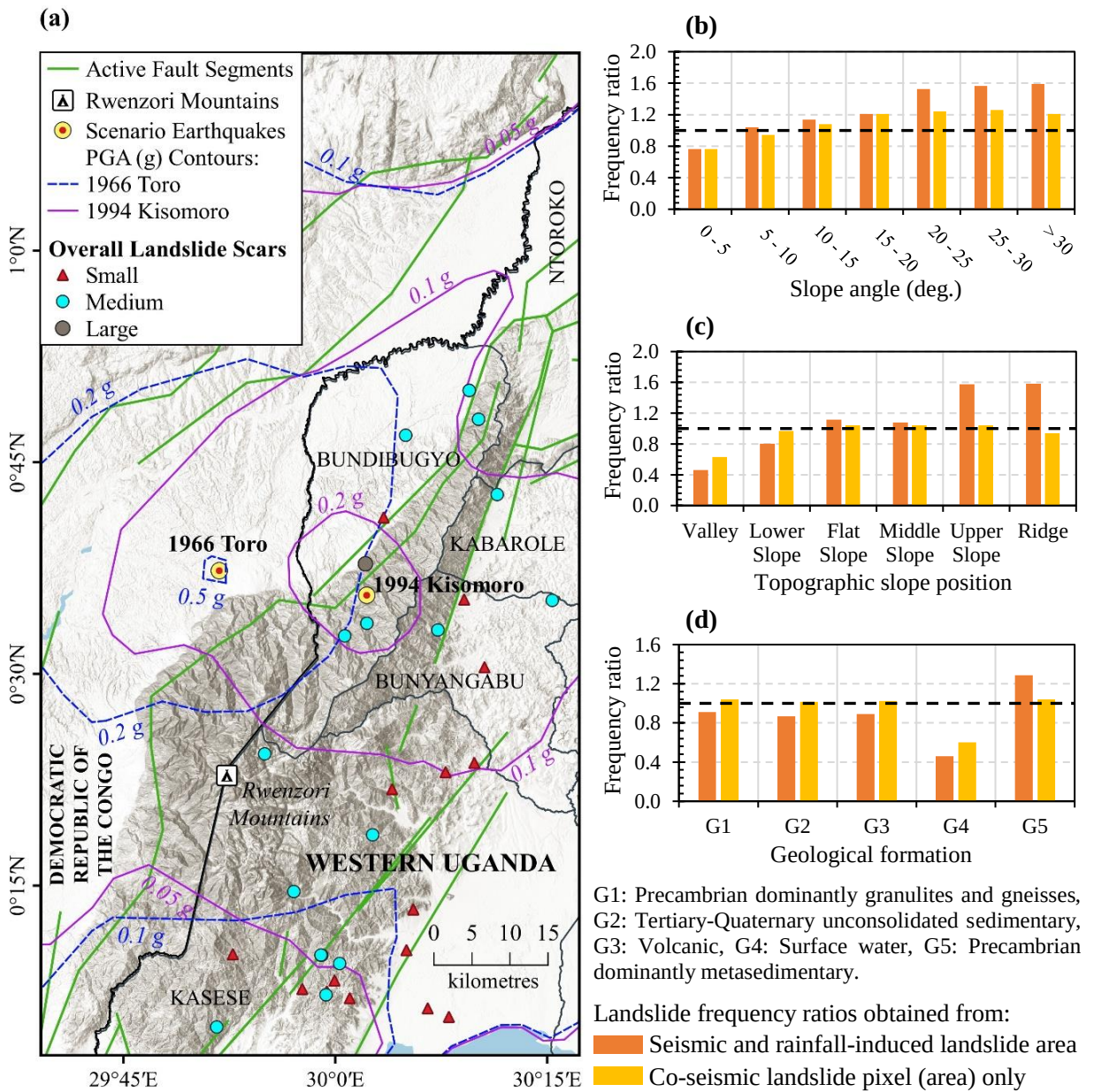


**Fig 3.13 (a)** Spatial distribution of landslide scars and epicentres of scenario earthquakes which triggered landslides in western Uganda; and comparison of the overall and co-seismic landslide frequency ratios for selected landslide conditioning parameters: **(b)** slope angle, **(c)** slope position, and **(d)** Geology

### 3.6.3 Fuzzy membership and aggregation

Using the coefficient of determination method, fuzzy membership curves are fitted to the normalized frequency ratios for the scenario earthquakes and their average fuzzy memberships

determined, as presented in Fig 3.14a-b. In both cases, fuzzy *MS Large* (sigmoid shape defined by mean and standard deviation) transformation function in which large values are more likely to be a member of the fuzzy set is used. In order to better represent the inferred influence of co-seismic factors and to account for any data inconsistencies, the fuzzy membership curve for the 1966 Toro earthquake is further subjectively adjusted from semi-data driven best fit curves so as to meaningfully represent larger memberships for higher PGA classes.

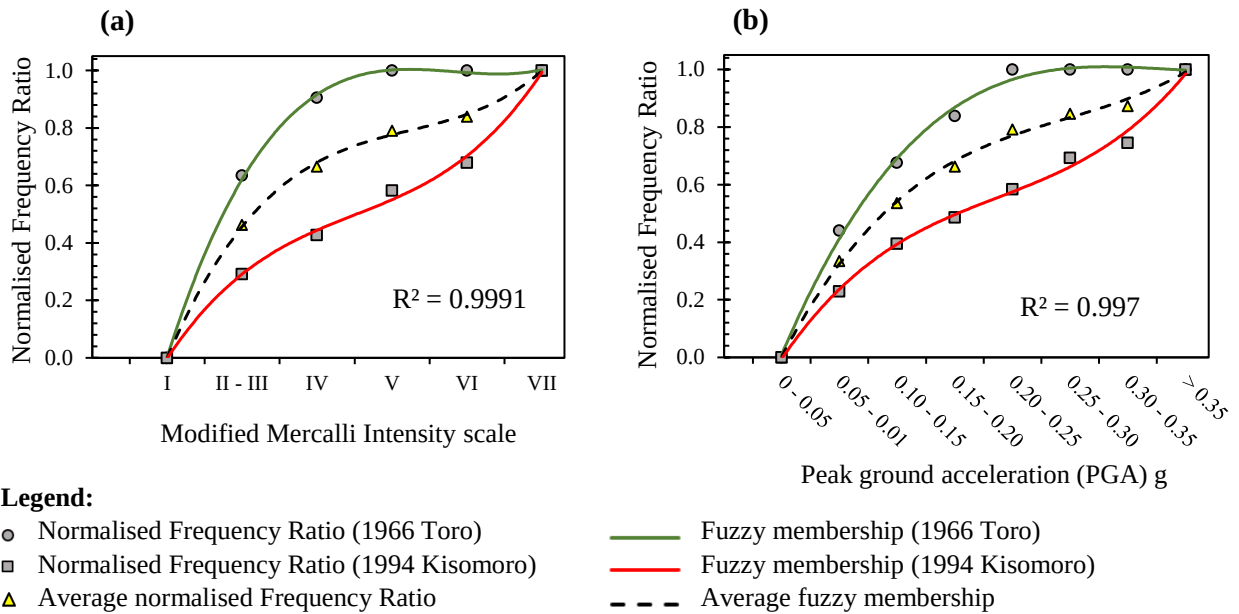


**Fig 3.14** Normalized landslide frequency ratios and fuzzy curves for 1966 Toro and 1994 Kisomoro earthquakes; assessed in terms of: **(a)** MMI scale, and **(b)** PGA on Type A rock/soil condition

Using the suitable fuzzy membership functions, fuzzy membership maps describing the relative influence of landslide conditioning parameters on a 0-1 scale (0 represents low hazard and 1 denotes high hazard susceptibility) are derived from the distribution of landslide frequency ratios and mapped in Fig 3.15a-c. In addition, the seismic hazard map on reference rock site conditions derived in terms of PGA (g) for a 475-year return period (presented in Fig 3.6a) is similarly normalised as shown in Fig 3.15d.

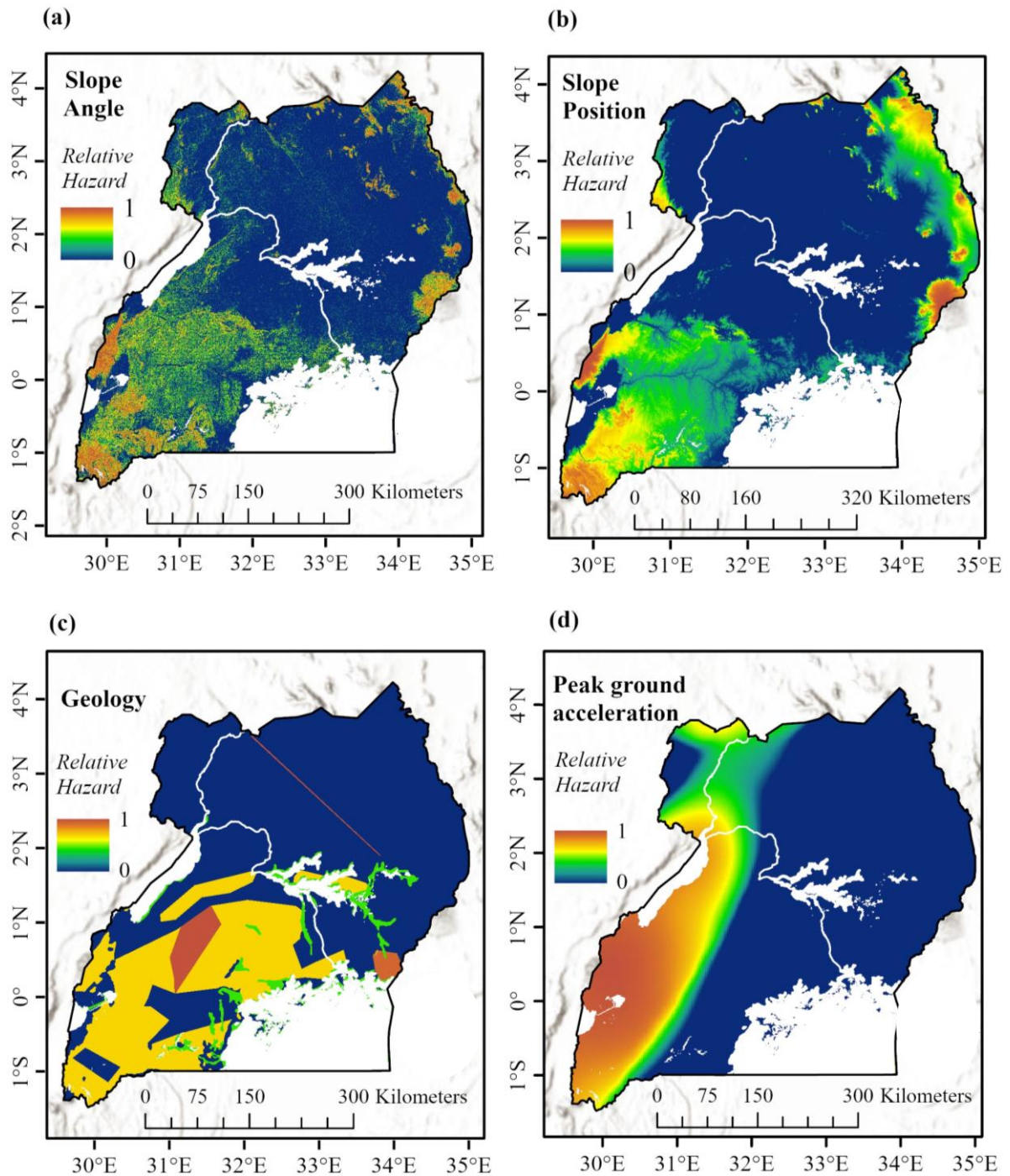


**Fig 3.15** Fuzzy membership maps for selected landslide conditioning factors: **(a)** slope angle, **(b)** slope position, **(c)** geology, and **(d)** landslide frequency ratio-based PGA (g) for a 475-year return period

### 3.6.4 Relative probability of co-seismic landslide in western Uganda

Using the fuzzy *GAMMA* overlay tool ( $\gamma = 0.95$ ) of *ArcGIS* (Raines et al. 2010), the fuzzy membership map corresponding to each landslide conditioning factor is individually correlated with normalised landslide frequency ratio-based PGA values corresponding to a 475-year return

period on reference rock site conditions (Fig 3.15d) in to map the relative probability of co-seismic landslide hazard for each pixel. The relative probability (frequency of a specific landslide outcome compared to the total number of outcomes) of a landslide occurring at a particular location for a given earthquake scenario is adequately modelled using fuzzy memberships. Since earthquake-induced landslides are typically concentrated in the Kigezi and Rwenzori sub-regions, and to more meaningfully depict the relative probability of co-seismic landslide hazard, the maps shown in Fig 3.16a-f are generated for the western part of country only. Bundibugyo and Fort Portal, have a highest relative chance of co-seismic landslides.

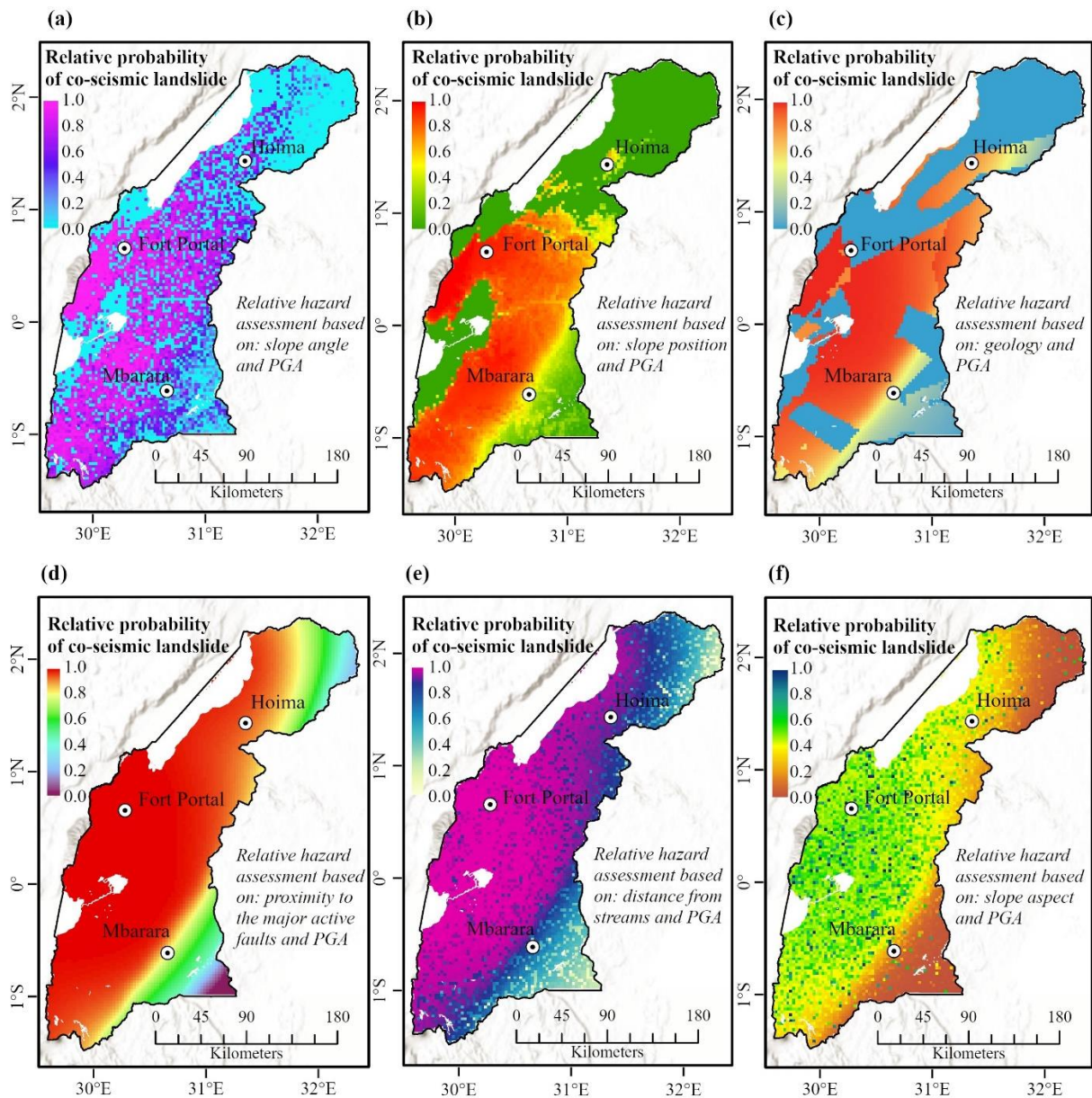


**Fig 3.16** Relative probability of co-seismic landslides in western Uganda, based on the conditioning factors and normalised landslide frequency ratio-based earthquake hazard map derived in terms of PGA (g) for 475-year return period and overlaid for: (a) slope angle, (b) topographic slope position, (c) geology, (d) proximity to major active faults, (e) distance from streams, and (f) slope aspect

### 3.6.5 Co-seismic and rainfall-induced landslide susceptibility maps

Following the determination of the relative probability of landslides, relative landslide susceptibility maps (showing low-high levels of relative hazard) are produced by executing the fuzzy operators. The relative co-seismic landslide hazard susceptibility maps for Uganda shown in Fig 3.17a-b are respectively derived by executing the GIS-based fuzzy *SUM* (Eq. 3.4) and fuzzy *PRODUCT* (Eq. 3.5) overlay tools. Whilst the landslide hazard susceptibility map based on fuzzy *SUM* (Fig 3.17a) shows a wider distribution of co-seismic landslides, the map derived following fuzzy *PRODUCT* (Fig 3.17b) indicates that co-seismic landslides are mainly concentrated in western Uganda. In addition, the GIS-based fuzzy *GAMMA* (Eq. 3.6) overlay tool (with  $\gamma = 0.95$ ) is used to generate the relative co-seismic and rainfall-triggered landslide hazard susceptibility maps shown in Fig 3.18a-b, respectively.

The relative earthquake-triggered landslide hazard susceptibility map shown in Fig 3.18a shows that only western Uganda is exposed to the highest level partly due to its active seismicity and geo-tectonic environment. Although the worst hazard level is predicted around the Rwenzori and Kigezi sub-regions, Uganda's north-western boarder (near Arua city) and Albertine graben (around Hoima city) can expect some co-seismic landslides. On the other hand, the relative rainfall-triggered landslide hazard susceptibility map shown in Fig 3.18b (obtained for conditioning factors only, without considering earthquake characteristics) confirms that several highlands are prone to rainfall-triggered landslides.

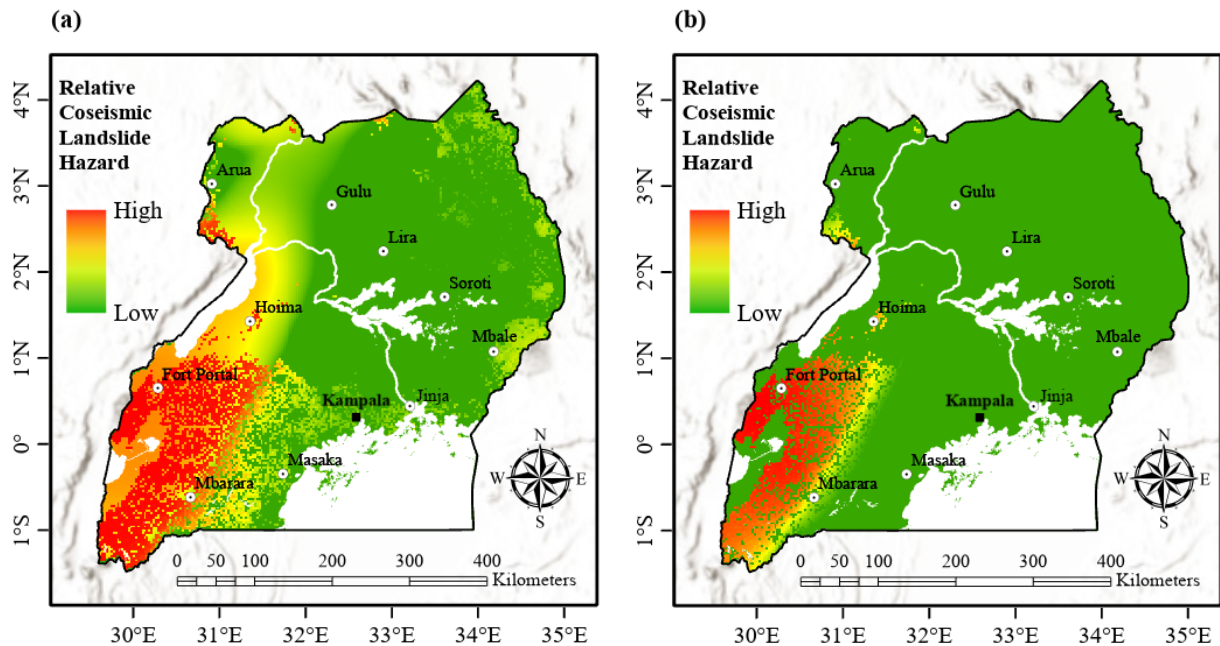


**Fig 3.17** Overall relative co-seismic landslide susceptibility maps of Uganda obtained by combining landslide conditioning factors and normalised landslide frequency ratio-based PGA values, generated using the GIS-based fuzzy overlay tool: **(a)** Fuzzy *SUM*, and **(b)** Fuzzy *PRODUCT*

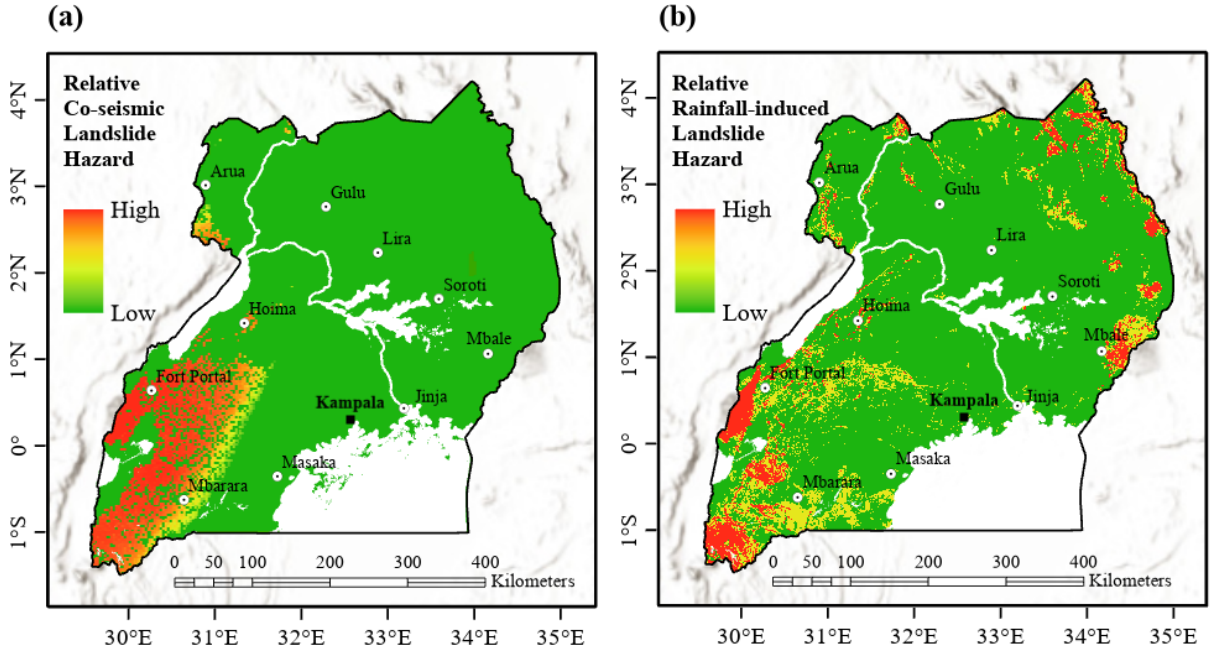


**Fig 3.18 (a)** Relative co-seismic landslide hazard susceptibility based on various landslide conditioning factors and normalised frequency ratio-based PGA ( $g$ ), and **(b)** Relative landslide hazard susceptibility obtained for conditioning parameters responsible for rainfall-induced landslides only generated using GIS-based fuzzy GAMMA with  $\gamma = 0.95$

### 3.7 Validation of landslide susceptibility maps

The accuracy of landslide susceptibility maps proposed in this work is validated using the area under the receiver operating characteristic curve method in which success rate curves show the model performance (Chung and Fabbri 1999; Frattini et al. 2010; van Westen et al. 2003a). To verify whether the fuzzy overlay operators described in Eqs. (3.2-3.6) accurately predict the occurrence or non-occurrence of pre-established (known) landslide scars, the trade-off between false-positive and false-negative rates are graphically represented (see Fig 3.19a-d) using the receiver operating characteristic (ROC) curves prior to determining area under curve (AUC) values (Gupta et al. 2023). False-positive rate  $\lambda_{FP}$  and true-positive rate  $\lambda_{TP}$  are defined as follows:

$$\lambda_{FP} = 1 - \frac{TN}{TN + FP} \quad (3.8)$$

$$\lambda_{TP} = \frac{TP}{TP + FN} \quad (3.9)$$

where  $TN$  (true negative) and  $TP$  (true positive) represent the count of correctly grouped pixels,  $FN$  (false negative) and  $FP$  (false positive) indicate the count of erroneously categorised pixels. Herein, landslide pixels are binned into 100 equal intervals and the number of landslide scars in each interval is summed (Miles and Keefer 2009). By comparing the proportion of total

landslides to the proportion of predictive bins in which landslide scars are mapped from highest to lowest (Beguería 2006; Pradhan and Lee 2010; Sema et al. 2017), the accuracy or success rate of the predictive models is assessed. In this work, success rate or model performance is defined by the AUC (ranging between 0.5 and 1.0) from which the highest value indicates the optimal approach (Nandi and Shakoor 2010). Whereas an AUC value equal to 1.0 represents a perfect forecast prediction,  $AUC \leq 0.5$  implies that the model does not predict landslide occurrences any better than any random guess (Gupta et al. 2023). In general, AUC values exceeding 0.7 are a good representation and deem the model to be successful (Kritikos et al. 2015).

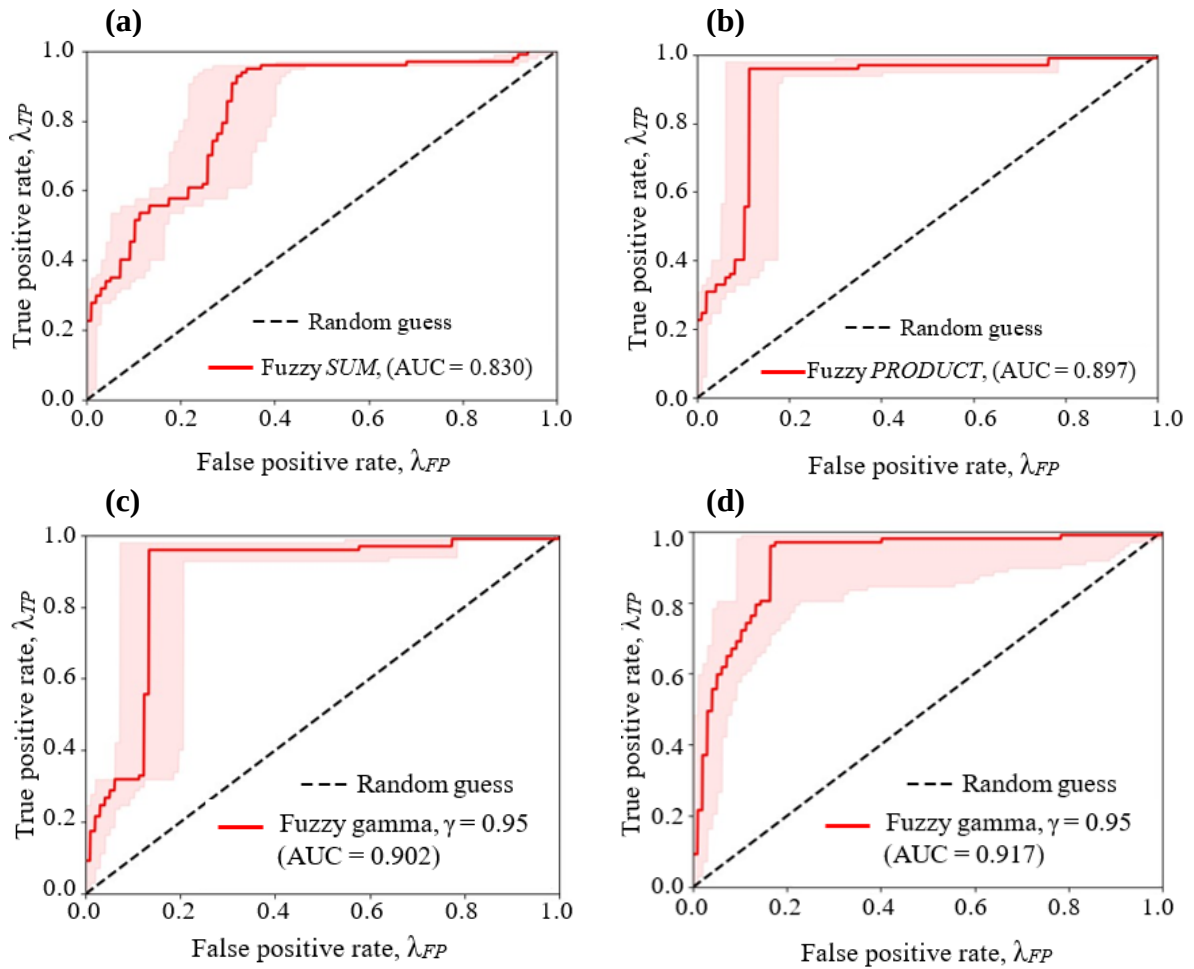


**Fig 3.19** Variation of true and false positive rates (AUC-ROC values) used to validate relative landslide hazard susceptibility maps derived for: **(a)** co-seismic fuzzy *SUM*, **(b)** co-seismic fuzzy *PRODUCT*, **(c)** co-seismic fuzzy *GAMMA* with  $\gamma = 0.95$ , and **(d)** rainfall-induced fuzzy *GAMMA* with  $\gamma = 0.95$

Success rates of landslide susceptibility maps shown in Fig 3.17a-b, obtained using fuzzy *SUM* and fuzzy *PRODUCT*, are indicated in Fig 3.19a-b. The landslide susceptibility map derived from fuzzy *PRODUCT* (Fig 3.17b) indicates a success rate of 89.7 % (Fig 3.19b) and is more accurate compared with the 83.0 % (Fig 3.19a) performance level obtained from fuzzy *SUM* map shown in Fig 3.17a. Although the performance levels obtained using fuzzy *SUM* and fuzzy

*PRODUCT* are deemed successful ( $AUC > 0.7$ ), more accurate predictions are obtained by implementing fuzzy *GAMMA* (Kritikos et al. 2015). The effect of  $\gamma$ -value on landslide susceptibility maps is assessed by generating AUC for various models in which  $\gamma$  is set between 0.65 and 0.95 in a 0.1 interval. As depicted in Fig 3.19c, an optimal model performance level of 90.2 % is obtained for co-seismic landslide susceptibility map in which  $\gamma$  is set to 0.95 (Fig 3.18a). Following the relative landslide susceptibility map based on topographic factors responsible for rainfall-induced landslides (Fig 3.18b), the evaluation of AUC indicates a higher success rate of 91.7 % as shown in Fig 3.19d. The improved success rate can be attributed to the accurate DEM from which conditioning landslide factors are modelled.

### 3.8 Final landslide hazard susceptibility map

The final overall relative landslide hazard susceptibility map shown in Fig 3.20 is obtained by combining the relative co-seismic and rainfall-induced landslide hazard susceptibility maps derived in Fig 3.18a-b and assigning the maximum value (worst-case scenario) to each investigation grid-cell. As expected, whereas several parts of Uganda are susceptible to low landslide hazard, majority of the country's highlands and seismically active zones (e.g., Fort Portal city) are prone to moderate and high intensities of slope failures. For the purpose of detailed absolute landslide hazard assessments envisaged as a possible extension of the present study, the overall landslide zones are broadly categorised into three hazard levels of low, moderate, and high; respectively depicted as *green*, *yellow*, and *red* pixels. Based on the findings of this work, critical landslide conditions under which detailed absolute landslide hazard assessments are highly recommended for buildings and infrastructure developments are summarised in Table 3.2.

Although detailed assessments may be neglected in low (*green*) hazard zones, this study recommends mandatory analysis in high (*red*) landslide hazard areas. On the other hand, prior to construction and infrastructure developments within moderate (*yellow*) hazard regions, it is recommended that detailed landslide hazard analysis be conducted if the following critical conditions presented in Table 3.2 are satisfied. Detailed landslide hazard analysis is encouraged in regions of moderate landslide hazard level comprising highly weathered outcropping rocks of Precambrian granites, dominantly metasedimentary, and granulites and gneisses geologies within 80 km from major active faults; where the bedrock  $PGA \geq 0.1$  g over a 475-year return period, topographic position index  $\geq 3.8$ , slope gradient  $\geq 10$  degrees, and the distance from streams  $\leq 1.25$  km. As an initial step, a local planning and regulatory approach that aims to manage development within disaster-prone areas, adopt and enforce robust building codes, advocate for good environmental practices like restoration of vegetation cover and afforestation, resettlement plans and utilization of disaster-prone areas for specific seasonal activities should be applied and appropriately implemented. Further to natural system protection remedies and

raising community awareness, infrastructure protection and structural retrofitting, removal of existing constructions from disaster-prone areas, structural mitigation techniques and protection of critical facilities like hospitals should be applied.

**Fig 3.20** Overall relative landslide hazard susceptibility map of Uganda combining both co-seismic and rainfall conditioning factors

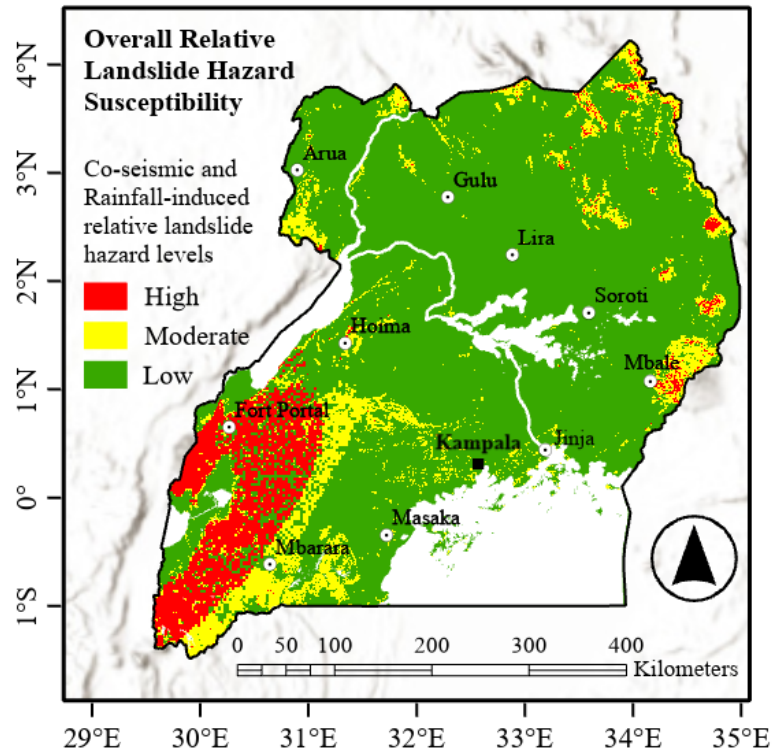


**Table 3.5** Critical landslide conditions under which detailed landslide hazard assessments are highly recommended for buildings and infrastructure developments

| Landslide parameters          | Minimum conditions                                                                                                                                                                         |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Peak ground acceleration   | Considering a 10 % POE in 50 years (475-year return period), PGA on reference rock site conditions $\geq 0.1$ g                                                                            |
| 2. Geology                    | Highly weathered outcropping rocks of Precambrian granites (G8), Precambrian dominantly granulites and gneisses (G1), and Precambrian dominantly metasedimentary (G5) geological structure |
| 3. Slope position             | $TPI \geq 3.8$ , which categorises all slope categories except U-shaped valley or spread water, and deeply incised streams valleys                                                         |
| 4. Slope angle                | $\geq 10$ degrees                                                                                                                                                                          |
| 5. Proximity to active faults | $\leq 40$ km                                                                                                                                                                               |
| 6. Distance from streams      | $\leq 1.25$ km                                                                                                                                                                             |

### 3.9 Discussion

In this work, a detailed co-seismic and rainfall-triggered landslide hazard susceptibility assessment is performed for Uganda using a geospatial-based fuzzy logic approach and the findings largely confirm that several parts of the country are prone to slope failures of varying degrees. To begin with the assessment of landslide frequency ratios, Fig 3.10b shows that for the 1966 Toro earthquake, landslide frequency ratios increase to a maximum value of 2.24 at PGA values ranging between 0.20 and 0.25 g, beyond which the likelihood of landslide occurrence reduces. On the other hand, a maximum landslide frequency ratio of 2.25 is estimated for PGA raising to 0.35 g for the 1994 Kisomoro earthquake. The main mechanical reason behind this trend is that shear resistance of the exposed material is more likely to be exceeded when higher stresses are induced by stronger shaking intensity, thereby inducing landslides of even larger magnitudes (Towhata et al. 2022; Valagussa et al. 2019).

Following the determination of landslide frequency ratios shown in Fig 3.11a, it is seen that although majority of Uganda's territory is largely dominated by slope angles between 0 and 5°, there is a significant contribution of rainfall-induced landslides from which frequency ratios increase with increasing slopes of up to 50°. Except for slopes < 5°, co-seismic landslide frequency ratios across slope classes range between 1.43 and 2.67; implying that earthquakes are capable of triggering co-seismic landslides along most slopes as indicated by Valagussa et al. (2019). Whereas the instability of lower slopes covered with thick residual soils is largely initiated by a high water table (Zhuang et al. 2015), overall landslide frequency ratios increase with slope angles increasing to a maximum of 40°. The increase is partly driven by gravitational forces from which greater shear stresses are generated along steeper slopes (Silalahi et al. 2019; Torizin 2011). However, the decline in landslide frequency ratios for slopes > 40° is partially attributed to increased shear resistance of the rock mass where relative landslide areas are minimal. The result presented in Fig 3.11a is consistent with the findings of Bizimana and Sönmez (2015) which indicate that landslide-prone areas are situated along concave slope angles exceeding 41°. In contrast, Bamutaze (2019) reported the highest frequency ratio along slopes of up to 31° in Elgon region while Nseka et al. (2019) indicated maximum frequency ratios for gradients of 25-35° in western Uganda. However, the analyses by Nseka et al. (2019) and Bamutaze (2019) ignored co-seismic landslides and did not cover the entire country.

Owing to the topographic variations induced by soil creep, incised channels, spurs, and ridges, the assessment of topographic slope position shown in Fig 3.11b indicates the highest overall landslide frequency ratios along upper slopes, followed by ridges and middle slopes; with the major contribution of rainfall-induced landslides expected along these slope positions. Except for lower slopes, there is a strong correlation between co-seismic landslides and the

other slope positions. Due to localised escalation of ground motion amplitudes generated by the propagation of seismic waves (Meunier et al. 2008), the trend shown in Fig 3.11b is partly attributed to greater seismic amplification along ridgelines which in turn increases the likelihood of slope failures (Buech et al. 2010). Moreover, the lateral spread of seismic waves propagating along river banks within valleys can significantly increase the likelihood of co-seismic landslide.

On the other hand, the highest landslide frequency ratios and relative landslide areas are observed within 40 km from fault traces as seen in Fig 3.11 c. As expected, regions closer to active faults are more susceptible to co-seismic landslides since previous earthquakes induce various weakening mechanisms which subsequently cause reduction in the strength of the neighbouring rock mass (Kellogg 2001; Korup 2004). With regard to hydrology herein assessed in terms of distance from streams as shown in Fig 3.11d, stream banks located within 0.75 km (comprising the majority of relative landslide areas) are overall more vulnerable to landslides. This is because fluvial erosion along streams causes higher shearing stresses. Moreover, the collective reduction in shear strength of slope materials located near streams, caused by presence of soil moisture and increased pore water pressure, is an exacerbating factor (Berhane et al. 2023; Korup 2004; Kritikos et al. 2015). While many rainfall-induced landslides may be triggered at  $\leq 1.25$  km, most co-seismic landslides are within 1.00 km from streams.

Regarding the variation of landslide frequency ratio and relative landslide areas with geology, Precambrian dominantly Metasedimentary and Precambrian granites (outcropping rocks which include a certain degree of fracturing and weathering) exhibit the highest overall landslide frequency ratios as shown in Fig 3.11e. Within Uganda's Precambrian basement/craton, the Precambrian dominantly metasedimentary, and Precambrian dominantly granulites and gneisses geologies are exposed to relatively high likelihood of co-seismic landslides. Gneisses geologies comprise coarse to medium grained banded metamorphic rocks (rich in feldspars and quartz, and mica and aluminous/ferromagnesian silicates) which are formed from igneous or sedimentary rocks. The correlation of landslides with the associated geologies is attributed to the reduction in material strengths as water percolates through columnar joints existing along geological fissures. Although the assessment of slope aspect (Fig 3.11f) shows uniform landslide distribution, the strongest correlation exists in the eastern aspect. This can be attributed to moisture and the flow direction of storm water runoff, essentially influenced by the direction of sunlight (Berhane et al. 2023).

In this regard, Uganda's directorate of disaster preparedness and management under office of the Prime Minister should develop suitable disaster risk mitigation measures aimed at reducing future earthquake and landslide risks across Uganda. The findings of this work can

be used to systematically suggest pre- and post-disaster remedies and inform the implementation of landslide prevention and mitigation strategies outlined in country's national policy for disaster preparedness and management (NPDPM 2010). The major limitation of this study is the lack of detailed information relating to co-seismic landslide occurrences and this points to the urgent need for a more robust scheme of monitoring, recording and mapping landslides, especially in potentially hazardous sites.

### 3.10 Conclusions

This study demonstrates the ability of a fuzzy logic approach combined with geospatial techniques in the development of a comprehensive national co-seismic and rainfall-induced landslide hazard susceptibility assessment, despite scarce historical landslide inventories. Topographical maps, geological maps, 30-metre digital elevation models and co-seismic and rainfall-induced landslide pixel datasets are collected from available resources. Five landslide conditioning factors including slope angle, topographic slope position, proximity to major active faults and geology are identified as the most prevalent conditioning factors. A statistical bivariate method is used to calculate the spatial relationship between landslide conditioning factors and their locations prior to implementation of fuzzy membership functions and subsequent fuzzy maps. The average fuzzy memberships, obtained for the 1966 Toro and 1994 Kisomoro earthquakes, is assigned to the seismic hazard map produced for a 475-year return period on reference rock site conditions. Landslide conditioning factor maps are quantified, aggregated with the fuzzy membership-based PGA and their spatial distribution overlaid to derive final fuzzy maps showing relative co-seismic and rainfall-triggered landslide hazards. The results show that areas of Precambrian granites located in ridges and upper slope gradients between 35 and 40° have the highest landslide hazard susceptibility. The findings conclude that Kigezi and Rwenzori sub-regions in western Uganda are highly prone to co-seismic landslides while landslide occurrences across the other parts are largely driven by rainfall. This work offers valuable insights into the relative co-seismic landslide hazard susceptibility towards informing the ministry of relief, disaster preparedness and management on the application of suitable landslide risk reduction strategies. As a precursor, the relevant government ministries and agencies should apply concerted efforts to strengthen existing pre- and post-disaster mitigation strategies aimed at reducing losses due to landslides in Uganda.

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## Statements and declarations

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All authors contributed to the study conception and design. Material preparation and data collection was performed by MO. The development of codes and analysis were performed by MO, and Dr ZO and Professor KP checked the results. The first draft of the manuscript was written by MO and Dr ZO and Professor KP commented on the previous versions of this manuscript. All authors read and approved the manuscript.

**Conflict of interest**

The authors declare no competing interests. The authors have no relevant financial or non-financial interests to disclose.

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# CHAPTER 4

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## STOCHASTIC EVENT-BASED PROBABILISTIC EARTHQUAKE RISK ASSESSMENT FOR UGANDA: TOWARDS INFORMING THE NATIONAL POLICY FOR DISASTER PREPAREDNESS AND MANAGEMENT

Morris Olang<sup>123</sup> · Zuhail Ozdemir<sup>1</sup> · Kypros Pilakoutas<sup>1</sup>

### Abstract

Catastrophic earthquakes in Uganda have the potential for detrimental consequences on the socio-economic welfare and resilience of communities. Despite considerable efforts in predicting earthquake risk across Africa, a comprehensive study on the associated earthquake risks, at a national level, is non-existent. Yet with increasing population, urbanisation and rapid construction, seismic risk is escalating fast and is compounded by the high vulnerability of buildings and scant disaster prevention and mitigation strategies. This study uses the probabilistic event-based risk calculator of the OpenQuake-engine to assess potential losses resulting from future earthquakes. While the building exposure model is largely inferred and projected from the national population and housing census of 2014, analytical vulnerability curves are selected from the Global Earthquake Model (GEM) database. Seismic hazard studies confirm that western Uganda is exposed to the highest level of seismicity where peak ground accelerations on rock ground can reach up to 0.27 g over a 475-year return period. The associated seismic risk estimates indicate mean economic losses in excess of US\$ 148 million, US\$ 1.12 billion and US\$ 2.04 billion over 10, 50 and 100-year return periods respectively; with mean annual economic loss of US\$ 74.5 million and annual deaths averaging 71.3 persons across the whole country. It is envisaged that the findings of this study will inform strategic land use planning patterns, earthquake insurance pricing and foster the continuous improvement of Uganda's National Policy for Disaster Preparedness and Management.

**Keywords** Building exposure; Probabilistic seismic hazard analysis; Probabilistic seismic risk assessment; Stochastic event-based modelling; Structural vulnerability; Uganda

### 4.1 Introduction

Earthquakes can potentially cause widespread and devastating damage to the built and natural environment, eventually affecting their communities ([Baker et al., 2021](#); [Daniell et al., 2011](#)). Uganda is located between the two seismically active branches of the East African Rift System

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(EARS), a tectonic environment that exposes the country to earthquakes with moment magnitude ( $M_w$ ) between 5.5 and 7.2. Moreover, many seismic events with  $M_w < 5.5$  have been recorded across the country (Midzi et al., 1999; Twesigomwe, 1997). Following the major earthquakes across Uganda (e.g., 1929 Masaka, 1966 Toro, 1994 Kisomoro and 2016 Bukoba), several structures were damaged in addition to the numerous deaths and injuries (Balikuddembe and Sinclair, 2018; Maasha, 1975; Midzi and Manzunzu, 2014). For instance, economic loss worth US\$ 60 million was incurred when the 1994 Kisomoro earthquake of surface-wave magnitude ( $M_s$ ) 6.2 struck Kabarole, Bundibugyo and Kasese districts in western Uganda. Furthermore, 8 people were killed and several injuries registered (Kahuma et al., 2006; NEDC, 1994). Moreover, economic losses were exacerbated by co-seismic landslides around the epicentral region (Oleng et al., 2023). The recent 2016 Bukoba earthquake of 5.9  $M_w$  generated an estimated economic loss of US\$ 458 million, with 11 deaths and over 440 injuries in the Kagera region of the Uganda-Tanzania border (Balikuddembe and Sinclair, 2018; Oleng et al., 2024).

Damage to buildings, injuries and fatalities in future events are likely to escalate due to Uganda's rapidly increasing population and urbanisation. Besides, the largest fraction of buildings in Uganda is mainly substandard and more than half of the housing stock comprises unreinforced masonry buildings which are more vulnerable to earthquakes, especially when seismic design principles are ignored (Brzev et al., 2013; Silva et al., 2015; Vicente et al., 2011). In this regard, seismic risk in Uganda ought to be comprehensively evaluated in order to develop reliable national risk mitigation strategies such as reinstating and enforcing standards and regulations towards design and construction of seismic-resistant structures, strengthening/retrofitting existing buildings located in earthquake prone areas, adequate emergency response planning at urban and district scale, and transferring financial costs of reconstruction and/or repair through creation of insurance and reinsurance schemes (Baker et al., 2021; Gkimprixis et al., 2021; Salgado-Gálvez et al., 2017).

Seismic risk assessment essentially requires hazard estimates which are then combined with the exposure and vulnerability models in order to predict possible consequences such as fatalities and infrastructure damages resulting from future earthquakes (Baker et al., 2021). Whereas deterministic seismic hazard analysis (DSHA) utilizes discrete models to obtain scenario earthquakes responsible for the worst-case ground motion (Reiter, 1991), conventional probabilistic seismic hazard analysis (PSHA) initially proposed by Cornell (1968) accounts for all earthquake magnitudes, distances and number of logarithmic standard deviations. Moreover, the epistemic and aleatory uncertainties associated with the earthquake model can be rationally incorporated to give more realistic hazard predictions (Crowley, 2005; Reiter, 1991). Recent studies (e.g., Johnson et al., 2023; Oleng et al., 2024 and Sianko et al., 2020) used stochastic event-based modelling approaches, described in literature (e.g., Baker et al., 2021;

Graves et al., 2011 and Musson, 1999), to generate synthetic earthquake catalogues by randomising key hazard parameters required for a PSHA.

Understanding the presence of exposed assets, especially the distribution of human population, buildings and other infrastructure such as roads and bridges, is an important aspect towards accurate seismic risk estimates (Baker et al., 2021; Sianko et al., 2023). The exposure model typically provides details on the number and geographical location, taxonomy, value, floor areas, and night/transit/daytime occupancy, vulnerability characteristics, average built-up area and replacement cost of assets. However, many African countries suffer from substantial lack of data required for a comprehensive seismic risk analysis. Except for Malawi that has a national exposure model (Kloukinas et al., 2020; Ngoma et al., 2019), many countries within Sub-Saharan Africa rely on national population and housing census data from local and global databases (e.g., De Bono and Chatenoux, 2015; Gamba et al., 2012; Jaiswal et al., 2010 and Jaiswal and Wald, 2008) to perform seismic risk analyses. For Uganda, projections based on the 2014 national housing and population census (UBoS, 2016) can be used to estimate the exposure model. Thereafter, several building classification systems like PAGER-STR (Jaiswal and Wald, 2008), ISK-UE project (Mouroux and Le Brun, 2006), European Macroseismic Scale (Grünthal, 1998), HAZUS (FEMA, 2003), and World Housing Encyclopedia (EERI, 2000) can be used to classify buildings into different taxonomies which are organised as a series of expandable tables with information pertaining to their various attributes (Brzev et al., 2013).

However, there are notable data insufficiencies in the 2014 Uganda national housing and population census (UBoS, 2016) and as such, it is challenging to develop detailed exposure models from these statistics alone. In such incidences, high resolution satellite imagery and gridded maps showing building patterns can be complementarily used (Dooley et al., 2020; Sirko et al., 2021). In addition to satellite imagery maps and other global datasets, national statistics can be spatially disaggregated to more realistically reflect the distribution of assets. For instance, Paul et al. (2022) developed a novel uniform exposure model for the African continent, from which it is indicated that the concentration of buildings in the urban centres of East Africa could nearly triple over the next decades. Recently, the Global Earthquake Model (GEM) Foundation based on national statistics, socio-economic data and local data largely provided by the corresponding national institutions/agencies to comprehensively develop a world-wide database of residential, commercial and industrial buildings (Yepes-Estrada et al., 2023). Following the hazard and exposure models, the susceptibility of exposed assets to damage from earthquakes is then evaluated using fragility/vulnerability models (Baker et al., 2021; Sianko et al., 2023).

Considering damage states such as slight, moderate, extensive and complete (Hazus-MH, 2003) and for a certain level of ground motion, the probability of exceedance (POE) can be predicted using fragility curves explicitly derived for particular building types. On the other hand, vulnerability curves can be derived by converting a set of fragility curves consequence models (e.g., Coburn and Spence, 2002; Erdik, 2017; Kohrangi et al., 2021 and So and Spence, 2013). Fragility/vulnerability models can be empirically calibrated through direct field observation of post-earthquake damages (Calvi et al., 2006; Crowley and Pinho, 2011; Rossetto and Ioannou, 2018). Although empirical approaches require fewer modelling assumptions, a careful survey of both undamaged and damaged buildings is required for robust and unbiased predictions; yet the already cumbersome field surveys pose huge challenges in obtaining key parameters of interest (Baker et al., 2021). Alternatively, conceptually straightforward analytical methods can offer more flexibility especially if asset-specific features are broadly incorporated in the predictions (Jayaram et al., 2012). Analytical fragility and vulnerability models are developed using nonlinear time history analysis (e.g., D'ayala et al., 2014; Ellingwood and Kinali, 2009 and Singhal and Kiremidjian, 1996) and other simplified methods such as pushover analysis (e.g., Crowley et al., 2004; Kircher et al., 1997 and Silva et al., 2014). In the absence of both numerical models and empirical observations, consequence functions can be developed based on expert opinion (Jaiswal et al., 2012).

In view of the fact that the efficacy of Uganda's seismic risk reduction and management strategies is undermined by the absence of a comprehensive national seismic risk framework, this study presents the first stochastic probabilistic earthquake risk assessment framework for Uganda; by combining the existing exposure and earthquake hazard models with the seismic vulnerability of the building inventory using the event-based calculator of *OpenQuake* engine (Pagani et al., 2014). Despite the lack of sufficient information regarding Uganda's building stock, the exposure model is projected from the 2014 population and housing census (UBoS, 2016). To estimate the Uganda exposure model in a more representative manner, subsequent adjustments are made on the additional information obtained from the GEM Foundation and the uniform exposure model of for Africa (Paul et al., 2022; Yepes-Estrada et al., 2023). Although fragility and vulnerability curves specifically calibrated for Uganda are non-existent, the country's building taxonomies are mapped with analytical vulnerability curves selected from the global vulnerability model database of the GEM Foundation (Martins and Silva, 2023). It is envisaged that the findings of this study will lead to reduced earthquake-related losses.

This paper begins with a sequential description of the location and demography of the study area which is preceded by the underlying methodology adopted prior to explaining the fault-oriented spatially smoothed seismicity technique used to develop a stochastic event-based PSHA for Uganda. The subsequent sections present the exposure and vulnerability models used

to describe the probability distribution of losses for a combination of intensity measure types and levels. The remaining parts of the paper present and discuss earthquake ruptures, seismic hazard outputs, loss exceedance curves, mean annual losses and aggregated asset loss statistics which are then compared with previous regional and global predictions. The framework proposed in this work not only aims to provide practitioners, policymakers, insurance companies and government stakeholders with practical earthquake risk appraisal techniques, but also make informative contributions towards improving the National Policy for Disaster Preparedness and Management (NPDPM, 2010).

## 4.2 Location and population distribution of Uganda

The location of the study area on the African continent and population density map of Uganda showing the estimated total number of people per 100-metre grid cell (at a resolution of 3 arc seconds), together with the epicentral location of major earthquakes that occurred in and around Uganda from the start of the twentieth century is shown in Fig 4.1.

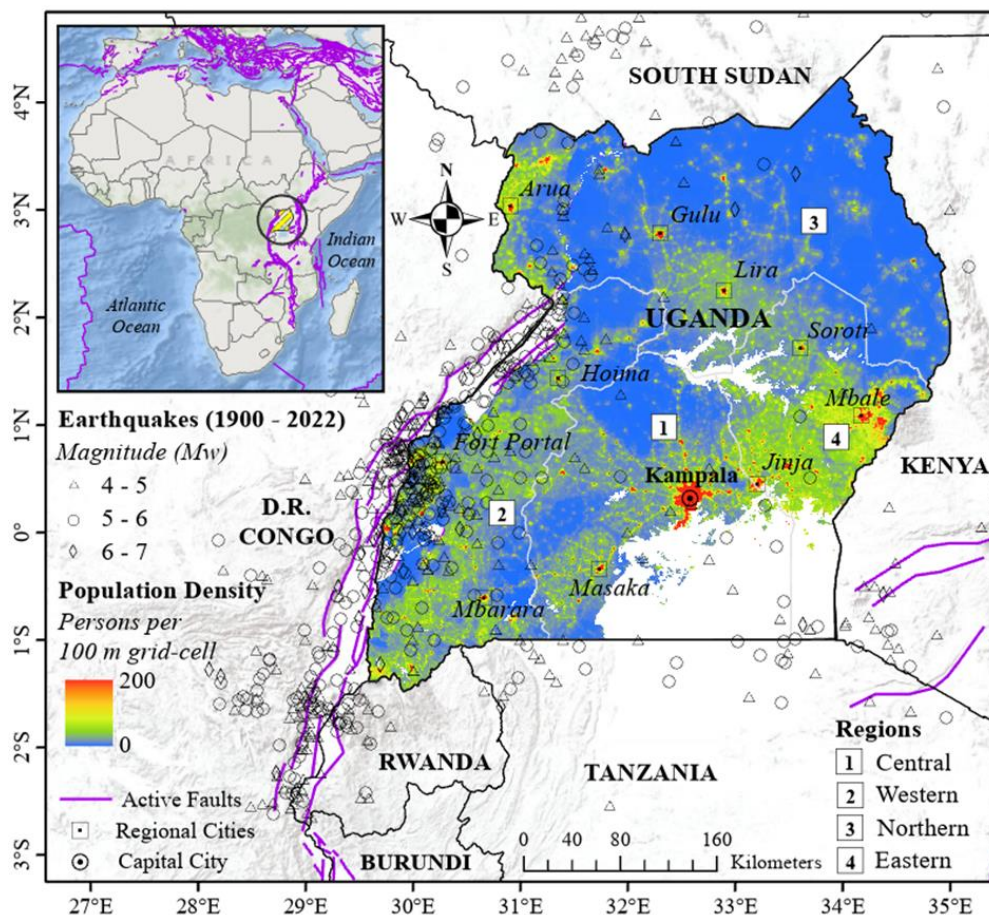


**Fig 4.1** Location of Uganda on the African continent; and its population density estimated per 100-metre grid (3 arc seconds resolution), position of the East African Rift System (EARS) relative to major cities, and major earthquake ( $M_w \geq 4$ ) epicentres that occurred between 1900 and 2022

The population density of Uganda, obtained from the 2014 national census and geoportal of climate prediction and applications centre (ICPAC, 2024; UBoS, 2016), is projected for the year 2022. The fault system shown in Fig 4.1 is obtained from the global homogenised database of Styron and Pagani (2020); and it indicates that Uganda lies between the Albertine (western) and Gregory (eastern) arms of the EARS from which majority of earthquakes are instigated. The most densely populated urban areas consist of approximately 200 persons per 100-metre cell grid. In addition to the north-eastern territory, which is largely semi-arid, the least populated areas are mostly occupied by game parks and forests. Although most regions around earthquake epicentres in western Uganda are largely less populated compared with the central and eastern parts, the growing economic activity and rapid urbanization which has led to the creation of major regional cities (e.g., Fort Portal, Hoima and Mbarara) are likely to **increase** the human and housing population in these areas; thereby posing increased seismic risks.

To better represent the human exposure to earthquake risk across Uganda, the population distribution of the country is aggregated for the major administrative units (district/municipality/county) as shown in Fig 4.2a-b. It can be seen that Kampala capital city and its immediate environs comprise the most highly populated areas, followed by the border trade districts and regional cities. The social indicators and the temporal distribution of Uganda's population over the past few decades are shown in Fig 4.3. Uganda's population has grown at an average annual rate of 3.19 %; and as at June 2022, the population of the country was estimated at over 44.2 million (UBoS, 2022).

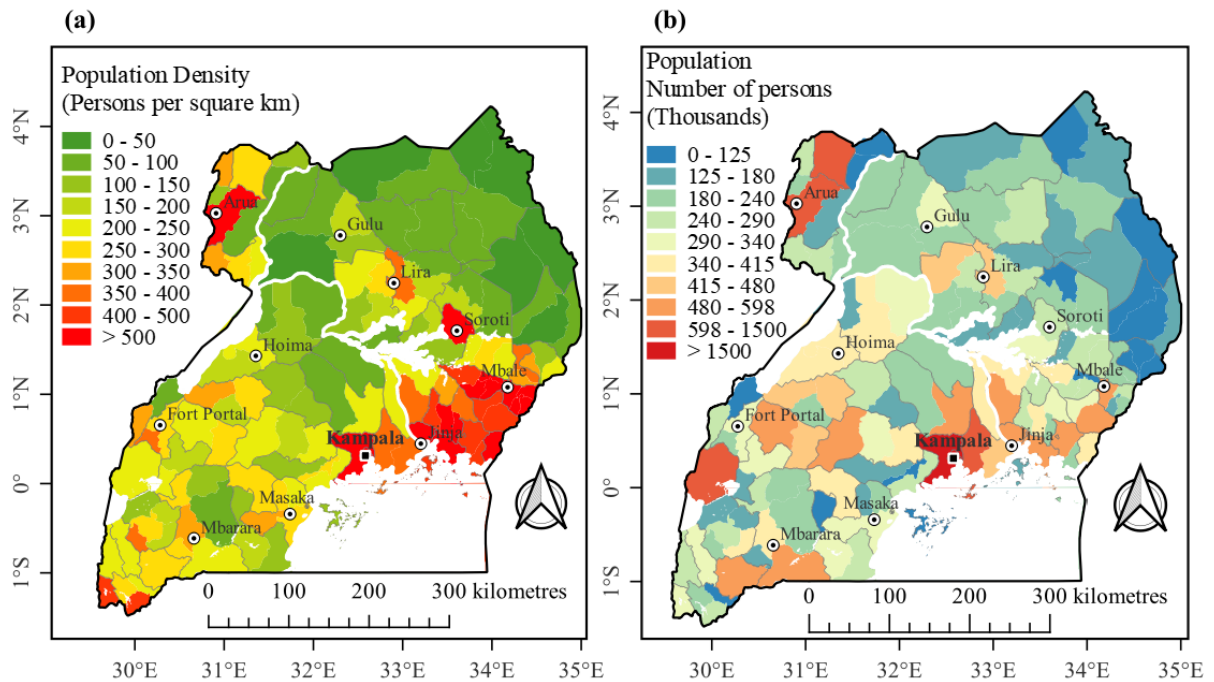


**Fig 4.2** Population projections for the baseline year 2022, aggregated for major administrative units and presented for: **(a)** district population per square km, and **(b)** total number of persons per district

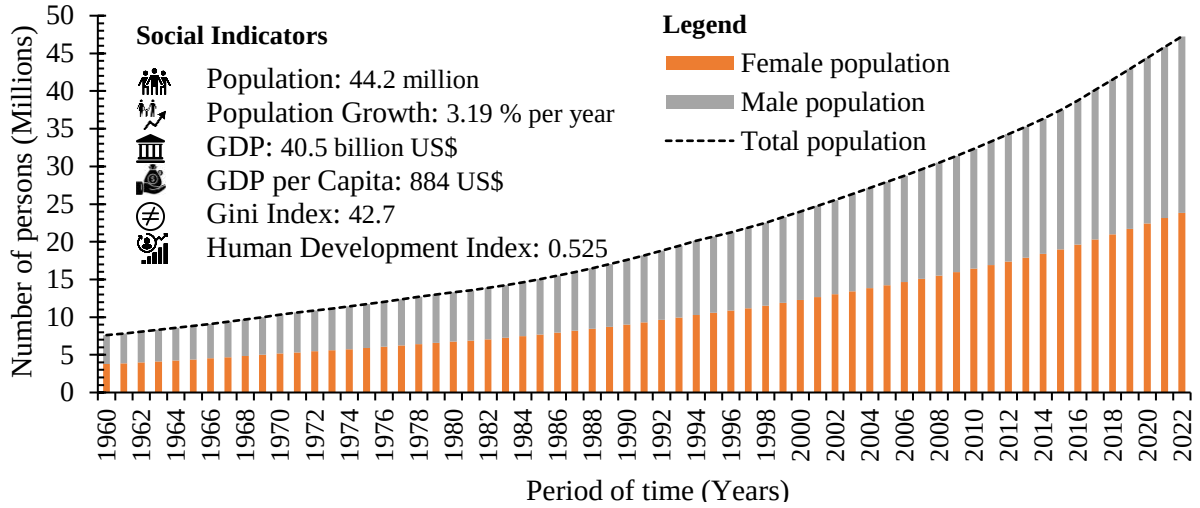


**Fig 4.3** Social indicators for Uganda towards earthquake risk assessment, and the temporal population distribution of the country between 1960 and 2022 (UBoS, 2022)

#### 4.3 Methodology: Event-based probabilistic seismic risk analysis

Earthquake risk assessment studies performed at various regional and national levels have been executed using several platforms like *Hazus-MH* (FEMA, 2003), *CRISIS* (Ordaz and Salgado-Gálvez, 2017) and *Seisan* (Havskov and Ottemöller, 2003). In the present study, the first national earthquake risk assessment framework for Uganda is proposed using a stochastic event-based modelling approach in *OpenQuake* engine (Pagani et al., 2014). The calculation workflow, illustrated in Fig 4.4, computes the probability of losses and loss statistics for a collection of exposed assets, based on the probabilistic seismic hazard (Silva et al., 2012). Within this methodological procedure, stochastic event sets representing regional seismicity over a given investigation time are generated using MC simulations (e.g., Graves et al., 2011; Musson, 1999 and Sianko et al., 2020). The number of event occurrences is then simulated by sampling the corresponding probability distribution for each rupture created by seismic sources. Whilst considering inter-event variability of ground motions and intra-event residuals, spatially correlated ground motion realisations are generated for each stochastic event sets rupture. Epistemic uncertainties associated with the seismic source and ground motion models are included through a logic tree approach. Whereas the POE for different loss levels over a given time period is described by loss exceedance curves, the loss maps show the loss values that have a specified POE within the particular investigation time. Despite the computational cost and complexity of MC simulations, the approach is adopted with the view of allowing model flexibility (Graves et al., 2011). Moreover, reliable predictions of the total loss value at higher return periods is determined when the spatial variability of intra-event residuals is incorporated within the MC simulations (Baker et al., 2021; Jayaram and Baker, 2009).

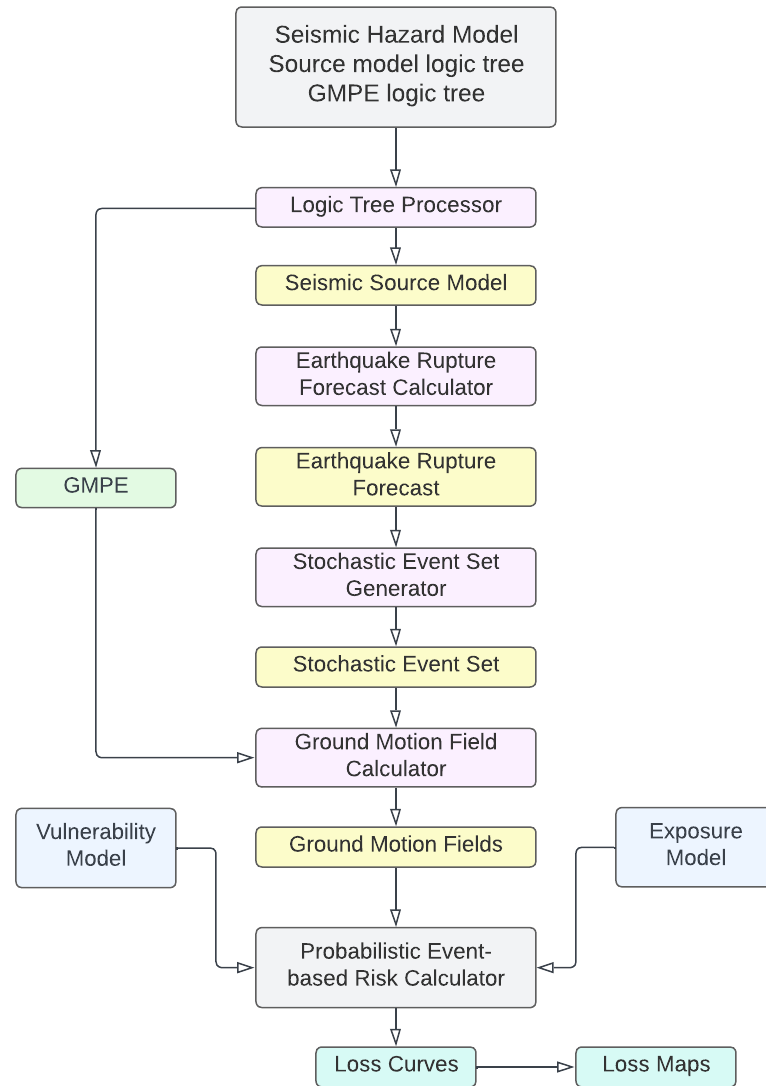


**Fig 4.4** Schematic diagram showing the chronological workflow of the probabilistic event-based risk and loss calculator embedded in the *OpenQuake*-engine.

#### 4.4 Probabilistic seismic hazard model for Uganda

To quantify seismic hazard across Uganda, earthquake catalogues are compiled from numerous sources (e.g., [Albini et al., 2013](#); [Ambraseys and Adams, 1991](#); [DGSM, 2022](#); [Di Giacomo et al., 2018](#); [ISC, 2022](#); [Maasha, 1975](#); [Storchak et al., 2013](#); [Storchak et al., 2015](#) and [USGS, 2022](#)), merged and refined using the GEM catalogue toolkit ([Weatherill, 2014](#)) and the ZMAP (2022) algorithm of [Wiemer \(2001\)](#). Based on the geology and seismo-tectonic setting of the region, a fault-oriented spatially distributed seismicity approach ([Vilanova et al., 2014](#)) is used to delineate seismic source zones shown in Fig 4.5. Calibrated seismicity parameters, defined in the [Gutenberg and Richter \(1944\)](#) law and their associated standard deviations are estimated using the [Weichert \(1980\)](#) maximum likelihood method. Whilst the estimators of [Kijko \(2004\)](#) are suitable for determining maximum magnitudes ( $M_{max}$ ), the lack of source-scaling relationships for Uganda was problematic ([Oleng et al., 2024](#)). Realistic  $M_{max}$  values are arbitrarily

estimated by adding a conservative increment of 0.5 magnitude units to the observed maximum earthquake size in each source zone.

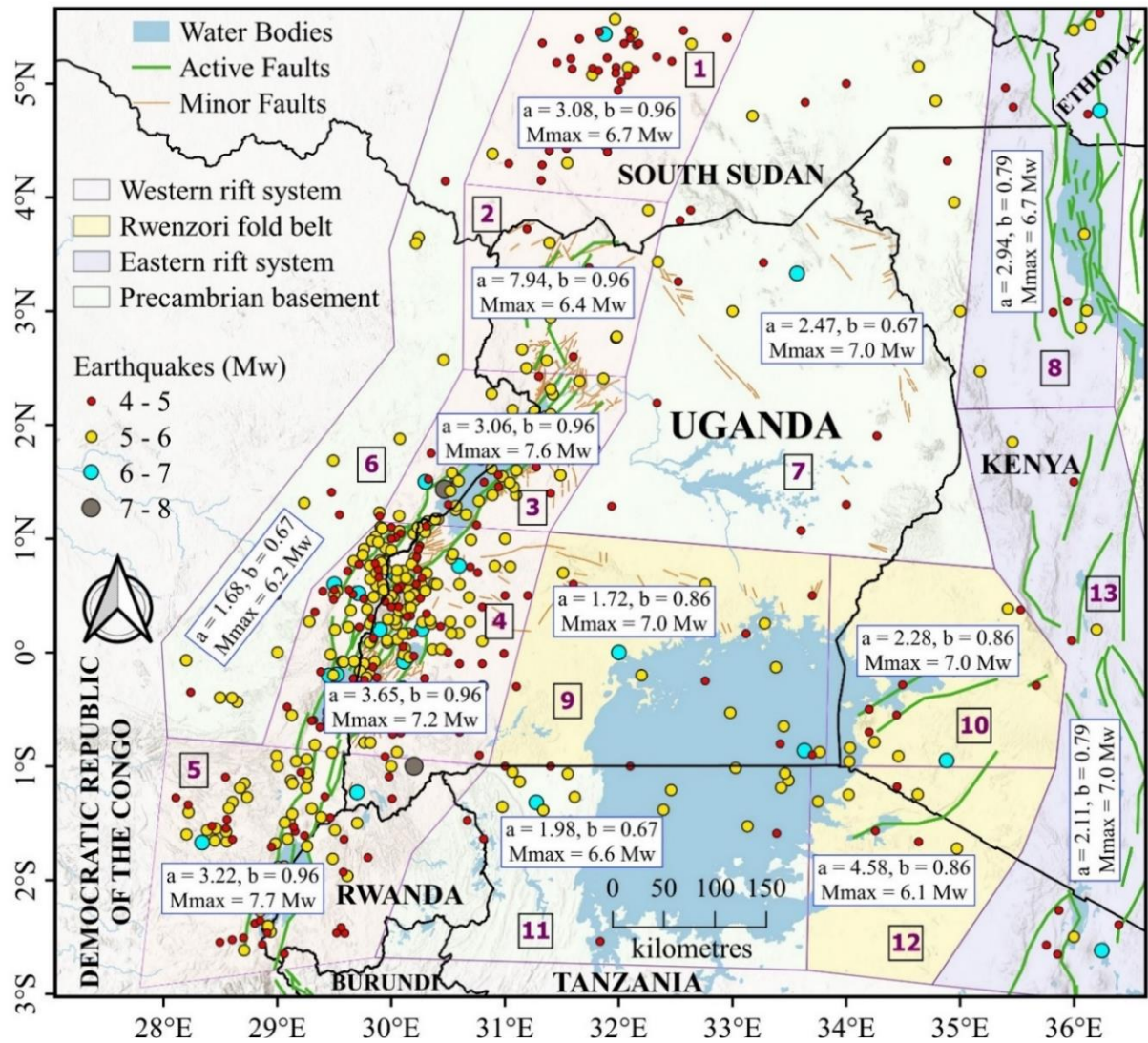


**Fig 4.5** Epicentres of  $M_w \geq 4.0$  earthquakes which hit Uganda and its neighbouring countries between 1900 and 2022, major and minor active fault systems, area source zonation model and the calibrated seismicity parameters used to perform the stochastic event-based PSHA for Uganda.

In a PSHA, suitable GMPEs are required to predict the site responses arising from possible ruptures. Unfortunately, there is a substantial lack of GMPEs developed based on actual strong ground motion records for Uganda (Bwambale et al., 2015; Poggi et al., 2017). In this work, suitable GMPEs for each tectonic regime are selected using functionalities of the GEM ground motion toolkit (Weatherill et al., 2014). Whereas the GMPEs of Akkar et al. (2014) and Chiou and Youngs (2014) are used to model ground motion in active shallow crust, seismic response in stable continental tectonic regime is predicted using the GMPEs of Atkinson and Boore (2006) and Pezeshk et al. (2011). The associated epistemic uncertainties are captured by

implementing a logic tree with weights assigned (as summarised in Table 4.1) according to the likelihood of each clustered tectonic types.

**Table 4.1** Weighting scheme for the GMPE logic tree implementation in PSHA calculation

| Source Group <sup>§</sup>    | Area Zone     | Active Shallow Crust |       | Stable Continental Crust |       |
|------------------------------|---------------|----------------------|-------|--------------------------|-------|
|                              |               | AA                   | CY    | PA                       | AB    |
| Western Rift System          | 1, 2, 3, 4, 5 | 0.250                | 0.250 | 0.250                    | 0.250 |
| Rwenzori Fold Belt           | 9, 10, 12     | 0.375                | 0.375 | 0.125                    | 0.125 |
| Eastern Rift System          | 8, 13         | 0.000                | 0.000 | 0.500                    | 0.500 |
| Congo-Uganda-Tanzania craton | 6, 7, 11      | 0.500                | 0.500 | 0.000                    | 0.000 |

<sup>§</sup> Zones sharing similar weights are grouped into four categories. Four GMPEs are applied (AA Akkar et al., 2014; CY Chiou and Youngs, 2014; PA Pezeshk et al., 2011; and AB Atkinson and Boore, 2006)

Whilst the Uganda seismic code of practice for structural designs (US319:2003) (UNBS, 2003) defines seismic source/site conditions using the standard penetration test, many modern seismic design codes (e.g., BSSC, 2004 and CEN, 2004) characterise local site conditions using the average velocity of seismic shear waves in the upper 30 m layer of soil ( $V_{s,30}$ ) value (Silva et al., 2015). Moreover, numerous GMPEs summarised by Douglas (2021) are calibrated against the  $V_{s,30}$  values (Bommer, 2022). Site conditions are first modelled using slope-based  $V_{s,30}$  reference values ranging between 180 and 900 m/s (Allen and Wald, 2007). In addition, more representative earthquake hazard estimates are derived for free rock conditions, with a fixed  $V_{s,30}$  reference value of 760 m/s assumed for each site of the investigation grid (Oleng et al., 2024).

## 4.5 Exposure model

### 4.5.1 Composition of the building stock in Uganda

The building stock in Uganda comprises traditional timber, daub and wattle, adobe blocks with mud mortar, baked clay bricks and cement mortar; all roofed with either grass-thatched, galvanised iron-sheet or burnt clay tiles (Hashemi, 2017; Twesigomwe, 1997). The wattle and daub buildings (e.g., Fig 4.6a) are especially spread in the rural countryside and villages. Majority of adobe with mud mortar buildings are the old government buildings such as the former Jinja prison administrative unit shown in Fig 4.6b. On the other hand, buildings consisting of baked clay brick walls which are held together with cement mortar (e.g., schools, hospitals and shops shown in Fig 4.6c) typically consists of two gable walls or poorly supported parapets with little resistance to horizontal forces. European-style category (e.g., depicted in Fig 4.6d) include multi-storey and bungalows that comprise load bearing baked brick or concrete block walls with strip foundations and/or framed column-beam layouts resting on pad foundation footings.

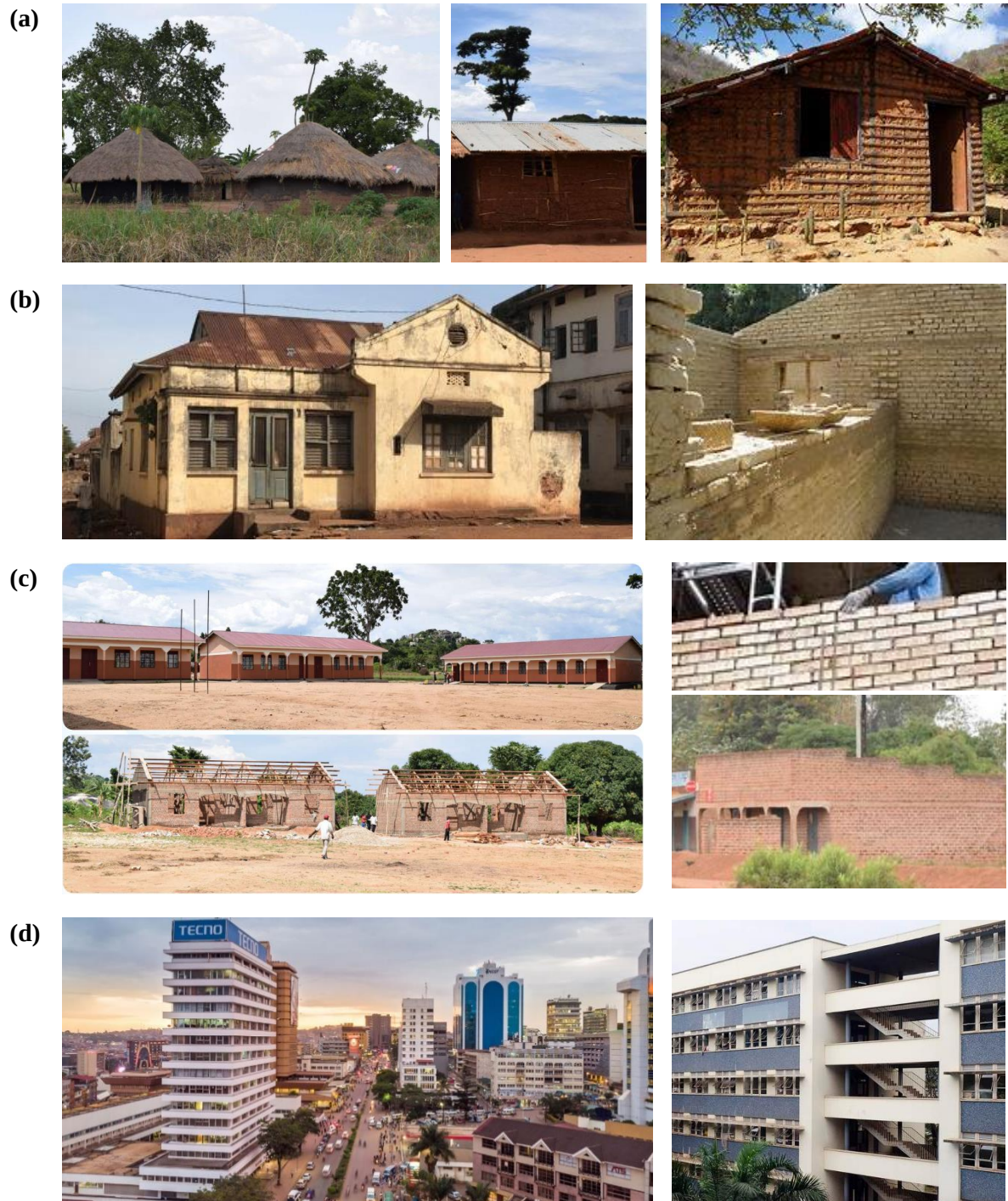


**Fig 4.6** Common building types constituting Uganda's building stock: **(a)** wattle-and-daub, **(b)** adobe with mud mortar, **(c)** baked bricks with cement mortar, and **(d)** European-style buildings

#### 4.5.2 Building typologies

The attributes adopted in this work use the building typology nomenclature defined in the GEM building taxonomy (Brzev et al., 2013; Silva et al., 2022). Attributes encoded in the condensed strings generally include primary construction material, type of vertical and lateral load-bearing system, number of storeys, and ductility class. In this study, information regarding Uganda's

building stock is extracted from the GEM Foundation (Yepes-Estrada et al., 2023) and the uniform exposure model for Africa (Paul et al., 2022). The data herein is largely inferred from the 2014 national population and housing census (UBoS, 2016) where buildings in each region are projected for a baseline year of 2024 and categorised according to their occupancy categories of residential, commercial, and industrial buildings as shown in Table 4.2. Whilst majority of national population and housing census such as UBoS (2016) largely provide information in terms of dwellings instead of building counts, numerous previous studies (e.g., Crowley et al., 2020; Dolce et al., 2021 and Yepes-Estrada et al., 2023) have estimated the number of buildings for each typology as follows:

$$N_B = \frac{N_D}{N_J \times N_K} \quad (4.1)$$

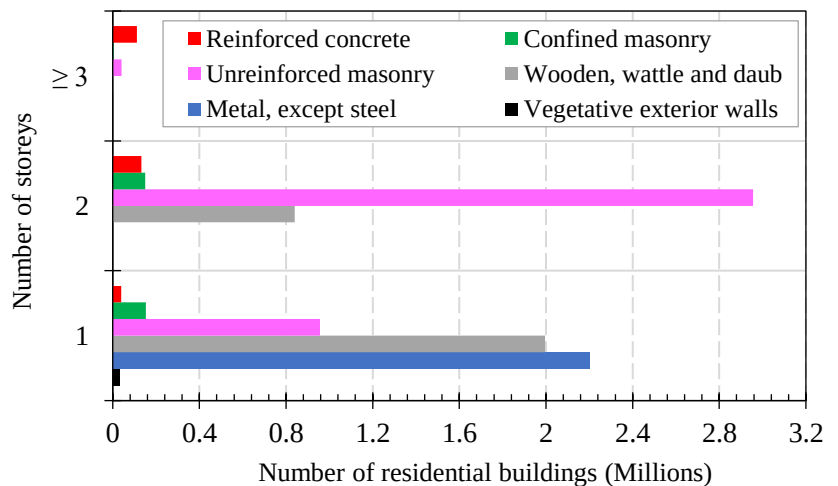
where  $N_B$  is the number of buildings for each typology,  $N_D$  is the number of dwellings,  $N_J$  is the number of units per storey, and  $N_K$  is the number of storeys per building class. In this work,  $N_D$ ,  $N_J$  and  $N_K$  are obtained from the 2014 national population and housing census of the country (UBoS, 2016). The number of residential buildings according to the number of storeys for each building typology is depicted in Fig 4.7. Metals, wooden wattle and daub, and unreinforced masonry constitute the bulk of bungalows. Whereas the majority of buildings exceeding three storeys are mainly reinforced concrete, the highest number of two-storey buildings are unreinforced masonry. The spatial distribution of each building type is shown in Fig 4.8a-f.

**Table 4.2** Distribution of estimated building stock across the four regions of Uganda

| Building category | Number of buildings ('000) located in each region* |         |          |         | Total ('000) |
|-------------------|----------------------------------------------------|---------|----------|---------|--------------|
|                   | Central                                            | Eastern | Northern | Western |              |
| Residential       | 2,675                                              | 2,514   | 1,982    | 2,450   | 9,621        |
| Commercial        | 55                                                 | 52      | 41       | 50      | 198          |
| Industrial        | 24                                                 | 22      | 18       | 22      | 86           |
| Total ('000)      | 2,754                                              | 2,588   | 2,041    | 2,522   | 9,905        |

\* The regional boundaries of Uganda are indicated in Fig 4.1 and Fig 4.19

**Fig 4.7** Distribution of residential buildings according to their number of storeys



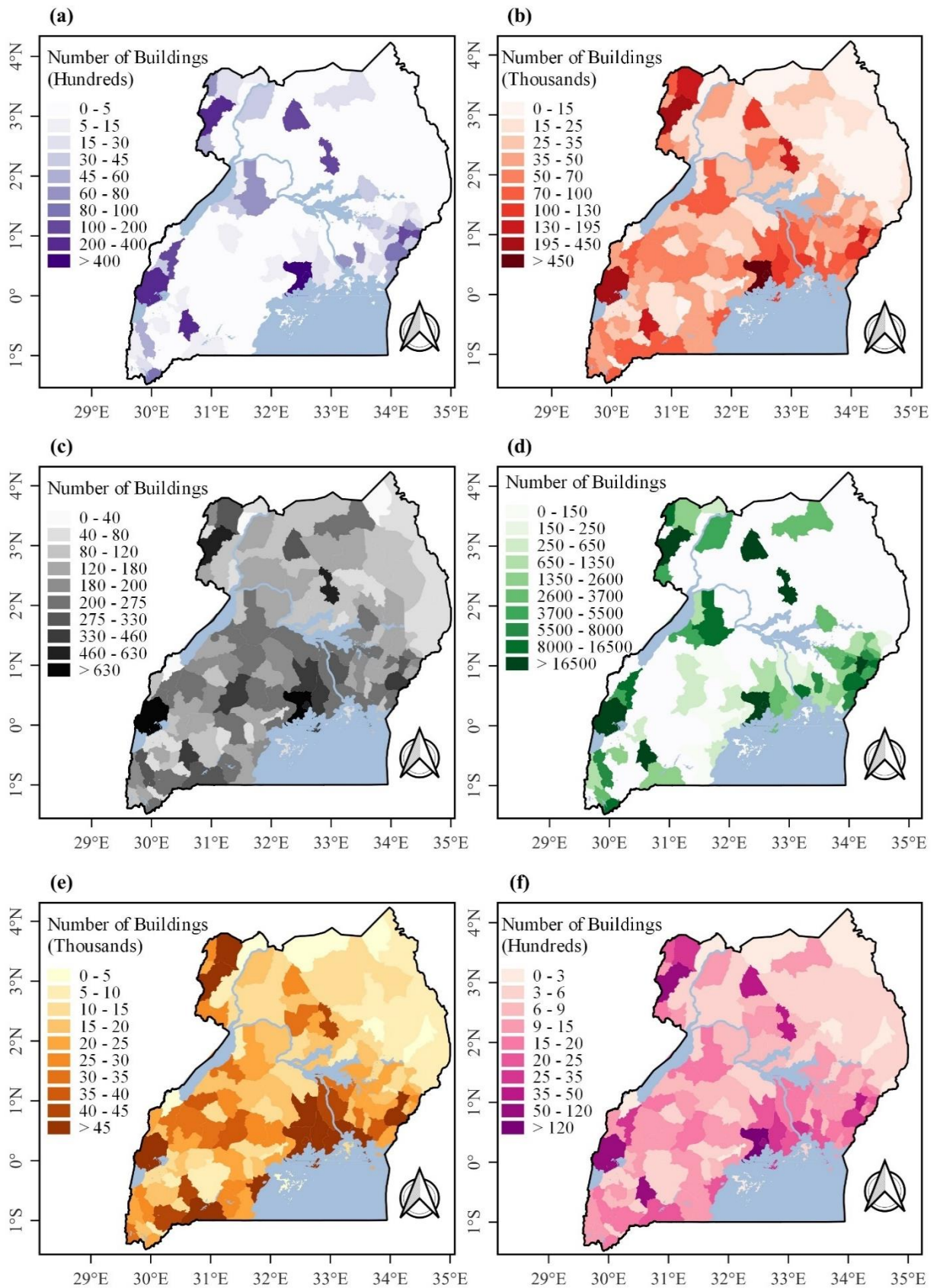


**Fig 4.8** Spatial distribution of the building exposure aggregated at district level and presented for: **(a)** reinforced concrete, **(b)** unreinforced masonry, **(c)** structural steel, **(d)** confined masonry, **(e)** wooden, including wattle and daub, and **(f)** exterior vegetative wall and all other metals except steel

### 4.5.3 Economic value of exposed buildings

In seismic risk analysis, replacement costs of a building account for: (1) structural components like foundations, columns, walls, slabs and staircases; (2) non-structural components including partition walls, facades, finishes, mechanical and electrical services, and ceiling works; and (3) building contents for instance office equipment and machinery. Considering that the main construction material and occupancy class typically dictate the replacement cost of each component, [Yepes-Estrada et al. \(2023\)](#) assumed “*build back better*” concept (e.g., [Der Sarkissian et al., 2023](#); [Dube, 2020](#) and [Mannakkara et al., 2014](#)) whilst relying on cost handbooks and expert opinion to estimate the total replacement cost of buildings as follows:

$$TRC = C_A \times A_D \times N_D \quad (4.2)$$

where  $TRC$  is the total replacement cost of the building,  $C_A$  is the cost per area,  $A_D$  is the area of dwelling or establishment, and  $N_D$  is the number of dwellings or establishments. Similarly, [Paul et al. \(2022\)](#) based on national building cost statistics and a literature review of independent international cost books to estimate the replacement costs of buildings in Africa.

Although the economic value of buildings in the uniform exposure model for Africa is estimated by [Paul et al. \(2022\)](#), this study further adjusts the total replacement costs of buildings following surveys conducted for various building taxonomies in the country. Engineering practitioners are interviewed, and consideration given to local market rates for materials, equipment and labour using single rate approximate estimating approach. In this method, total replacement costs are determined as the product of cost per square metre of a given building and its total floor area. Within this floor area method, different types of slabs and their corresponding costs per square meter are taken into consideration. Even though no substantive deductions are made for internal partition walls, ducts, lifts and/or stairs, the costs of past similar buildings are used to establish a sound and realistic costs per square meter. The fluctuation in costs of building materials, labour rates and price variations regarding equipment hire are taken into account in addition to the experiences and subjective judgements of engineering practitioners. For each building typology, the cost per square metre is standardised for the 2024 baseline year and local currency values converted to US\$.

A summary of the total replacement costs for each settlement type is presented in [Fig 4.9](#). Replacing RC and MCF buildings costs about US\$ 400 per m<sup>2</sup> while replacement cost per m<sup>2</sup> of MUR buildings ranges between US\$240 and US\$275 in both settlements types. Overall, the exposure model estimates approximately 9.62 million residential buildings valued at over US\$ 171.45 billion. In addition, the building stock includes more than 198000 commercial buildings and 85000 industrial facilities valued more than US\$ 11.9 billion and US\$ 6.6 billion,

respectively. As per Uganda's nominal gross domestic product (GDP), estimated at US\$ 40.53 billion in June 2022 (UBoS, 2022), the occupancy classes amounts to approximately 4.7 times the country's nominal GDP.

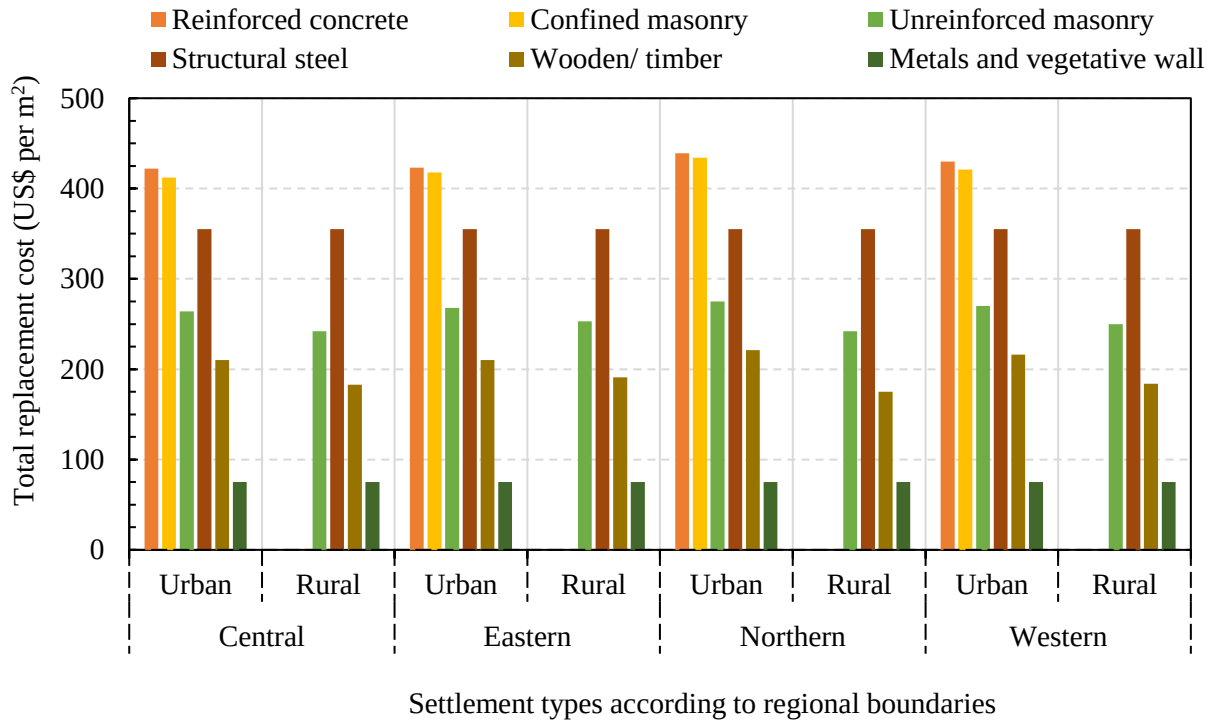


**Fig 4.9** Total replacement cost per area in urban and rural settlements for different building types located in each of the four regions of Uganda

#### 4.6 Fragility and vulnerability models

To minimise uncertainties and achieve accurate predictions of seismic risk, a rigorous selection of suitable fragility models for the area of interest is required (Riga et al., 2017; Sianko et al., 2023). In this regard, fragility curves benchmarked against post-earthquake damage data and specifically developed for the building stock in the region in question should be used (Sianko et al., 2023; Villar-Vega and Silva, 2017). For instance, the set of analytical fragility curves shown in Fig 4.10a-b were derived for informal and code-conforming unreinforced fired brick masonry buildings constituting the Malawian housing stock (Giordano et al., 2023). However, the substantial lack of fragility models developed with holistic considerations of buildings in many African countries, except for some building typologies in Ghana (Adom-Asamoah, 2012) and Malawi (Giordano et al., 2023; Giordano et al., 2021), poses huge challenges towards more accurate seismic risk analyses. Although the building stock may be similar across Sub-Saharan African countries, post-earthquake damage data may vary extensively; and as such, fragility curves for a particular region can give more representative and accurate results.

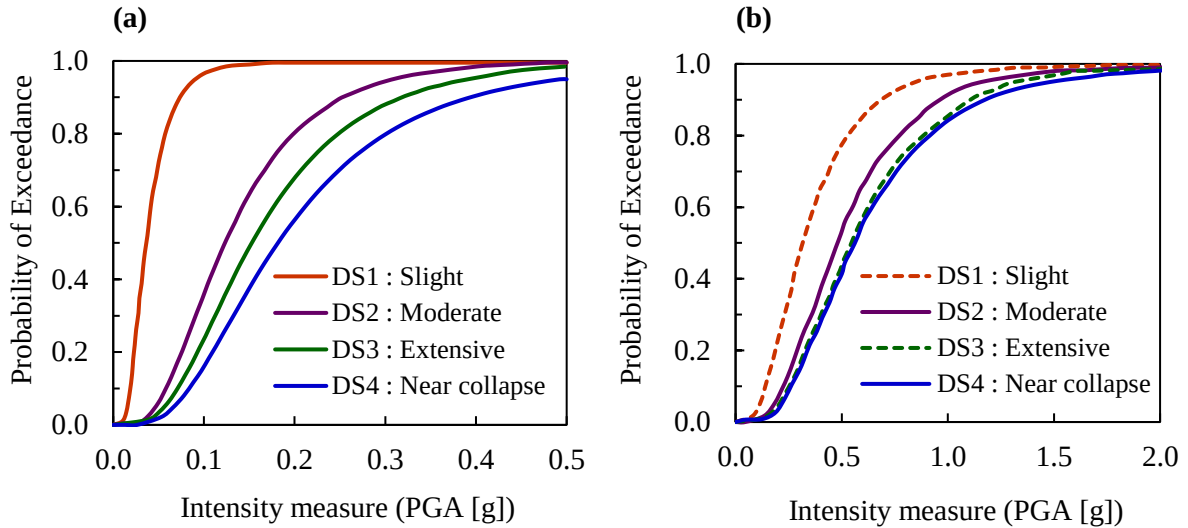


**Fig 4.10** Analytical fragility curves derived for unreinforced fired brick masonry buildings constituting the Malawian housing stock, derived for: **(a)** non-code-conforming or informal buildings, and **(b)** code-conforming buildings (Giordano et al., 2023)

Unfortunately, distinct fragility curves published for Uganda do not exist. Vulnerability curves for estimating the distribution of economic losses can be derived through the straightforward convolution of fragility curves and consequence models (e.g., Bal et al., 2008; Crowley et al., 2005; Hazus-MH, 2003 and Smyth et al., 2004) whereas the distribution of the human loss ratios can be described using casualty models. Consequence and casualty models can be defined by specifying parameters of the continuous distribution of loss ratios for each damage/limit state (Pagani et al., 2023).

The plausible lack of fragility, consequence and casualty models particularly published for Uganda is amongst the dominant limitations of this study. In that respect, analytical vulnerability curves derived for equivalent single degree of freedom models of different typologies analysed using non-linear time history analysis (D'ayala et al., 2014; Martins and Silva, 2021; Rao et al., 2020) are selected from the GEM global vulnerability database (Martins and Silva, 2023) and adopted in the present study. The vulnerability curves for loss estimation are shown in Appendix E, and uncertainties in loss ratios are modelled with log-normal or beta distribution. Although the exposure model adopted in this study includes some buildings of medium ductility, the taxonomy mapping herein assigns vulnerability curves for buildings of low ductility class which is essentially more representative of Uganda's building stock. Depending on the number of storeys, the various building taxonomies across Uganda are mapped to their corresponding conversion of vulnerability models as shown in Table 4.3. The nomenclature and corresponding plots for each vulnerability curve in the taxonomy mapping above can be obtained from GEM Foundation vulnerability database (Martins and Silva, 2023) which is hosted within: [https://github.com/gem/global\\_vulnerability\\_model/](https://github.com/gem/global_vulnerability_model/).

**Table 4.3** Mapping of the various building taxonomies to the GEM global vulnerability curves

| Building taxonomy                                                          | Corresponding conversion of the vulnerability model                                                           |
|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| 1. Low-medium code reinforced concrete with:                               |                                                                                                               |
| (a) Infill walls                                                           | CR/LFINF+CDL+DUM/H1; CR/LFINF+CDL+DUM/H2;<br>CR/LFINF+CDL+DUM/H3; CR/LFINF+CDL+DUM/H5;<br>CR/LFINF+CDL+DUM/H8 |
| (b) Shear walls                                                            | CR/LWAL+CDL+DUM/H1; CR/LWAL+CDL+DUM/H2;<br>CR/LWAL+CDL+DUM/H3; CR/LWAL+CDL+DUM/H5;<br>CR/LWAL+CDL+DUM/H8      |
| 2. Non-ductile unreinforced masonry consisting of:                         |                                                                                                               |
| (a) Adobe blocks                                                           | MUR+ADO/LWAL+DNO/RWO/H1;<br>MUR+ADO/LWAL+DNO/RWO/H2; MUR+ADO/LWAL+DNO/RWO/H3                                  |
| (b) Concrete blocks                                                        | MUR+CBH/LWAL+DNO/H1; MUR+CBH/LWAL+DNO/H2;<br>MUR+CBH/LWAL+DNO/H3; MUR+CBH/LWAL+DNO/H4                         |
| (c) Fired clay bricks                                                      | MUR+CLBRH/LWAL+DNO/H1; MUR+CLBRH/LWAL+DNO/H2;<br>MUR+CLBRH/LWAL+DNO/H3; MUR+CLBRH/LWAL+DNO/H4                 |
| (d) Dressed stone masonry                                                  | MUR+STDRE/LWAL+DNO/H1; MUR+STDRE/LWAL+DNO/H2;<br>MUR+STDRE/LWAL+DNO/H3; MUR+STDRE/LWAL+DNO/H4                 |
| (e) Rubble stone masonry                                                   | MUR+STRUB/LWAL+DNO/H1; MUR+STRUB/LWAL+DNO/H2;<br>MUR+STRUB/LWAL+DNO/H4                                        |
| 3. Confined masonry of low-medium ductility                                | MCF/LWAL+DUL/H1; MCF/LWAL+DUL/H2; MCF/LWAL+DUL/H4                                                             |
| 4. Structural steel buildings of low-medium ductility                      | S/LFM+CDL+DUM/H1; S/LFM+CDL+DUM/H2                                                                            |
| 5. Wooden, wattle and daub, metal and vegetative exterior walled buildings | W/LFM+CDL+DUM/H1; W/LFM+CDL+DUM/H2;<br>W/LFM+CDL+DUM/H3; W+WWD/LWAL+DNO/H1;<br>W+WWD/LWAL+DNO/H2              |

## 4.7 Results

### 4.7.1 MC-based probabilistic seismic hazard

In stochastic event-based earthquake loss assessment, the high computational demand of MC simulations renders the evaluation of seismic risk for each logic tree branch combination impracticable. Following a branch sampling strategy (e.g., [Porter et al., 2017](#) and [Rao AS, 2017](#)) which relies on sensitivity analysis to trim an intractable logic tree whilst minimising the propagation of the associated epistemic uncertainties, 100 terminal branches are sampled from the overall logic tree and 100 sets of stochastic events are simulated for each logic tree path. The rupture geometries shown in Fig 4.11 are then generated by sampling ground motion intensity values using the GMPEs assigned for each tectonic sub-region. As expected, the largest earthquake ruptures strike along the two geo-tectonic and seismically active branches of the EARS. Whereas the Precambrian basement of Uganda is largely stable and inactive, several earthquake ruptures have been recorded along the Rwenzori fold belt: especially around the Lake Victoria microplate, Utimbere, Nyanza and Speke rifts at the Uganda-Kenya-Tanzania border.

Within an investigation period of 50 year, the seismic hazard maps on reference rock site conditions with  $V_{s,30} = 760 \text{ m/s}$  and site-dependent hazard maps estimating 10 % POE (475-year return period) and 2% POE (2475-year return period) in terms of peak ground acceleration (PGA) in g are shown in Fig 4.12a-b and Fig 4.13a-b, respectively. The seismic hazard estimate presented herein is largely consistent with previous national and regional studies and further confirms that the highest level of seismicity is concentrated in western Uganda. Rwenzori and Kigezi regions which can expect maximum PGA values between 0.24 and 0.27 g on Type A (rock) ground over a 475-year return period are prone to the worst level of seismicity. Additional discussions into the findings and implications of the earthquake hazard model presented in this work can be found in the study by [Oleng et al. \(2024\)](#). Even though more representative earthquake ground-motion fields can be estimated when both inter-event and intra-event residuals at each site are incorporated in the seismic risk model ([Crowley et al., 2008](#); [Erdik, 2021](#); [Weatherill et al., 2015](#)), the present study does not consider the inclusion of spatial correlation of ground motion intensities into the earthquake risk analysis performed herein.

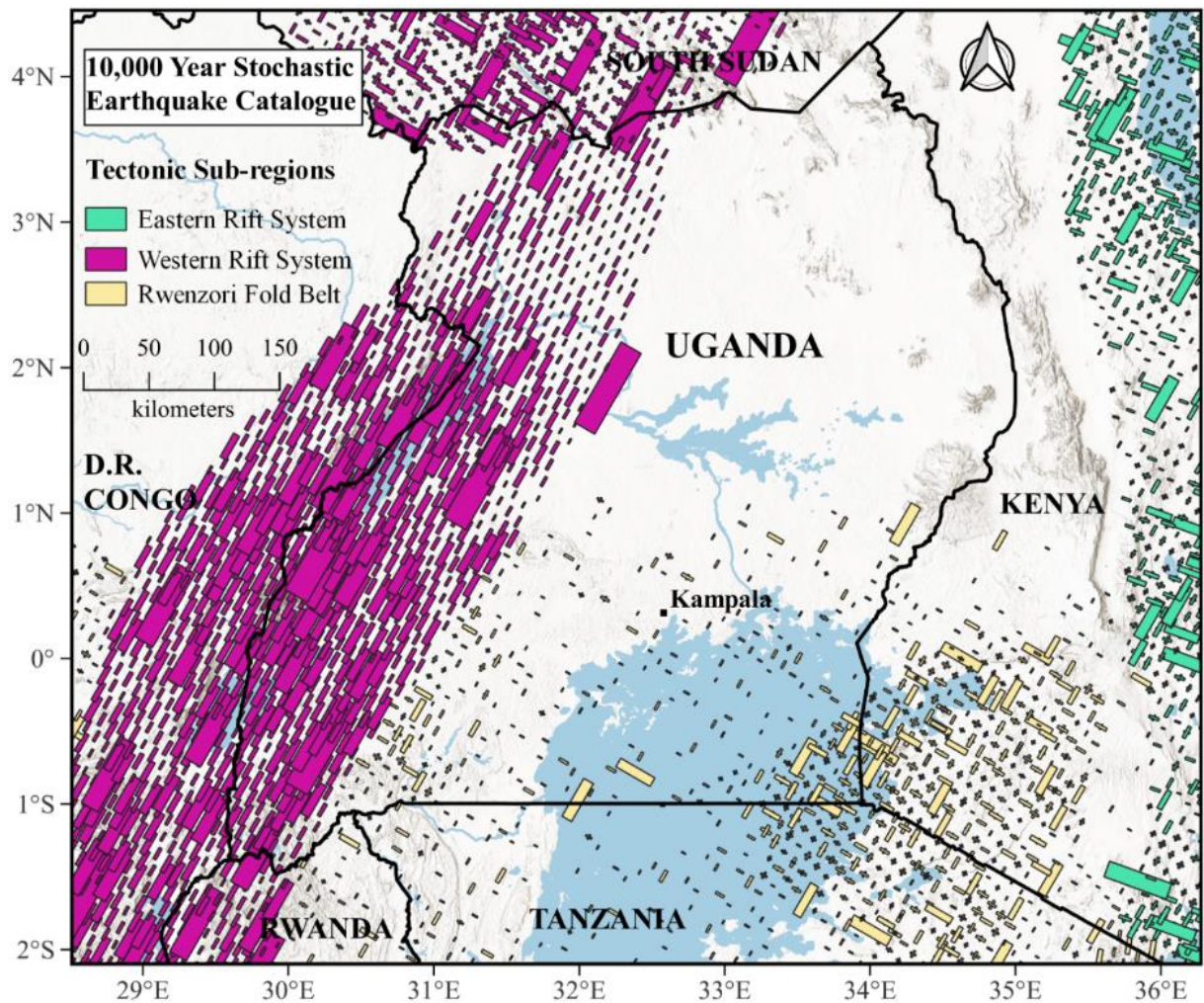


**Fig 4.11** Earthquake rupture geometries illustrating a 10000-year subset of stochastic event catalogue striking each tectonic regime, following the major earthquakes ( $M_w \geq 4.0$ ) in Uganda

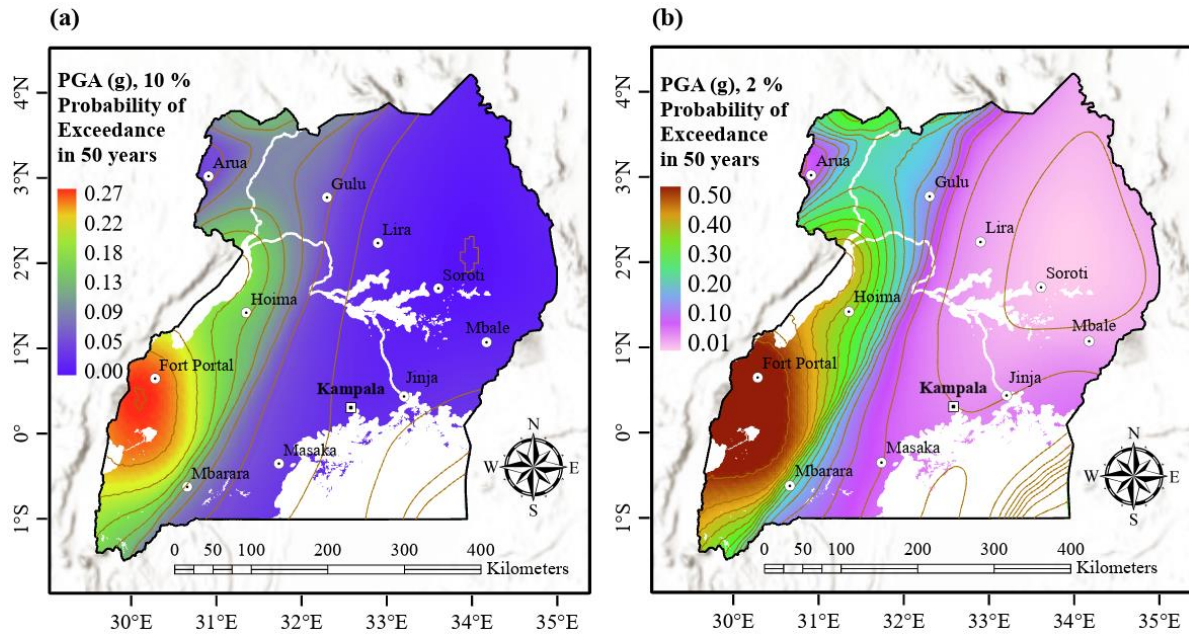


**Fig 4.12** Earthquake hazard maps of Uganda on reference rock site conditions with a 0.03 g contour interval investigated in terms of PGA (g) and presented for: **(a)** 475-year return period (10 % POE in 50 years), and **(b)** 2475-year return period (10 % POE in 50 years) (Olenge et al., 2024)

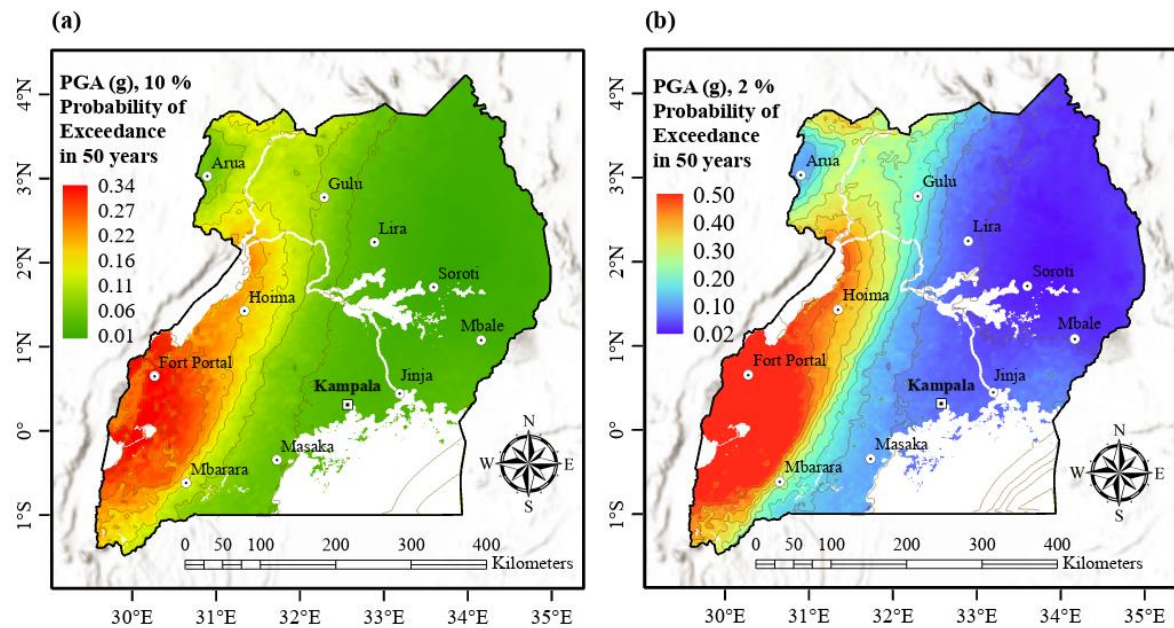


**Fig 4.13** Site-dependent seismic hazard maps of Uganda investigated over 50 years, in terms of PGA (g) and computed for: **(a)** 10 % POE (475-year return period), and **(b)** 2 % POE (2475-year return period). Contour lines are imposed on the maps at 0.05 g contour interval (Olenge et al., 2024)

## 4.7.2 Probabilistic seismic risk

### 4.7.2.1 Mean annual loss maps

In this work, the spatial correlation of intra-event residuals is considered by associating losses between buildings of similar vulnerability classes (Jayaram and Baker, 2009), and as such the

aggregated loss maps derived can be more representative of the entire exposure (Carvalho et al., 2008; Park et al., 2007). The economic loss maps of Uganda showing mean annual loss values which are aggregated according to municipality/county, sub-county, parish, and grid-based exposure levels are shown in Fig 4.14a-d. On the other hand, mean annual fatalities are computed for night-time occupancy in all residential buildings comprising Uganda's building stock and their spatial distribution aggregated at various levels as portrayed in Fig 4.15a-d.

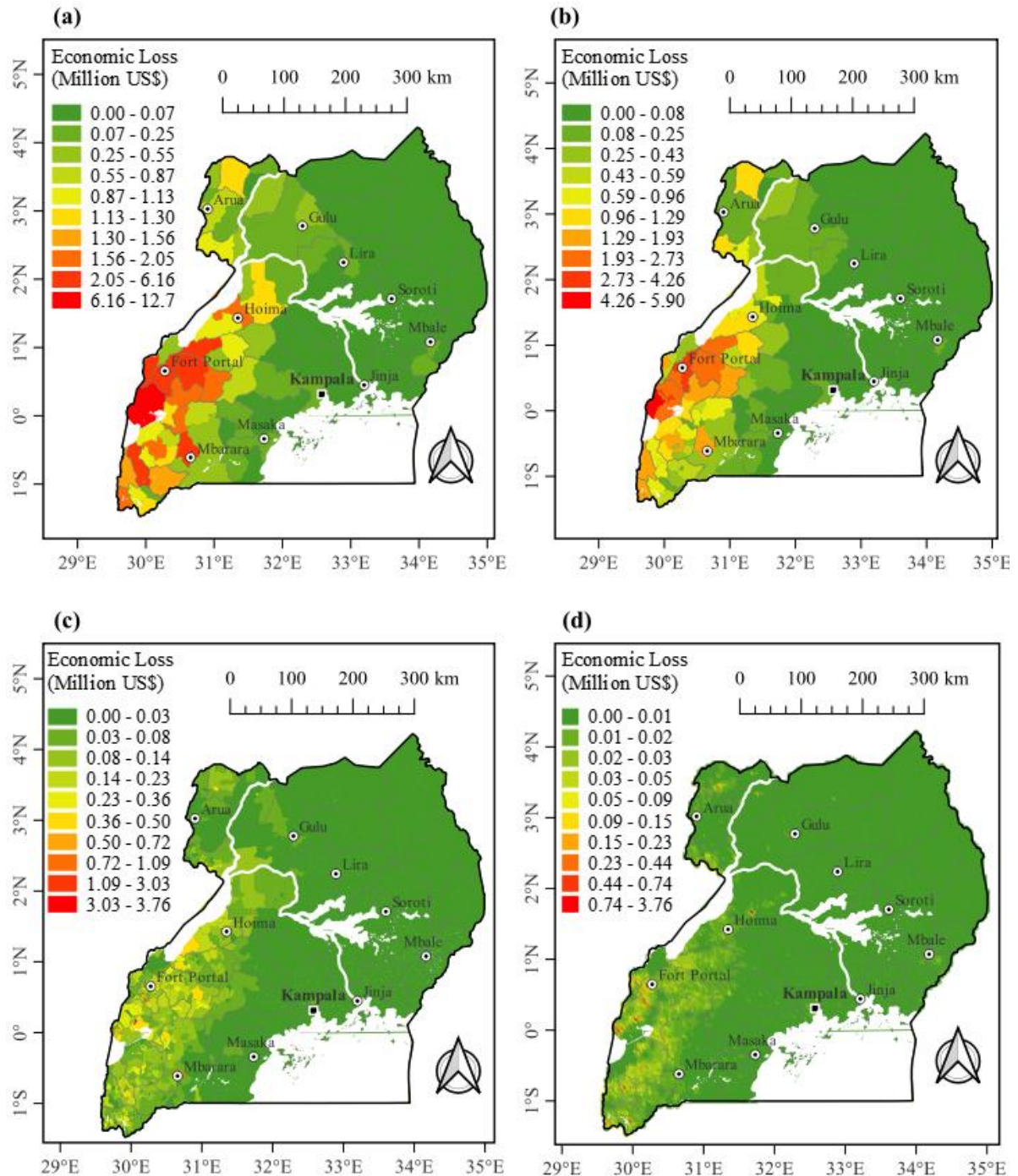


**Fig 4.14** Economic loss maps of Uganda indicating the average annual loss values for all occupancy types and aggregated at various exposure categories corresponding to: **(a)** municipality/county boundaries, **(b)** sub-county level, **(c)** parish extents, and **(d)** grid cell-based exposure model

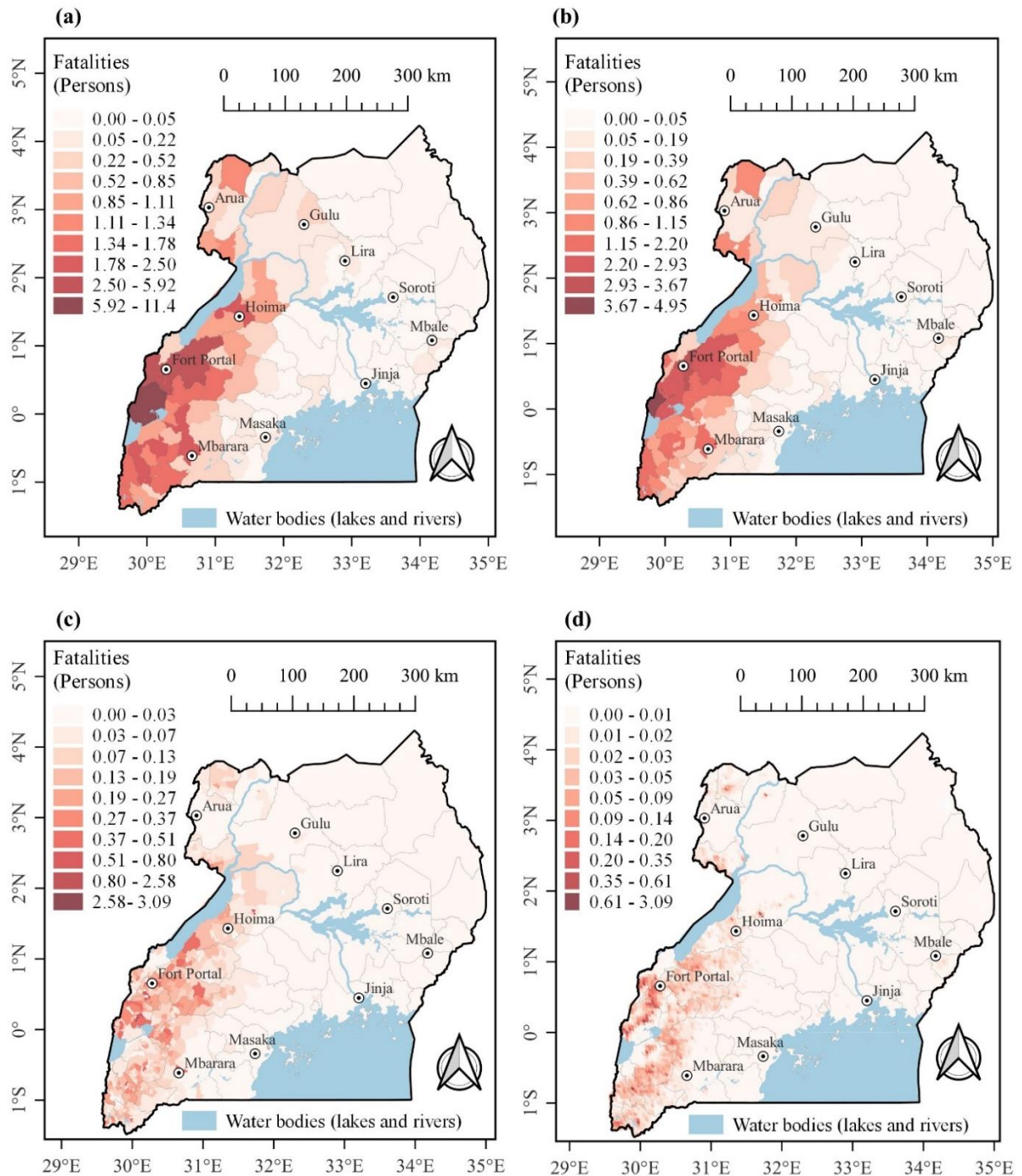


**Fig 4.15** Loss maps of Uganda showing the mean annual fatalities for night-time occupancy in residential buildings, aggregated for exposure categories corresponding to: (a) municipality/county boundaries, (b) sub-county level, (c) parish extents, and (d) grid cell-based exposure model

For purposes of providing a more accurate picture of the real impacts of earthquakes, especially on more socially vulnerable sectors within the community of those living in highly vulnerable assets characterized by low replacement values, average annual economic loss ratios aggregated at municipality and sub-county level are mapped in Fig 4.16a-b. Considering the same administrative boundaries, mean loss ratios for annual fatalities are shown in Fig 4.16c-d.

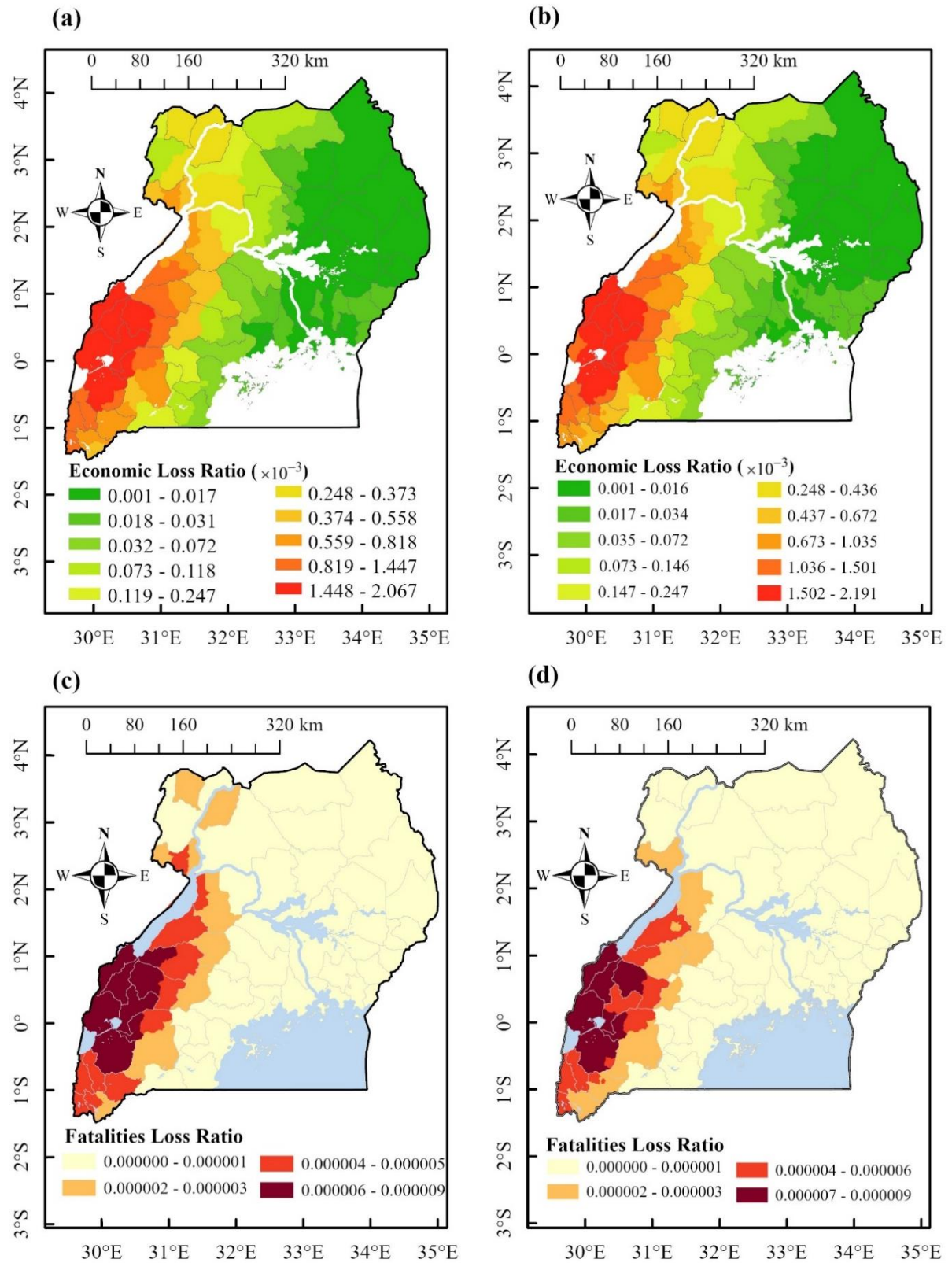


**Fig 4.16** Average annual economic loss ratios obtained for all occupancy types and aggregated at **(a)** municipality/county, **(b)** sub-county; and mean loss ratio maps showing the annual fatalities for night-time occupancy in residential buildings comprising Uganda's building stock and aggregated at **(c)** municipality/county, and **(d)** sub-county

In order to ascertain the spatial distribution of mean annual economic losses and average yearly fatalities across rural and urban settlements in each region of Uganda, seismic risk calculations are aggregated, and results plotted as shown in Fig 4.17a-b. It is observed that, mainly due to its active seismicity yet comprising many substandard buildings coupled with a highly escalating population growth, western Uganda is exposed to the highest level of seismic risk.

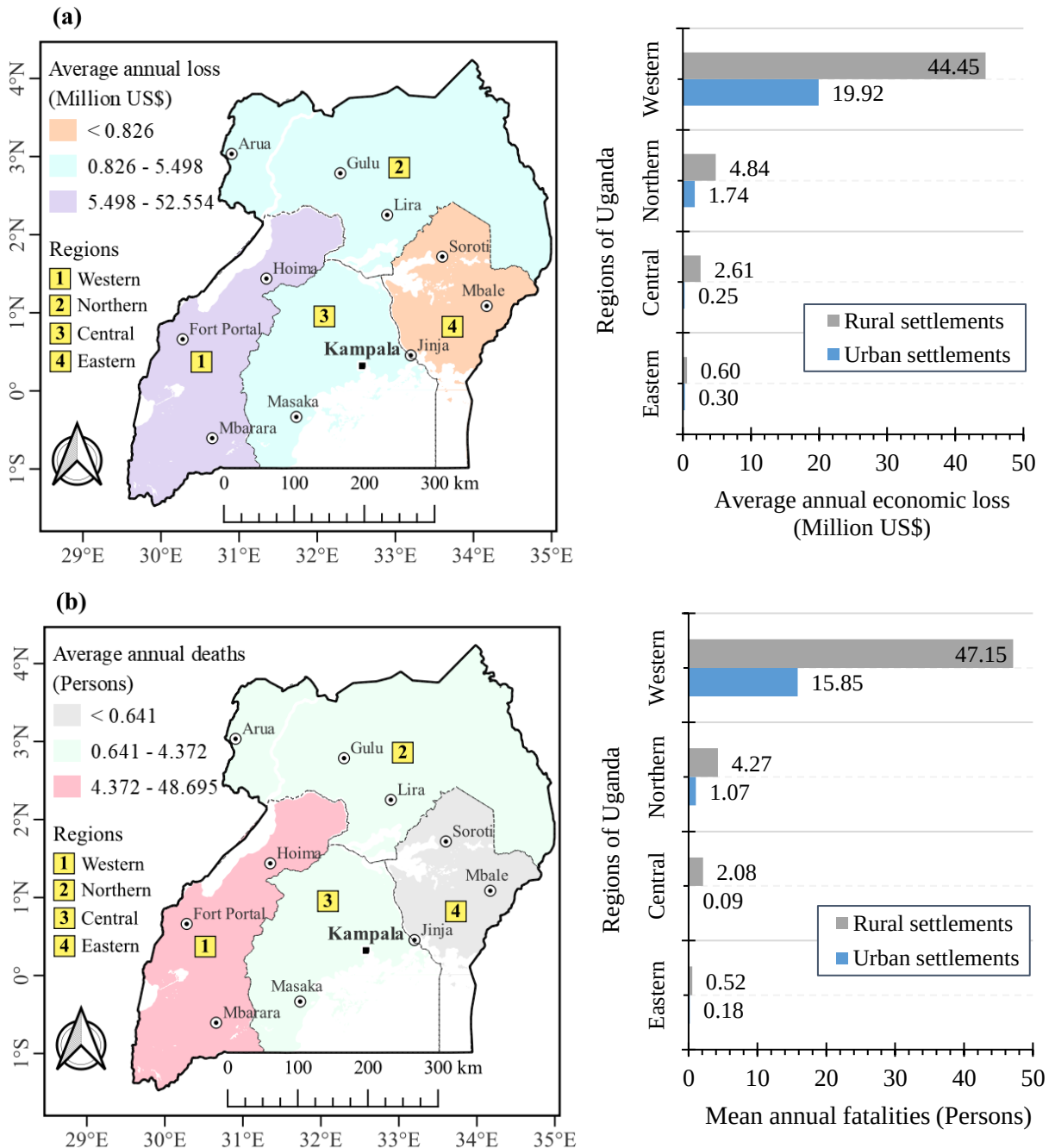
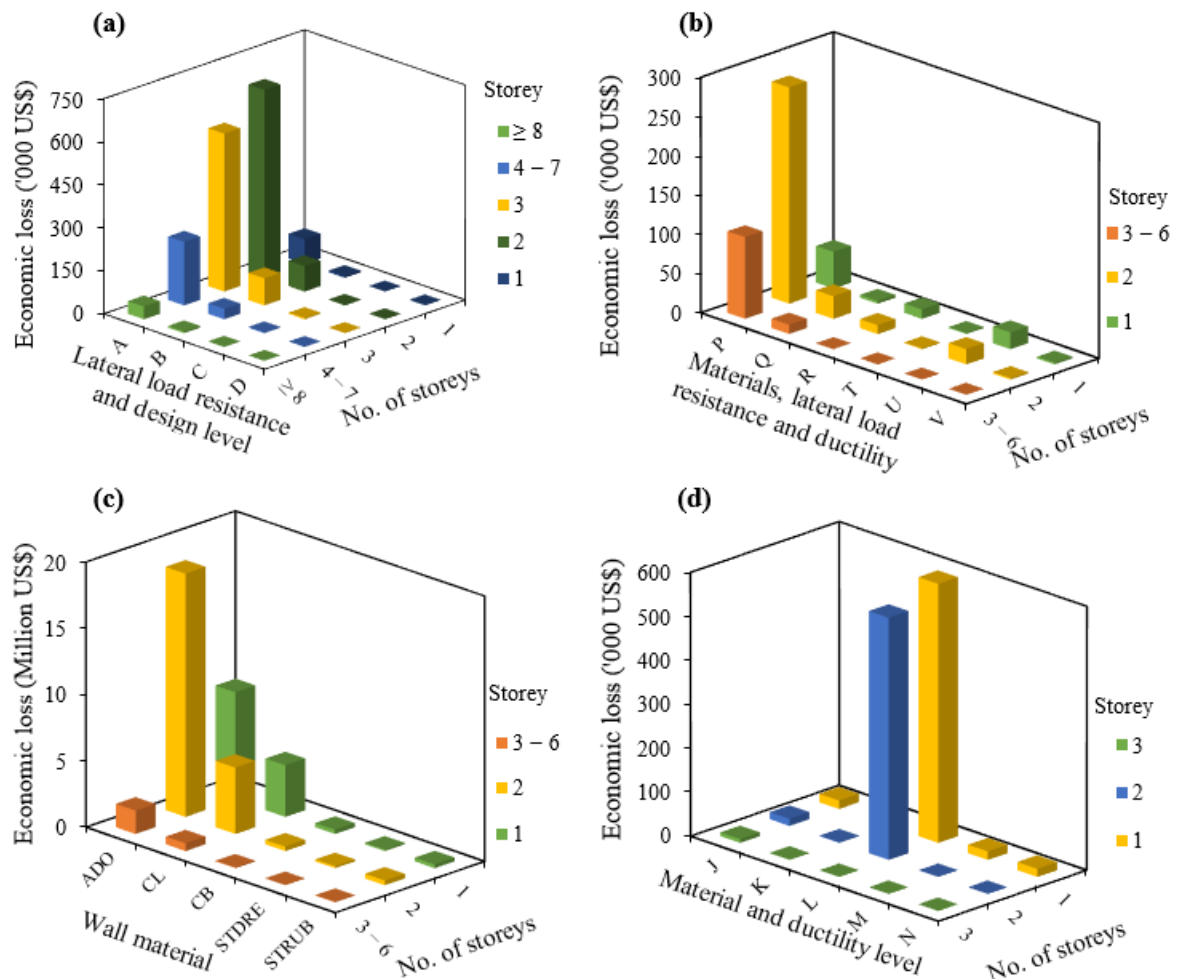


**Fig 4.17** Loss maps of Uganda and the distribution of losses across rural and urban settlements, aggregated on a regional basis and presented for: **(a)** economic (structural) average annual losses for all occupancy categories, and **(b)** mean annual fatalities for night-time occupancy in residential buildings comprising the country's housing stock

#### 4.7.2.2 Aggregated asset loss statistics

Mean annual economic losses per building taxonomy are disaggregated to understand the contribution of each building type to the overall economic losses incurred as shown in Fig 4.18a-d. In general, the largest average annual economic losses are generated by non-ductile unreinforced masonry buildings consisting of adobe blocks, which comprise the main proportion of Uganda's building stock.



**Legend:** (A) and (B) RC with infill walls for resisting lateral loads in low and medium ductility buildings respectively, (C) and (D) RC with shear wall lateral load resisting systems of low and medium ductility respectively, (P) and (Q) confined masonry of low and medium ductility classes respectively, (R) and (T) hot-rolled steel sections of low and medium ductility respectively, (U) and (V) light weight cold-foamed steel sections of low and medium ductility respectively, (ADO) adobe blocks, (CL) fired clay bricks, (CB) concrete blocks, (STDRE) dressed stone masonry, (STRUB) rubble or semi-dressed stone, (J) and (K) wooden and low and medium ductility respectively, (L) non-ductile wood together with wattle and daub, (M) buildings with vegetative exterior walls, and (N) all other metals except steel

**Fig 4.18** Average annual economic losses computed for: (a) reinforced concrete, (b) confined masonry and steel, (c) non-ductile unreinforced masonry, and (d) wooden and other building types

#### 4.7.2.3 Loss exceedance curves

For a set of loss values, mean loss exceedance curves can be used to describe exceedance probabilities within a given investigation time. Alongside Uganda's nominal GDP estimate of US\$

40.53 billion (UBoS, 2022) which is used to display loss values relative to the national GDP on the secondary vertical axis, mean and quantile loss exceedance curves estimating economic losses over several return periods are presented in Fig 4.19. On the other hand, loss exceedance curves predicting the likely number of deaths over various return periods are shown in Fig 4.20.

**Fig 4.19** Mean and quantile economic loss exceedance curves showing losses relative to the country's nominal gross domestic product

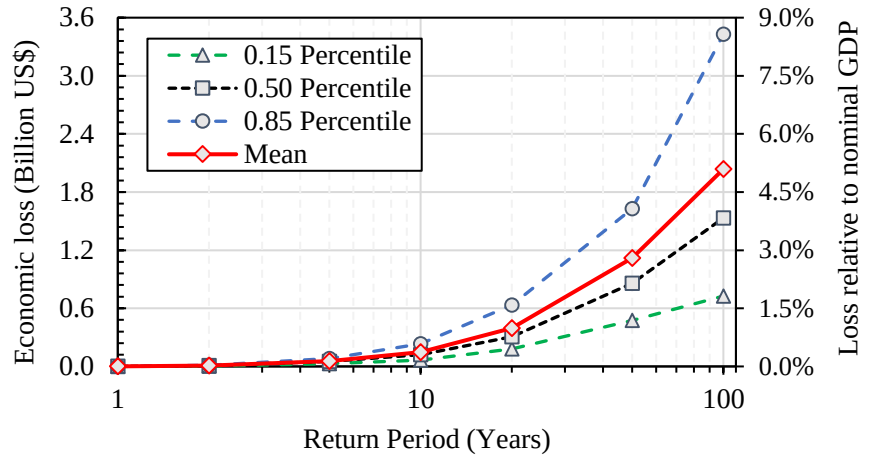
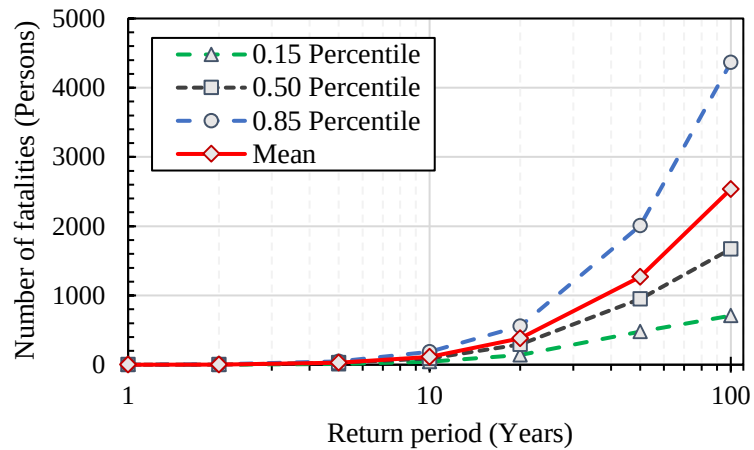


**Fig 4.20** Mean and quantile loss exceedance curves for number of deaths that are likely to occur in various return periods



#### 4.7.3 Comparison with previous regional predictions

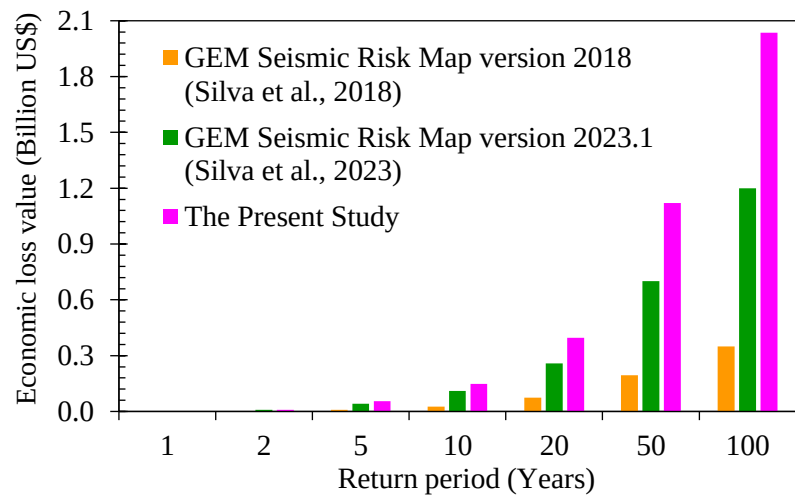
This work considers three lines of business (residential, commercial, and industrial) whose risk indicators are compared with the global earthquake risk model estimated by Silva et al. (2023) as presented in Table 4.4. Whilst the present study estimates a total average annual loss value in excess of US\$ 74.722 million, Silva et al. (2023) predicted lower average annual losses due to damaged buildings of US\$ 64.739 million across the whole country. Furthermore, average economic loss values obtained for all occupancy types are computed for return periods of 1, 2, 5, 10, 20, 50, and 100 years and compared with the overall previous estimates by GEM Foundation (Silva et al., 2018; Silva et al., 2023) as shown in Fig 4.21. Whereas there are insignificant differences in economic loss values at lower return periods, larger variations are observed

for long return periods. In general, the present study predicts higher losses compared with GEM Foundation (Silva et al., 2018; Silva et al., 2023) estimates. For instance, compared with the GEM seismic risk map version 2023.1 (Silva et al., 2023), a difference of more than approximately US\$ 25.3 million, US\$ 195.4 million and US\$ 349.4 million is estimated over 10, 50 and 100-year return periods respectively.

**Table 4.4** Comparison of seismic risk indicator obtained in the present study with previous estimates of the Global Earthquake Model seismic risk map derived by Silva et al. (2023)

| Occupancy type | Silva et al. (2023)                 |                            | Present study                       |                            |
|----------------|-------------------------------------|----------------------------|-------------------------------------|----------------------------|
|                | Average annual loss (Thousand US\$) | Mean annual loss ratio (%) | Average annual loss (Thousand US\$) | Mean annual loss ratio (%) |
| Residential    | 59,134                              | 0.376                      | 67,385                              | 0.339                      |
| Commercial     | 4,699                               | 0.400                      | 5,555                               | 0.405                      |
| Industrial     | 906                                 | 0.165                      | 1,782                               | 0.235                      |
| Total          | 64,739                              | 0.371                      | 74,722                              | 0.340                      |

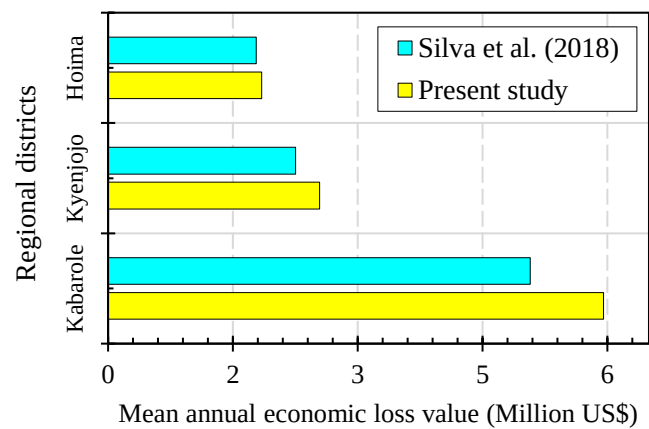
**Fig 4.21** Average economic loss curves derived for occupancy types estimated in the present study, compared with the predictions from GEM Seismic Risk Models



Although Silva et al. (2023) relied on the global seismic hazard map of Johnson et al. (2023) from which a maximum PGA raising to 0.35 g is predicted, this study adopts the hazard model by (Oleng et al., 2024) in which lower PGA values increasing to a maximum of 0.27 g are estimated over a 475-year return period across Uganda. Whereas a lower earthquake risk is expected on the basis of the present seismic hazard model, the current study generally estimates a higher risk partly due to higher total building replacement costs which are adjusted to reflect current market rates of construction. Moreover, as opposed to Silva et al. (2023) who mapped some building taxonomies to vulnerability curves developed for buildings of medium ductility, this study maps all building taxonomies (see Table 4.3) to analytical vulnerability curves derived for non-ductile and low code buildings which typically represent the bulk of Uganda's housing stock.

According to the disaster risk profile of Uganda (WorldBank, 2019), an earthquake capable of causing strong ground shaking is expected to occur at least once in a person's lifetime, especially for the exposed population in high hazard regions. Uganda's disaster risk profile (WorldBank, 2019) further indicates that the highest contribution to the national seismic risk, in terms of average annual population affected, is generated within Ntoroko, Kabarole, Kasese and Nebbi districts. In that regard, mean annual economic losses are determined for some high risk districts in western Uganda and compared with the net present value (NPV) of the previous GEM Foundation estimates by Silva et al. (2018) as presented in Fig 4.22. It is observed that the seismic risk model herein, which relies on non-ductile and low code vulnerability models for building exposure projections as of 2024, estimates higher economic mean annual losses.

**Fig 4.22** Comparison of mean annual economic losses estimated in the present study with the net present value of the predictions by Silva et al. (2018) for major high-risk districts in western Uganda



## 4.8 Discussion

Despite the lack of a national earthquake risk assessment conducted for Uganda, the stochastic event-based seismic risk framework derived herein is largely consistent with previous global estimates. To begin with, the mean annual loss maps presented in Fig 4.14a-d indicate that the economic loss is largely concentrated in Kigezi, Rwenzori and Albertine regions of western Uganda; where for instance a maximum mean annual economic loss of US\$ 12.7 million can be incurred at a given county or municipality as illustrated in Fig 4.14a. In terms of the average annual population affected by earthquakes, the districts (e.g., Kasese, Kabarole, Bundibugyo, Ntoroko, Hoima, and Mbarara) located near the western branch of the EARS have the highest contribution to seismic risk in Uganda. High economic losses are attributed to the high seismicity and a growing population of the districts of western Uganda (Oleng et al., 2024).

It is worth noting that damages of more than US\$ 1.13 million per year is anticipated in a given municipality located the north-eastern part of the country, near Arua city. In addition, Kampala capital city and its immediate environs can expect a maximum mean annual economic loss of US\$ 0.55 million. Although Kampala is situated in an area of low seismicity, the asso-

ciated relatively high absolute damage costs can be attributed to the high concentration of exposed assets (Mujugumbya et al., 2006). Whereas the seismic hazard across the rest of Uganda is very low, substantial economic losses are still expected to increase owing to the presence of many substandard buildings located in soft soils, notwithstanding the already high rate of urbanisation and population growth across the region. By and large, the seismic risk model derived in this work estimates an overall economic mean annual loss of US\$ 74.722 million across the whole country. This value is fairly realistic compared with economic losses indicated in previous damage reports (e.g., Balikuddembe and Sinclair, 2018; Kahuma et al., 2006 and USGS, 2016), where for instance economic losses worth US\$ 60 million were incurred in the aftermath of the catastrophic 1994 Kisomoro earthquake which struck Kabarole, Bundibugyo and Kasese districts (NEDC, 1994). Furthermore, the mean annual fatalities map for night-time occupancy in residential buildings (shown in Fig 4.15a) indicates that, within a county/municipality, up to 11.4 deaths could be incurred on average per year in western Uganda. Across the whole country, the mean annual death toll due to seismic activity is estimated to increase to a maximum value of 71.3 persons.

Following the mean annual economic losses and average annual fatalities aggregated by region and settlement type (see Fig 4.17a-b), mean annual economic loss of US\$ 64.37 million and average fatalities of 63 persons can be incurred per year across rural and urban settlements in western Uganda. This indicates that over 86.2 % of Uganda's total seismic risk originates from its western territory. Whereas about 8.8 and 3.8 % contribution of mean annual economic losses are generated from the northern and central territories respectively, eastern Uganda is exposed to the lowest level of seismic risk with less than US\$ 900000 likely to be incurred on average, per year. It is worth noting that, in addition to over 75.8 % likely deaths, more than 70.2 % of mean economic annual losses originate from the widely spread rural settlements in Uganda; partly due to the high vulnerability of most substandard buildings.

The asset loss statistics shown in Fig 4.18a indicate that low ductility RC buildings that rely on infilled walls for resisting lateral loads can suffer mean annual economic losses of over US\$ 655000, US\$ 550000, and US\$ 220000 for 2, 3, and 4-7 storeyed buildings, respectively. More than US\$ 275000 and US\$ 103000 are respectively calculated for 2- and 3-storeyed confined masonry buildings of low ductility (see Fig 4.18b). Whereas most typologies generate low losses, possibly due to their lower likelihood of damage due to ground shaking and the fact that they represent only a small fraction of Uganda's building stock, the largest disaggregation of economic losses comes from non-ductile unreinforced masonry buildings (see Fig 4.18d). For instance, the mean annual loss for single and double storeyed buildings comprising adobe block wall construction material is estimated at over US\$ 8.1 million and US\$ 18.4 million, respectively. On the other hand, the mean economic loss exceedance curve showing the losses

relative to nominal GDP (see Fig 4.19) indicates that the mean economic losses for 10, 50 and 100-year return periods are in excess of US\$ 147.78 million (0.36% GDP), US\$ 1.12 billion (2.72% GDP) and US\$ 2.04 billion (4.94% GDP) respectively. Similarly, the mean loss exceedance curve showing likely fatalities (see Fig 4.20) indicates average death estimates of 112.8, 1270.2 and 2537.2 persons over a 10, 50 and 100-year return periods, respectively.

Although the framework presented in this study provides a fundamental basis for practical seismic risk appraisals across Uganda, the major challenge faced in this work is lack of detailed information regarding assets contained in the exposure model. Uganda Bureau of Statistics and National Planning Authority should conduct a thorough population and housing census (supplemented by quick walkthrough and detailed surveys of individual buildings, satellite images and remote street surveys) to specifically derive a more elaborate building classification scheme that describes different building attributes in a more refined manner. Government agencies (e.g., the National Building Review Board in conjunction with Uganda Institution of Professional Engineers, Institution of Surveyors of Uganda and Uganda Society of Architects) endeavour to establish actual building construction costs which will inform more detailed and refined seismic risk analyses. Another major drawback of this study is the lack of casualty, consequence, fragility and vulnerability models which are developed with holistic considerations of the building stock in Uganda. A possible extension of the present study will aim to derive fragility and vulnerability curves for the building stock in Uganda. Realistic finite element models of selected building types in Uganda should be developed to derive fragility curves that satisfactorily reflect the corresponding capacity, demand and limit state uncertainties. In this regard, the relevant government institutions like the Directorate of Geological Survey and Mines and Ministry of Relief, Disaster Preparedness and Management ought to improve earthquake monitoring and recording of post-earthquake damage data.

Considering that mitigation of seismic risk at a national level largely requires the formulation and implementation of appropriate earthquake design codes, a possible extension of the present study is to identify key deficiencies and make recommendations toward performing an in-depth review and update of Uganda's seismic code of practice for structural designs (US 319:2003). Further to aligning US 319:2003 to modern seismic design standards, there is need to explore the use of locally sourced timber as a structural material for post-disaster relief housing. Earthquake-resistant timber houses which suit the social and cultural practices of the communities living in in Uganda's earthquake-prone zones can be designed and tested under earthquake loads through numerical simulations. On the other hand, scenario-based analyses (e.g., [Opabola and Galasso, 2024](#)) can be employed to comprehensively revise the policies stipulated in the National Policy for Disaster Preparedness and Management ([NPDPM, 2010](#)). Moreover,

gross insurance premiums and a government insurance scheme should be determined for various types of construction in each region based on the seismic risk levels.

Succinctly, strengthening public awareness of earthquake-induced disaster is critical and can be achieved through promoting risk education, universal access to disaster risk information, building social demand for risk mitigation and encouraging individual safety as well as public responsibility. Information campaigns towards creating earthquake awareness can be instigated through the preparation of videos and maps based on the findings of the present study. Moreover, a participatory approach is critical for local communities to adopt mitigation measures that fully or partially change their lifestyle. For the strongest possible earthquake in scenario cities (e.g., Fort Portal), emergency plans catering for the number of buildings likely to be damaged and require immediate inspections, number of people required to stay away from buildings and provisions to be made for temporary accommodation, water and food should be set in place. In addition, the number of people likely to be injured and the number of field hospitals equipped with beds to be deployed within 24 hours can be determined based on the framework presented in this study. Finally, efficient and effective coordination of emergency response resources at local and national levels should be planned at both civil and military levels.

#### 4.9 Conclusions

Seismic risk in Uganda is intensifying due to its rapidly-growing population and urbanisation coupled with a highly vulnerable substandard building stock caused by lack of building control and out-of-date seismic design guidelines. As a pioneering step towards building seismic risk and resilience for the country, the present study employs the probabilistic event-based risk calculator of *OpenQuake*-engine to holistically assess potential losses resulting from future earthquakes. Uganda's exposure model estimates approximately 9.62 million residential buildings, 198000 commercial buildings and 85000 industrial facilities respectively valued in excess of US\$ 171.45 billion, US\$ 11.9 billion and US\$ 6.6 billion. Globally calibrated analytical vulnerability curves derived for equivalent single degree of freedom models of various building typologies in various tectonic regimes are combined with the event-based probabilistic seismic hazard model for Uganda. The seismic hazard map computed for a 475-year return period indicates a maximum reference PGA of 0.27 g on rock ground in western Uganda. In general, over 86.2 % of the total earthquake risk originates from western Uganda (particularly within the districts of Kasese, Kabarole, Bundibugyo, Ntoroko, Hoima, and Mbarara) and only about 8.8, 3.8 and 1.2 % contribution of mean annual losses are generated from the northern, central and eastern territories, respectively. Overall, mean annual losses worth US\$ 74.722 million coupled with a mean annual death toll of up to 71.3 persons can be expected to be instigated by seismic activity nationwide. On average, economic losses worth 0.36, 2.72, and 4.94 % of

the country's nominal GDP can be expected over 10, 50 and 100-year return periods, respectively. Partly due to their high vulnerability and the fact that they represent the bulk of Uganda's building stock, the largest disaggregation of the losses originates from non-ductile unreinforced masonry buildings comprising adobe blocks. However, seismic risk in Uganda is not very high and could be easily dealt with via compulsory building insurance such as a National Insurance Scheme (NIS) that allows for fixed compensation per square-metre. The seismic risk assessment framework proposed in this work presents a huge step towards providing practitioners, policymakers, insurance companies and government stakeholders with practical seismic risk appraisals towards risk-informed decision making, especially at a national policy level.

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## Statements and declarations

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### Author contributions

All authors contributed to the study conception and design. Material preparation and data collection was performed by Morris Oleng. The development of codes and analysis were performed by Morris Oleng, and Dr Zuhal Ozdemir and Professor Kypros Pilakoutas checked the results. The first draft of the manuscript was written by Morris Oleng and Dr Zuhal Ozdemir and Professor Kypros Pilakoutas commented on previous versions of the manuscript. All authors read and approved the manuscript.

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**Conflict of interest**

The authors declare no competing interests. The authors have no relevant financial or non-financial interests to disclose.

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# CHAPTER 5

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## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Summary

This thesis entails an earthquake hazard and risk assessment framework for Uganda. In its first part, a robust probabilistic seismic hazard assessment is conducted using a fault-oriented spatially distributed seismicity approach. The second part of this thesis demonstrates the ability of fuzzy logic and geospatial modelling techniques in deriving a national co-seismic and rainfall-induced landslide hazard susceptibility framework for the country. The final part focusses on assessing potential losses due to future earthquakes in Uganda by combining seismic hazard predictions with the country's building exposure and the available global analytical vulnerability models. The following sub-section summarises a generic overview (e.g., purpose, methods and results) into the main parts of this thesis.

#### 5.1.1 Event-based probabilistic seismic hazard analysis

This part of the thesis employs a fault-oriented spatially distributed seismicity approach and a novel stochastic event-based modelling technique to probabilistically analyse seismic hazard across Uganda. To begin with, the first earthquake catalogue is acquired locally from the Directorate of Geological Survey and Mines ([DGSM, 2022](#)) under the Ministry of Energy and Mineral Development (MEMD). However, because Uganda suffers from a substantial lack of information in addition to the existence of large solution uncertainties caused by scarce historical records and inadequate seismic network coverage, more earthquake data is acquired from credible global agencies including: ISC-GEM catalogue ([Di Giacomo et al., 2018](#); [Storchak et al., 2013](#); [Storchak et al., 2015](#)), USGS database ([USGS, 2022b](#)), ISC reviewed bulletin ([ISC, 2022](#)), GEM global historical earthquake archive ([Albini et al., 2013](#)), and compilations from literature review (e.g., [Ambraseys and Adams, 1991](#) and [Maasha, 1975](#)).

Upon earthquake catalogue acquisition, data obtained from credible global databases is merged with the records of [DGSM \(2022\)](#), and duplicate events are removed using time and distance windows of 120 seconds and  $0.5^\circ$  (55.5 km) respectively as proposed by [Poggi et al. \(2017\)](#). Due to relative uncertainties between agencies recording and reporting earthquakes in Sub-Saharan Africa, 768 duplicates are reported; leaving the final catalogue with 744 events out of the overall 1512 earthquakes recorded by all credible agencies. Using suitably derived conversion equations ([Edwards et al., 2010](#); [Engdahl, 2002](#); [Weatherill et al., 2016](#)), earthquake magnitudes are harmonised to the moment magnitude ( $M_w$ ) scale prior to the execution of the modified [Knopoff \(2000\)](#) declustering algorithm extended by [Bustos \(2009\)](#). The declustered

catalogue comprises 543 mainshocks out of 744 events from which a *Poisson* model (Cornell and Winterstein, 1988) is used to subsequently describe Uganda's seismicity. Using the statistical maximum curvature (Wiemer and Wyss, 2000) and *b-value* stability (Cao and Gao, 2002) methods, the Uganda earthquake catalogue is complete for:  $M_w \geq 4.5$  from 1980,  $M_w \geq 4.8$  from 1970,  $M_w \geq 4.9$  from 1965,  $M_w \geq 5.3$  from 1960,  $M_w \geq 5.6$  from 1930 and  $M_w \geq 6.0$  from 1900.

The zonation of seismic sources adopted in this work is a mixed approach that accounts for observed seismicity and geo-tectonic characteristics of the region in question (Baker et al., 2021; Vilanova et al., 2014). Employing this strategy splits Uganda into 13 area source zones (ASZs) from which ASZs of similar geo-tectonic settings are grouped into four gross sources. Seismicity parameters defined within the Gutenberg-Richter recurrence law are then estimated using the maximum likelihood algorithm of Weichert (1980). Since the seismogenic depth potential, active fault characteristics and source-scaling relationships are insufficiently known, maximum earthquake magnitudes are arbitrarily estimated by adding a conservative increment of 0.5 magnitude units to the maximum observed magnitude for each ASZ. Further notwithstanding the non-existence of ground motion prediction equations (GMPEs) developed based on actual strong ground motion records for Uganda, a logic-tree is used to implement GMPEs proposed for active shallow crust (Akkar et al., 2014 and Chiou and Youngs, 2014) and stable continental crust (Pezeshk et al., 2011 and Atkinson and Boore, 2006) tectonic regimes.

The investigation area comprises a mesh spacing of 2.5 km from which site-specific hazard is modelled using the upper 30-metre average shear-wave velocity reference ( $V_{s,30}$ ) obtained from the USGS database of Allen and Wald (2007). In addition to site-specific and bedrock ( $V_{s,30} = 760$  m/s) seismic hazard maps for Uganda, mean hazard curves, uniform hazard spectra and disaggregation are derived for some regional cities across the country. Whereas the site-dependent hazard model predicts a maximum peak ground acceleration (PGA) of 0.34 g for a 475-year return period in western Uganda, the bedrock hazard model estimates a PGA raising to 0.27 g. The findings confirm that western Uganda is exposed to the highest level of hazard.

Lastly, elastic acceleration response spectra representing seismic actions in the horizontal direction are developed for two example sites located in Mbarara and Fort Portal. Type 1 (high seismicity) spectrum and Type A (rock) ground are assumed according to the provisions of Eurocode 8-1 (CEN, 2004). From the seismic hazard results (Oleng et al., 2024), reference bedrock PGAs of 0.122 and 0.255 g are respectively considered for Mbarara and Fort Portal cities, along with a 5 % damping ratio. Low ductility class is selected and a behaviour factor of 1.5 is used to derive the corresponding design response spectra. Although defining behaviour factors considered in the Uganda seismic code of practice for structural designs (US 319:2003) (UNBS, 2003) involves several assumptions, the design spectra derived according to Eurocode

8-1 (CEN, 2004) predict lower spectral accelerations compared with the design spectra computed using US 319:2003 (UNBS, 2003). The seismic hazard model presented in this study can reliably be used to kick-start the update and continuous improvement of a more robust version of US 319:2003 (UNBS, 2003).

### 5.1.2 Relative co-seismic landslide hazard susceptibility

Despite the limited historical inventory data describing complex geo-physical processes associated with landslides across Uganda, the second part of this thesis demonstrates the ability of fuzzy logic and geospatial methods in developing a comprehensive national co-seismic and rainfall-induced landslide hazard susceptibility framework for the country. In addition to earthquake characteristics, the most prevalent predisposing and geomorphological landslide conditioning factors considered in this study include slope angle, topographic slope position, geology and proximity to major active faults. Landslide frequency ratios (Lee and Pradhan, 2007; Lee and Sambath, 2006; Yilmaz, 2009) for various landslide conditioning factors are calculated using a statistical bivariate method (Aleotti and Chowdhury, 1999; Leroi, 1996). Next, fuzzy membership functions embedded in *ArcGIS 10* (Raines et al., 2010) are implemented to generate fuzzy maps which are then overlaid to produce the final fuzzy sets describing relative probabilities of co-seismic and rainfall-triggered landslide occurrences across the country.

To derive normalised landslide frequency ratio-based PGA values for the whole country, the analysis performed in this study relies on two scenario events (the 1966 Toro and 1994 Kisomoro earthquakes) that triggered extensive landslides around their epicentres. In addition to geology and major fault segments, topographic parameters are modelled using a 30-metre digital elevation model (RCMRD, 2022; USGS, 2022a). The spatial distribution of major landslide pixels and scars indicates the largest concentration of co-seismic and rainfall-triggered landslide occurrences in highlands, predominantly along the slopes of Rwenzori and Elgon mountains, respectively. The results show that although Uganda is largely dominated by slope angles between 0 and 5°, there is a significant contribution of landslides from which frequency ratios increase with increasing slopes of up to 50°. The highest overall landslide frequency ratios are observed along upper slopes, followed by ridges and middle slopes.

The highest landslide frequency ratios and relative landslide areas are observed within 40 km from major active faults. On the other hand, stream banks located within 750 m from water bodies are more vulnerable to landslides. Predominantly Metasedimentary geological formations and Precambrian granitic outcropping rocks with a certain degree of fracturing and weathering exhibit the highest overall landslide frequency ratio. The GIS-based fuzzy *GAMMA* map indicates that while majority of the country's territory is susceptible to very low co-seismic landslide hazard, western Uganda is highly exposed. On the other hand, the rainfall-induced

landslide hazard susceptibility map, obtained for predisposing landslide factors only, confirms that several highlands are prone to slope failures.

For purposes of further detailed absolute landslide hazard assessments, envisaged as a possible extension of the present study, the overall landslide zones are broadly categorised into three levels: low (*green*), moderate (*yellow*) and high (*red*). Whereas detailed assessments may be ignored in low hazard zones, mandatory analysis is recommended in high landslide hazard areas. Detailed landslide hazard analysis is strongly encouraged in regions of moderate landslide comprising highly weathered outcropping rocks of Precambrian granites, dominantly metasedimentary, and granulites and gneisses geologies within 80 km from major active faults. This study offers valuable insights into the relative co-seismic landslide hazard susceptibility towards informing the relevant government agencies and the other key stakeholders on practical applications of more appropriate landslide risk reduction strategies.

### 5.1.3 Stochastic probabilistic earthquake risk analysis

Regardless of the substantial efforts towards the prediction of seismic hazard in Uganda, there is no comprehensive study published on the associated earthquake risks. Yet, seismic risk within the country is escalating fast due to increasing population, urbanisation and rapid construction. Moreover, majority of Uganda's building stock especially in the remote rural and urban densely populated areas is largely substandard. Future earthquake losses are likely to increase due to lack of building control and inadequate disaster prevention and mitigation strategies. The third part of this study employs the probabilistic event-based risk calculator of *Open-Quake* to assess losses resulting from future earthquakes. The prediction of earthquake risk is based on the stochastic event-based seismic hazard model derived by [Oleung et al. \(2024\)](#).

Information regarding the building stock in Uganda, projected for the baseline year 2024, is largely extracted from the uniform exposure model for Africa and GEM Foundation ([Paul et al., 2022](#); [Yepes-Estrada et al., 2023](#)), wherein exposure distribution is inferred from Uganda's 2014 national population and housing census ([UBoS, 2016](#)). The building typology nomenclature defined in the GEM building taxonomy ([Brzev et al., 2013](#); [Silva et al., 2022](#)) is adopted to assign attributes to buildings in the exposure. Total replacement costs of buildings are then adjusted based on local market rates for construction. Overall, the exposure model estimates approximately 9.62 million residential buildings, 198000 commercial buildings and 85000 industrial facilities respectively valued more than US\$ 171.45 billion, US\$ 11.9 billion and US\$ 6.6 billion. Uganda's housing stock accounts for approximately 4.7 times of the country's nominal gross domestic product (GDP) of June 2022 ([UBoS, 2022](#)). Owing to the unfortunate lack of fragility and vulnerability curves explicitly developed for the country, this study adopts analytical vulnerability curves derived for equivalent single degree of freedom (SDOF) models

of various building typologies in various tectonic regimes (Martins and Silva, 2023). Since Uganda's building stock is largely dominated by substandard constructions, this study uses low-code vulnerability curves for estimating seismic risk across the country.

The findings of this study indicate that the largest losses are incurred in Kigezi, Rwenzori and Albertine regions of western Uganda. For instance, a maximum mean economic loss of US\$ 12.7 million and on average, a maximum of 11.4 deaths are likely to be suffered in a given county or municipality per year. The earthquake risk assessment framework proposed in this work can provide engineering practitioners, policymakers, insurance companies and government stakeholders with practical seismic risk appraisal techniques.

## 5.2 Conclusions

### 5.2.1 Probabilistic seismic hazard assessment

The seismic hazard model presented in this thesis is largely consistent with previous regional studies and the following conclusions are drawn from the findings:

1. Western Uganda especially the Rwenzori, Kigezi and Albertine regions are exposed to the highest level of seismicity; with PGA increasing to a maximum of 0.27 g on Type A (rock) ground for a 475-year return period. Amongst Uganda's regional cities, the largest bedrock hazard over a 475-year return period is predicted in Fort Portal where PGA can raise to a maximum value of 0.255 g; whilst Soroti city is the least prone to seismic hazard. Excluding Hoima and Mbarara cities where maximum bedrock PGA values in the range of 0.09-0.165 g are estimated over a 475-year return period, the rest of the country's territory is prone to relatively low hazards with bedrock  $PGA \leq 0.09$  g.
2. Considering a 10 % probability of exceedance in 50 years, the site-dependent hazard model predicts a maximum PGA of 0.34 g in Rwenzori region while the bedrock hazard model estimates PGA values raising to 0.27 g. This is due to possible discrepancies between the resolutions of slope-based site condition maps and hazard computation grids. A user with better site condition data may incorporate them to modify the bedrock hazard values provided in the present study.
3. A maximum mean spectral acceleration (SA) of 0.623 g at a period of 0.1 second can be expected in Fort Portal city. For the same spectral period, the other major regional cities can expect mean SAs  $\leq 0.1$  g; except Hoima, Mbarara, Gulu, and Arua cities where mean SAs of 0.379, 0.269, 0.155 and 0.126 g are predicted, respectively.
4. The bedrock earthquake disaggregation indicates the largest contribution to the design PGA in high hazard regions like Fort Portal to arise from a modal earthquake of 4.6  $M_w$

striking within 10 km. Whilst the local source governs the hazard for short period ground motions, additional long-term disaggregation indicates that the modal earthquake of 4.6  $M_w$  striking within 5 km corresponds to the design PGAs in such high hazard regions.

5. The current seismic zones and zoning factors described in US 319:2003 need to be updated based on more accurate local ground accelerations derived in the present study. Moreover, the shape of the elastic response spectrum presented in US 319:2003 should be aligned to modern seismic design codes and standards which explicitly consider the magnitude of earthquakes that contribute most to seismic hazard in the site defined for the purpose of probabilistic hazard assessment.
6. The design spectrum derived according to Eurocode 8-1 generally predicts lower spectral accelerations compared to the design spectrum computed in accordance with US 319:2003. The seismic hazard assessment framework presented in this work can reliably be used as a starting point for the update and continuous improvement of a more robust seismic design code.

### 5.2.2 Co-seismic and rainfall triggered landslide hazard susceptibility

The output of this part of the thesis demonstrates the ability of employing a geospatial-based fuzzy logic methodology in the development of a comprehensive national earthquake- and rainfall-induced landslide hazard susceptibility framework for Uganda. From this part of the study, it is concluded that:

1. Although majority of unstable slope failures along Uganda's highlands, especially in Elgon and Rwenzori regions, are attributed to high precipitation rates, there is a significant contribution of co-seismic landslide pixels to the overall landslide hazard across Uganda. The highest overall landslide frequency ratios are observed along upper slopes, followed by ridges and middle slopes. Except for lower slopes, there is a strong correlation between co-seismic landslides and the other slope positions across Uganda.
2. The highest landslide frequency ratios and relative landslide areas are observed within 40 km from major active fault segments. Whereas rainfall and earthquake-induced landslides are predominantly initiated within 100 km from active faults, landslide occurrences elsewhere are mainly controlled by rainfall only. The highest co-seismic landslide densities are within Euclidian distances of up to 1 km from streams while many rainfall-induced landslides are triggered in regions located within 1.5 km of streams.
3. Predominantly Metasedimentary and Precambrian granites (outcropping rocks with a certain degree of fracturing and weathering) located in ridges and upper slope gradients

between 35 and 40° exhibit the highest overall landslide frequency ratios. Except for the volcanics where rainfall-induced events are dominant, landslides across the country are typically associated with earthquakes.

4. In general, Kigezi and Rwenzori sub-regions in western Uganda are highly prone to co-seismic landslides while landslide occurrences across the other parts of the country are largely driven by rainfall. It is worth noting that because of its low level of seismicity, regions around Mount Elgon in eastern Uganda (which has experienced several rainfall-induced landslides in the past) has lower relative probabilities of co-seismic landslides.
5. Whereas mandatory absolute landslide hazard analysis is recommended in high landslide hazard areas, detailed hazard analysis is encouraged in regions of moderate landslide hazard level comprising highly weathered outcropping rocks of Precambrian granites, dominantly metasedimentary, and granulites and gneisses geologies within 80 km of active faults: where bedrock PGA  $\geq 0.1$  g over a 475-year return period, topographic position index  $\geq 3.8$ , slope gradient  $\geq 10$  degrees, and distance from streams  $\leq 1.25$  km.

### 5.2.3 Event-based probabilistic earthquake risk assessment

The earthquake risk assessment framework developed in this study offers a basis for strategic land use planning patterns, earthquake insurance pricing, and disaster risk reduction and management measures towards improving the Uganda National Policy for Disaster Preparedness and Management. From this Chapter of the thesis, the following conclusions are drawn:

1. The Kigezi, Rwenzori and Albertine regions of western Uganda are exposed to the highest level of seismic risk; partly due to its active seismicity, yet comprising many substandard buildings coupled with a highly escalating population growth and urbanisation. In general, over 86.2 % of the total earthquake risk originates from western Uganda and the only about 8.8, 3.8 and 1.2 % contribution of mean annual economic losses are generated from northern, central and eastern territories, respectively.
2. Kasese, Kabarole, Bundibugyo, Ntoroko, Hoima, and Mbarara districts have the highest contribution to the country's overall seismic risk. On average, a maximum economic loss of US\$ 12.7 million and fatalities amounting to 11.4 deaths are likely to be incurred in a given district per year. Although seismic risk is relatively low across the rest of Uganda, losses are still expected to increase substantially because of many substandard buildings located in soft soils, notwithstanding the already high rates of urbanisation, population growth and inadequate building control in the region.

3. In general, an overall economic mean annual loss of US\$ 74.722 million coupled with a mean annual death toll increasing to a maximum of 71.3 persons can be expected to be instigated by seismic activity across the whole country. Moreover, mean economic losses over 10-, 50- and 100-year return periods are expected to be more than US\$ 147.78 million (0.36 % GDP), US\$ 1.12 billion (2.72 % GDP) and US\$ 2.04 billion (4.94 % GDP). Over the same return periods, the average deaths are likely to increase to 112.8, 1270.2 and 2537.2 persons.
4. The largest disaggregation of the economic losses comes from non-ductile unreinforced masonry building comprising adobe blocks. For instance, the mean annual economic loss for 1-2 storey buildings can increase to a maximum of US\$ 26.5 million. Whilst double storeyed low ductility RC buildings can suffer mean annual economic losses worth US\$ 655000, losses more than US\$ 275000 are estimated for confined masonry buildings. Other building types have lower losses, partly due to their lower likelihood of damage and the fact that they represent a small fraction of Uganda's building stock.
5. Seismic risk in Uganda is not very high and could be easily dealt with via compulsory building insurance such as for fire or a National Insurance Scheme (NIS) that allows for fixed compensation per m<sup>2</sup>. The relevant stakeholders can use the earthquake risk assessment framework presented in this study as a basis for practical seismic risk appraisals in order to aid risk-informed decision making.

### 5.3 Disaster risk reduction and management

The devastating effects of natural hazards on affected communities can cause damaging social and economic impacts, especially due to multi-hazards like earthquakes and landslides where several disruptive events can occur at the same time or successively ([Gupta et al., 2024](#)). In addition to damaging the ecosystem, natural hazards affect the built environment and key infrastructure such as power systems, communication and transport services, education facilities and health-care centres ([Kappes et al., 2012](#); [Koliou et al., 2020](#)). Consequentially, the community's social capital, economy and regional trade can seriously suffer ([Almoghathawi et al., 2021](#); [Behera, 2023](#); [Bhakta Bhandari, 2014](#); [Boin et al., 2018](#); [Panday et al., 2021](#); [Sanyal and Routray, 2016](#); [Savari et al., 2023](#)). Enhancing the resilience of communities to suitably withstand and recover from damages due to such hazardous events is amongst the critical steps towards appropriate disaster risk reduction (DRR) frameworks ([Costa et al., 2021](#); [Cutter et al., 2006](#); [Masaba et al., 2017](#)). The concept of community resilience is defined as the ability of the affected communities to adapt and continue with operations during and after hazardous events ([Bruneau et al., 2003](#)).

At a national policy level, the formulation and implementation of appropriate mitigation strategies for reducing damages largely depend on the associated risks, budgetary constrictions, community values and implementation timelines (Gupta et al., 2024; Nozhati et al., 2020). Improving a community's capabilities of responding to natural hazards requires an objective quantification of DRR strategies prior to their application (Nofal et al., 2021; Shane Crawford et al., 2022; Sutley et al., 2017). In this regard, suitable community resilience planning ought to properly consider multi-objective optimisation of the built as well as the natural and socio-economic environments (Dessavre et al., 2016; Hosseini et al., 2016; Karakoc et al., 2019); without ignoring the interplay between social resources and physical infrastructure (Davidson et al., 2022; Zeballos-Velarde et al., 2023). To boost community resilience and substantially reduce the associated risks, robust decision support systems for earthquake and landslide hazards should be inaugurated. Such suitable decision support systems involve exploration of the associated risk under current conditions, applying “*what-if* scenarios” to evaluate DRR alternatives, and generating DRR plans using models that assess the most viable and optimal solutions (Frangopol and Bocchini, 2011; Gomez and Baker, 2019; Kameshwar et al., 2019; Kappes et al., 2012; Newman et al., 2017). Additional descriptions of multi-objective natural hazard optimization models for short- and long-term mitigation strategies, towards building community resilience can be found in literature (e.g. Gupta et al., 2022; Wen, 2021 and Zhang and Nicholson, 2016).

### 5.3.1 National Policy for Disaster Preparedness and Management, NPDPM (2010)

The increasing frequency of natural hazards such as landslides and earthquakes can potentially wreak havoc and retard the efforts towards achieving sustainable growth and development in the fragile mountainous ecosystems of Uganda (Barasa et al., 2022). In response to the upsurge in natural-hazard-induced disasters across the country, the government published the National Policy for Disaster Preparedness and Management (NPDPM, 2010). The policy largely points towards the urgent need for disaster policy reforms, resettlement plans, land use planning, early warning systems and budgetary allocations. The overall goal of the NPDPM (2010) is to promote national vulnerability appraisals, risk mitigation, disaster prevention and preparedness, response and recovery mechanisms in a way that integrates DRR and disaster risk management (DRM) with the general development plans and programs of the country. The mission of the NPDPM (2010), whose implementation mandate falls under Ministry of Relief, Disaster Preparedness and Management (MRDPM)<sup>2</sup> in the Office of the Prime Minister (OPM), is to minimise vulnerability levels of Uganda's population against natural and human-induced hazards

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<sup>2</sup> The Ministry of Disaster Preparedness and Refugees, a cabinet-level Uganda government ministry, is responsible for national preparedness for disasters, including floods, landslides, earthquakes, droughts, and famine. The ministry is also mandated to coordinate all refugee matters in the country.

by creating an integrated and multi-sectoral approach to disaster planning, preparedness and management. The policy focusses on building the capacity of Uganda's disaster-prone communities towards minimising serious social and economic disruptions during disasters. Within the [NPDPM \(2010\)](#), earthquakes and landslides are recognised amongst the major hazards and their DRR/DRM policy actions include:

*“gazetting, prohibiting settlement and resettling persons living in landslide and/or mudslide-prone zones; restoration of vegetation cover and afforestation; applying suitable farming technologies and land use practices; enforcing relevant laws and policies; mapping out earthquake-prone areas; developing and ensuring adherence to earthquake resistant building codes and regulations; education towards increasing public awareness on disaster preparedness; acquiring technology for monitoring and recording earthquakes; undertaking geology, tectonic and seismogenic investigations; and promoting seismic safety activities”.*

Following the recommendations indicated in the [NPDPM \(2010\)](#), the recent national risk and vulnerability atlas of Uganda ([OPM, 2019](#)) emphasises some key structural and non-structural actions, purposes and tools (annexed in Appendix F) for identifying and designing robust DRR/DRM action plans towards mitigating the adverse impacts of natural hazards in the country. The combined activities that the government inaugurated towards increasing community resilience in Uganda broadly encompass policy and planning measures, implemented at national and sub-national levels, which fundamentally seek to integrate DRR into the wider growth and development framework for the country. On the other hand, physical strategies are essentially designed to reduce the exposure and vulnerability of the population and infrastructure to natural hazards in addition to providing effective and efficient recovery mechanisms.

### 5.3.2 Recommendations for DRR/DRM in Uganda

Although implementation of DRR/DRM policy actions stipulated in the [NPDPM \(2010\)](#) has over the years been hampered by several challenges, especially those emphasised in the country's national risk and vulnerability atlas ([OPM, 2019](#)), the present study makes the following recommendations towards a more robust implementation plan of DRR/DRM actions:

1. Strengthening public awareness of disaster risks is critical and this should be achieved through promoting risk education, universal access to disaster risk information, building social demand for DRR/DRM and encouraging individual safety and public responsibility. More specifically, an information campaign for seismic and landslide awareness through the preparation of videos and maps based on the findings of the present

- study is proposed. On the other hand, a participatory approach is critical for local communities to adopt DRR/DRM measures that fully or partially change their lifestyle.
2. The government and its relevant stakeholders should produce emergency plans for scenario-based earthquake and landslide disasters that can be assessed following the framework developed in the present study. For example, for the strongest possible seismic event in the western part of the country (e.g., Fort Portal city), the number of buildings likely to be damaged and require immediate inspections, number of people required to stay away from buildings and number provisions to be made for temporary accommodation, water and food should be established. In addition, the number of people likely to be injured and the number of field hospitals equipped with beds to be deployed within 24 hours can also be determined based on the framework presented in this study.
  3. Regarding landslide risk across the country, the use of Green-Yellow-Red zonation is encouraged throughout the country for determining whether landslide evaluation is necessary during planning consent for new constructions. The MRDPM under the OPM should undertake robust microzonation and hazard investigations for hazard-prone scenario cities across Uganda.
  4. On the other hand, there is need to instigate adequate plans for efficient and effective coordination of emergency response resources at both local and national levels as well as at the civil and military levels.

## **5.4 Limitations and recommendations for further study**

### **5.4.1 Seismic hazard analysis**

The major limitation of the seismic hazard study was the lack of strong ground motion data required to calibrate GMPEs for the region of interest. Although the model developed in this work relies on GMPEs developed for regions of similar geology and seismo-tectonics, predicting seismic hazard using locally derived GMPEs would in general give more representative results. It is therefore recommended herein that potentially hazardous sites be monitored by installing new stations to record strong ground movement as a prerequisite towards the derivation of suitable GMPEs for Uganda. This will not only aid the calibration of seismic response models based on strong ground motion records (e.g., [Huang and Galasso, 2018](#)), but also become a precursor to microzonation and hazard investigations in scenario cities such as Fort Portal, Hoima and Mbarara. Moreover, completeness analysis of earthquake catalogues was problematic largely due to data deficiencies, especially historical records. Even though statistical techniques were employed to realistically estimate completeness thresholds, the Directorate of Geological Survey and Mines under the MEMD should aim to install and strengthen the seismic networks within the region.

In addition, the lack of sufficient information relating to the country's seismogenic depth potential and active fault characteristics (e.g., rupture lengths, rupture widths and slip rates) which made it impossible to estimate the largest potential earthquakes for regional seismicity representing each areal source using source-scaling relationships was another challenge faced in the present study. Although the maximum earthquake magnitudes are arbitrarily determined by adding a conservative increment of 0.5 magnitude units to the maximum observed magnitudes for each ASZ, future studies should potentially aim to characterise fault segments and comprehensively establish source-scaling relationships in order to derive more accurate calibrated seismicity parameters.

On the other hand, zonation of seismic sources adopted in this study can be further refined to incorporate both background source zones (BSZs) and fault source zones (FSZs) from which additional subjectivity in delineation can be reduced, for instance via the chi-square test method described by [Musson and Winter \(2012\)](#), so as to portray seismicity patterns in the study region in a more viable manner. The last challenge in hazard analysis was the discrepancies between the resolutions of site condition maps and hazard computation grids since the slope-based site classification map used herein comes from very crude estimations. A user with better site-specific data may incorporate them to modify the bedrock hazard values provided in this study.

#### **5.4.2 Co-seismic landslide hazard analysis**

The main limitation of the co-seismic landslide hazard analysis presented in this study was the lack of detailed information and inadequate knowledge relating to landslide occurrences across Uganda. This points to the urgent need for a more robust scheme of monitoring, recording and mapping landslides, especially within the potentially hazardous sites. Despite the challenges and uncertainties involved in predicting future co-seismic and rainfall-induced landslides, fuzzy logic and geospatial modelling techniques were applied to reasonably estimate relative landslide hazard. However, future studies should aim to develop absolute probabilistic co-seismic landslide hazard assessment framework for Uganda (e.g., using physical prediction and Copula modelling techniques).

On the other hand, while landslide risk assessment is not included in this study, integration of the associated co-seismic and rainfall-triggered landslide hazards into the overall earthquake risk assessment (ERA) framework for the country is envisaged as a possible extension of the present study. Moreover, in view of interconnected risks and impacts including systemic risk and resilience as well as multi-hazard risk and community involvement, other secondary hazards (especially volcanism and liquefaction) associated with earthquakes should also be included into the overall ERA framework for Uganda.

### 5.4.3 Earthquake risk assessment

Although seismic risk assessment performed in this study relies on an exposure model which is largely projected and inferred from the national housing and population census data of 2014, the major challenge was that the deficiencies in data especially number of buildings, building types, day- and night-time occupancy rates, and built year or seismic design regulation. This study recommends more elaborate building classification and exposure models supplemented with street surveys (both quick walkthrough and detailed surveys of individual buildings), satellite images and remote street surveys in order to obtain more realistically representative building typologies, as well as proportions and structural characteristics of the building stock. Bearing in mind that the Uganda Bureau of Statistics (UBoS) under Ministry of Finance, Planning and Economic Development (MFPED) is scheduled to conduct a national population and housing census commencing in May 2024, future studies should aim to incorporate more recent statistics into the country's updated exposure model.

Another key limitation in the prediction of seismic risk across Uganda was the scarcity of specific fragility curves, consequence/casualty models, and vulnerability curves developed with holistic considerations of the building stock in Uganda. Although the present study utilised low-code analytical vulnerability curves derived for equivalent SDOF models of various building typologies in various tectonic regimes using non-linear time history analysis, analysing seismic risk using locally derived vulnerability curves would give more representative estimates. In this regard, realistic finite element (FE) models of selected building typologies should be developed considering emblematic deficiencies (e.g., for masonry and adobe construction: slender walls and unsupported gables, weak connections between internal and external walls, absent or insufficient lintels, weak mud mortar, thick and uneven joints, erosion of walls and loss of bricks, and cracks due to differential settlement of foundations; and for RC structures: shear, corrosion, buckling and bond-slip failures, and soft storey) observed within Uganda's building stock. The developed FE models can be validated against experimental data collected from studies performed on similar building types in other developing countries.

For the building categories comprising Uganda's housing stock and following numerical analysis (FE models), fragility curves which satisfactorily reflect the corresponding capacity, demand and limit state uncertainties should be developed using the incremental dynamic analysis. In addition, the influence of deficiencies such as buckling and bond-slip failures on the fragility curves for RC structures should be evaluated. The change in seismic vulnerability over time due to structural deterioration (e.g. corrosion) should be taken into account using an adaptive vulnerability modelling approach. Moreover, special emphasis should be placed on how simplifications in damage indices affect existing fragility curves. Based on expert

knowledge, empirical evidence from earthquake reconnaissance surveys, and experimentally validated analytical models, regression and cross-event analyses should be performed to determine reliable vulnerability relationships. Predictions from such relationships can be validated by comparisons with post-earthquake reconnaissance field data from major destructive earthquakes in Uganda.

#### 5.4.4 Disaster management and community resilience

Considering that mitigation of seismic risk at a national level largely requires the formulation and implementation of appropriate earthquake design codes, a possible extension of the present study is to identify key deficiencies and make recommendations toward performing an in-depth review and update of Uganda's seismic code of practice for structural designs (US 319:2003). Further to aligning US 319:2003 to modern seismic design standards, there is need to explore the use of locally sourced timber as a structural material to develop post-disaster relief housing for the communities living in Uganda's earthquake prone zones. Data on material, element and frame-level tests performed on timber can be collected experimentally and/or from existing literature. An earthquake resistant timber house which suits the social and cultural practices of the communities living in Uganda can be designed and tested under earthquake loads through numerical FE simulations. The design will provide a longer-term sustainable housing solution for people rebuilding their livelihoods after the loss of homes following an earthquake and landslides. Simple guidelines for the design and construction of earthquake resistant non-engineered residential buildings should also be prepared including selection of locally sourced materials, adequate building control and good construction practices. On the other hand, scenario-based analyses (e.g., [Opabola and Galasso, 2024](#)) can be employed to comprehensively re-informed and revised DRR/DRM policies, such as those stipulated in the [NPDPM \(2010\)](#), for specific buildings and critical infrastructure such as hospitals as well as education centres. Finally, gross insurance premiums and a government insurance scheme should be determined for the various types of construction in each region based on the risk level determined in addition to engagement with policy makers and community-level.

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# APPENDICES

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## APPENDIX A: EARTHQUAKE CATALOGUE FOR UGANDA

In PSHA, earthquake catalogues are required to quantify seismicity of a region, determine seismic source zonation, and compute parameters associated with seismicity of the area. Consequently, the first step taken towards performing PSHA is to compile and merge existing historical and instrumental catalogues prior to the refinement process involving earthquake magnitude homogenisation, declustering and completeness analyses. In the acquisition of earthquake data for Uganda used in this study, the area selected shown in Fig I (e.g., search taken from USGS website, 2021: <https://earthquake.usgs.gov/earthquakes/search/>) is used.

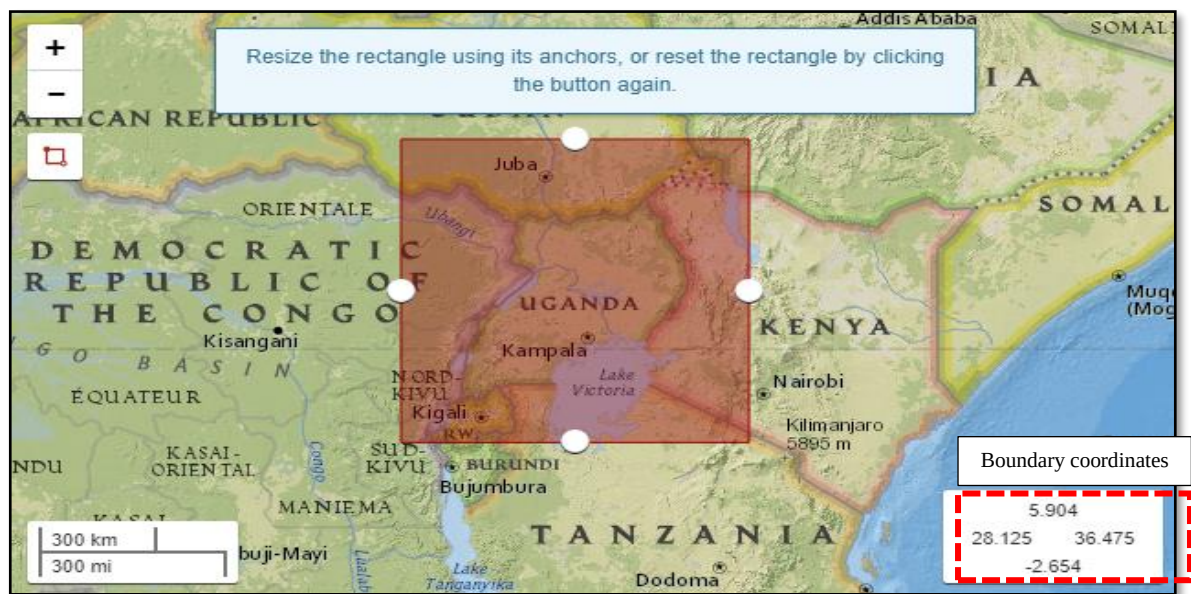


Fig I: Extent of the geographical area used in compiling earthquake catalogue for Uganda

Earthquake catalogues are first obtained from the Directorate of Geological Surveys and Mines, a department under the Ministry of energy and Mineral Resources in Uganda. However, due to the existence of large solution uncertainties e.g., insufficient station coverage and the absence of historical data, additional catalogues are obtained from other credible global agencies/bulletins.. The following sub-sections present earthquake catalogues from the available databases described in Section 2.5.1. These include:

- 1 Appendix A-1: ISC-GEM Catalogue
- 2 Appendix A-2: USGS Catalogue
- 3 Appendix A-3: ISC Reviewed Bulletin
- 4 Appendix A-4: GEM Global Historical Earthquake Archive (GHEA)
- 5 Appendix A-5: DGSM Catalogue
- 6 Appendix A-6: Compilations from Literature Review (Maasha, 1975)

**Appendix A-1: ISC-GEM Catalogue**

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0001    | 1913 | 9     | 16  | 11   | 56     | 31     | 35.9810   | 4.4230   | 10.0  | mw    | 6.06      |
| 0002    | 1915 | 5     | 21  | 4    | 19     | 11     | 32.3240   | 5.6300   | 15.0  | mw    | 6.46      |
| 0003    | 1928 | 1     | 6   | 19   | 31     | 58     | 36.0690   | 0.1130   | 15.0  | mw    | 6.65      |
| 0004    | 1928 | 1     | 10  | 2    | 25     | 38     | 35.5490   | 0.4780   | 10.0  | mw    | 6.2       |
| 0005    | 1945 | 3     | 18  | 8    | 1      | 26     | 31.2890   | -0.2140  | 15.0  | mw    | 6.35      |
| 0006    | 1961 | 11    | 12  | 2    | 15     | 18     | 29.4360   | 0.3750   | 30.0  | mw    | 5.75      |
| 0007    | 1965 | 4     | 25  | 10   | 1      | 11     | 28.9190   | -2.5260  | 15.0  | mw    | 5.31      |
| 0008    | 1966 | 3     | 20  | 1    | 42     | 54     | 29.8630   | 0.6220   | 29.3  | mw    | 6.6       |
| 0009    | 1966 | 3     | 21  | 1    | 30     | 41     | 29.8360   | 0.6890   | 15.0  | mw    | 5.07      |
| 0010    | 1966 | 3     | 21  | 9    | 23     | 52     | 29.9490   | 0.6370   | 15.0  | mw    | 5.31      |
| 0011    | 1966 | 4     | 16  | 14   | 43     | 21     | 29.9150   | 0.7130   | 15.0  | mw    | 5.37      |
| 0012    | 1966 | 5     | 17  | 7    | 3      | 33     | 30.0810   | 0.6530   | 15.0  | mw    | 5.57      |
| 0013    | 1966 | 7     | 31  | 15   | 17     | 19     | 30.0630   | 0.6130   | 15.0  | mw    | 5.26      |
| 0014    | 1966 | 10    | 5   | 8    | 34     | 41     | 29.8410   | 0.0090   | 22.8  | mw    | 5.17      |
| 0015    | 1967 | 11    | 11  | 2    | 28     | 44     | 31.3880   | 2.0130   | 15.0  | mw    | 5.37      |
| 0016    | 1968 | 6     | 29  | 11   | 48     | 19     | 29.2350   | -1.0550  | 15.0  | mw    | 5.35      |
| 0017    | 1972 | 1     | 8   | 17   | 27     | 51     | 30.0940   | 0.5200   | 15.0  | mw    | 5.21      |
| 0018    | 1972 | 4     | 18  | 15   | 8      | 17     | 29.8570   | 0.6100   | 15.0  | mw    | 5.44      |
| 0019    | 1974 | 4     | 25  | 0    | 3      | 48     | 30.0830   | 1.0420   | 10.0  | mw    | 5.04      |
| 0020    | 1977 | 1     | 6   | 18   | 33     | 44     | 28.6960   | -2.5610  | 14.1  | mw    | 5.06      |
| 0021    | 1978 | 10    | 6   | 4    | 12     | 2      | 28.7450   | -1.9610  | 15.0  | mw    | 5.19      |
| 0022    | 1979 | 3     | 9   | 10   | 1      | 20     | 30.5010   | 1.2670   | 25.0  | mw    | 5.25      |
| 0023    | 1979 | 12    | 4   | 7    | 34     | 44     | 31.3590   | 1.6400   | 14.4  | mw    | 5.31      |
| 0024    | 1981 | 3     | 4   | 1    | 58     | 56     | 30.6740   | 1.2200   | 17.6  | mw    | 5.22      |
| 0025    | 1982 | 1     | 9   | 17   | 30     | 28     | 28.3460   | -1.6430  | 19.1  | mw    | 5.43      |
| 0026    | 1983 | 1     | 15  | 16   | 34     | 10     | 30.0770   | 0.4150   | 10.0  | mw    | 5.4       |
| 0027    | 1983 | 9     | 24  | 23   | 26     | 24     | 28.2190   | -1.7870  | 14.0  | mw    | 5.37      |
| 0028    | 1985 | 8     | 20  | 5    | 46     | 4      | 35.9840   | 5.4380   | 15.3  | mw    | 5.39      |
| 0029    | 1990 | 5     | 20  | 2    | 22     | 4      | 32.1810   | 5.1490   | 15.0  | mw    | 7.09      |
| 0030    | 1990 | 5     | 24  | 19   | 34     | 46     | 31.9460   | 5.3650   | 15.0  | mw    | 6.48      |
| 0031    | 1990 | 5     | 24  | 20   | 0      | 10     | 31.8920   | 5.3070   | 15.0  | mw    | 7.06      |
| 0032    | 1990 | 5     | 24  | 22   | 16     | 6      | 31.9500   | 5.4640   | 13.0  | mw    | 5.66      |
| 0033    | 1990 | 5     | 25  | 0    | 42     | 35     | 31.8650   | 5.3430   | 21.2  | mw    | 5.46      |
| 0034    | 1990 | 5     | 26  | 14   | 22     | 44     | 31.7140   | 5.1020   | 15.0  | mw    | 5.33      |
| 0035    | 1990 | 6     | 3   | 16   | 23     | 42     | 32.1680   | 5.3910   | 15.0  | mw    | 5.24      |
| 0036    | 1990 | 7     | 9   | 15   | 11     | 23     | 31.6790   | 5.3670   | 13.2  | mw    | 6.29      |
| 0037    | 1990 | 7     | 28  | 16   | 46     | 4      | 32.6980   | 5.2470   | 10.0  | mw    | 5.33      |
| 0038    | 1990 | 9     | 4   | 1    | 48     | 4      | 29.0320   | -0.4060  | 12.9  | mw    | 5.32      |
| 0039    | 1990 | 9     | 7   | 0    | 12     | 29     | 31.6000   | 5.4100   | 17.8  | mw    | 5.52      |
| 0040    | 1991 | 1     | 10  | 7    | 6      | 28     | 31.7390   | 5.0340   | 12.5  | mw    | 5.41      |
| 0041    | 1991 | 3     | 29  | 9    | 6      | 9      | 32.5830   | 5.2040   | 15.8  | mw    | 5.41      |
| 0042    | 1991 | 10    | 9   | 17   | 22     | 5      | 31.3000   | 1.7280   | 10.0  | mw    | 5.59      |
| 0043    | 1993 | 10    | 18  | 5    | 50     | 16     | 30.2070   | 0.4550   | 14.0  | mw    | 5.18      |
| 0044    | 1994 | 2     | 5   | 23   | 34     | 11     | 30.1780   | 0.4470   | 11.5  | mw    | 6.16      |
| 0045    | 1994 | 8     | 31  | 14   | 59     | 59     | 30.9430   | 1.4770   | 10.0  | mw    | 5.19      |
| 0046    | 1995 | 4     | 29  | 11   | 50     | 55     | 28.5800   | -1.2530  | 10.0  | mw    | 5.29      |
| 0047    | 1996 | 3     | 24  | 8    | 24     | 27     | 29.8000   | 0.4640   | 10.0  | mw    | 5.32      |
| 0048    | 2000 | 3     | 2   | 2    | 44     | 54     | 28.4440   | -2.3360  | 10.0  | mw    | 5.46      |
| 0049    | 2001 | 1     | 31  | 19   | 15     | 32     | 29.4730   | 0.3290   | 26.3  | mw    | 5.17      |
| 0050    | 2001 | 6     | 29  | 23   | 40     | 4      | 30.0900   | 0.1150   | 19.8  | mw    | 5.24      |
| 0051    | 2002 | 1     | 4   | 13   | 2      | 22     | 29.8200   | -0.2450  | 15.3  | mw    | 5.16      |
| 0052    | 2002 | 1     | 17  | 20   | 1      | 30     | 29.2780   | -1.7990  | 10.0  | mw    | 5.13      |
| 0053    | 2002 | 1     | 20  | 0    | 14     | 46     | 29.0830   | -1.7470  | 10.0  | mw    | 5.12      |
| 0054    | 2002 | 1     | 21  | 1    | 19     | 34     | 28.8900   | -1.7380  | 10.0  | mw    | 5.13      |
| 0055    | 2002 | 1     | 21  | 4    | 39     | 24     | 28.9810   | -1.7790  | 10.0  | mw    | 5.09      |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0056    | 2002 | 1     | 21  | 10   | 55     | 5      | 29.1140   | -1.9130  | 10.0  | mw    | 5.17      |
| 0057    | 2002 | 1     | 22  | 15   | 32     | 7      | 29.1530   | -1.6590  | 10.0  | mw    | 5.19      |
| 0058    | 2002 | 10    | 24  | 6    | 8      | 39     | 28.9800   | -2.0020  | 11.0  | mw    | 6.16      |
| 0059    | 2002 | 10    | 24  | 7    | 12     | 20     | 28.8840   | -1.9150  | 11.0  | mw    | 5.75      |
| 0060    | 2002 | 10    | 24  | 8    | 3      | 17     | 28.9680   | -2.0780  | 10.0  | mw    | 5.15      |
| 0061    | 2002 | 12    | 23  | 2    | 50     | 40     | 34.9710   | -1.8680  | 10.0  | mw    | 5.18      |
| 0062    | 2003 | 3     | 20  | 6    | 15     | 22     | 29.6170   | -2.4540  | 10.0  | mw    | 5.19      |
| 0063    | 2003 | 8     | 5   | 18   | 56     | 54     | 29.4180   | -0.7330  | 20.0  | mw    | 5.21      |
| 0064    | 2006 | 4     | 27  | 4    | 18     | 30     | 30.0200   | 0.3520   | 18.8  | mw    | 5.24      |
| 0065    | 2007 | 2     | 19  | 2    | 33     | 44     | 30.8410   | 1.7640   | 25.0  | mw    | 5.61      |
| 0066    | 2007 | 6     | 15  | 18   | 49     | 53     | 30.7480   | 1.7270   | 23.0  | mw    | 5.85      |
| 0067    | 2008 | 2     | 3   | 7    | 34     | 12     | 28.8930   | -2.3370  | 10.0  | mw    | 5.94      |
| 0068    | 2008 | 2     | 3   | 10   | 56     | 10     | 29.0380   | -2.3960  | 10.0  | mw    | 5         |
| 0069    | 2008 | 2     | 14  | 2    | 7      | 48     | 28.9200   | -2.3850  | 15.0  | mw    | 5.26      |
| 0070    | 2008 | 10    | 5   | 0    | 2      | 13     | 29.1350   | -1.1980  | 7.8   | mw    | 5.28      |
| 0071    | 2010 | 6     | 13  | 12   | 13     | 24     | 34.5790   | -0.2160  | 10.0  | mw    | 5.01      |
| 0072    | 2010 | 10    | 23  | 11   | 8      | 22     | 36.0570   | 4.7760   | 10.0  | mw    | 5         |
| 0073    | 2011 | 3     | 15  | 3    | 25     | 21     | 31.1600   | 1.7150   | 22.5  | mw    | 5.01      |
| 0074    | 2012 | 1     | 22  | 21   | 3      | 36     | 36.1190   | 3.7300   | 10.0  | mw    | 5.12      |
| 0075    | 2012 | 11    | 20  | 16   | 23     | 50     | 29.9080   | -0.3790  | 20.7  | mw    | 5.13      |
| 0076    | 2013 | 4     | 20  | 0    | 30     | 29     | 30.7950   | 1.5100   | 20.5  | mw    | 5.15      |
| 0077    | 2013 | 7     | 2   | 13   | 33     | 18     | 30.9090   | 1.5670   | 15.0  | mw    | 5.04      |
| 0078    | 2013 | 7     | 3   | 19   | 21     | 47     | 30.8590   | 1.5750   | 17.9  | mw    | 5.69      |
| 0079    | 2013 | 7     | 3   | 22   | 22     | 20     | 30.8260   | 1.5710   | 17.5  | mw    | 5.16      |
| 0080    | 2015 | 8     | 7   | 1    | 25     | 2      | 28.8770   | -2.1020  | 12.6  | mw    | 5.78      |
| 0081    | 2015 | 8     | 7   | 1    | 28     | 37     | 28.9240   | -2.0960  | 15.0  | mw    | 5.55      |
| 0082    | 2016 | 9     | 10  | 12   | 27     | 30     | 31.5490   | -1.0590  | 21.8  | mw    | 5.88      |
| 0083    | 2017 | 7     | 30  | 7    | 2      | 30     | 29.7670   | -0.2180  | 16.9  | mw    | 5.36      |
| 0084    | 2017 | 11    | 30  | 21   | 48     | 35     | 28.8340   | -2.5530  | 7.1   | mw    | 4.97      |

## Appendix A-2: USGS Catalogue

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0085    | 1912 | 7     | 9   | 8    | 18     | 14.36  | 32.3470   | 3.1560   | 10    | mw    | 6.1       |
| 0086    | 1913 | 9     | 16  | 11   | 56     | 31.42  | 35.9810   | 4.4230   | 10    | mw    | 6.06      |
| 0087    | 1915 | 5     | 21  | 4    | 19     | 10.66  | 32.3240   | 5.6300   | 15    | mw    | 6.46      |
| 0088    | 1928 | 1     | 6   | 19   | 31     | 57.69  | 36.0690   | 0.1130   | 15    | mw    | 6.65      |
| 0089    | 1928 | 1     | 10  | 2    | 25     | 38.05  | 35.5490   | 0.4780   | 10    | mw    | 6.2       |
| 0090    | 1945 | 3     | 18  | 8    | 1      | 25.64  | 31.2890   | -0.2140  | 15    | mw    | 6.35      |
| 0091    | 1952 | 6     | 30  | 21   | 4      | 30.87  | 29.9140   | -0.3600  | 15    | mw    | 6.45      |
| 0092    | 1961 | 11    | 12  | 2    | 15     | 18.48  | 29.4360   | 0.3750   | 30    | mw    | 5.75      |
| 0093    | 1965 | 4     | 25  | 10   | 1      | 10.73  | 28.9190   | -2.5260  | 15    | mw    | 5.31      |
| 0094    | 1966 | 3     | 20  | 1    | 42     | 53.71  | 29.8630   | 0.6220   | 29.3  | mw    | 6.6       |
| 0095    | 1966 | 3     | 21  | 1    | 30     | 40.88  | 29.8360   | 0.6890   | 15    | mw    | 5.07      |
| 0096    | 1966 | 3     | 21  | 9    | 23     | 52.36  | 29.9490   | 0.6370   | 15    | mw    | 5.31      |
| 0097    | 1966 | 4     | 16  | 14   | 43     | 20.6   | 29.9150   | 0.7130   | 15    | mw    | 5.37      |
| 0098    | 1966 | 5     | 17  | 7    | 3      | 32.55  | 30.0810   | 0.6530   | 15    | mw    | 5.57      |
| 0099    | 1966 | 7     | 31  | 15   | 17     | 18.76  | 30.0630   | 0.6130   | 15    | mw    | 5.26      |
| 0100    | 1966 | 10    | 5   | 8    | 34     | 41.3   | 29.8410   | 0.0090   | 22.8  | mw    | 5.17      |
| 0101    | 1967 | 11    | 11  | 2    | 28     | 44.09  | 31.3880   | 2.0130   | 15    | mw    | 5.37      |
| 0102    | 1968 | 6     | 29  | 11   | 48     | 18.77  | 29.2350   | -1.0550  | 15    | mw    | 5.35      |
| 0103    | 1972 | 1     | 8   | 17   | 27     | 51.26  | 30.0940   | 0.5200   | 15    | mw    | 5.21      |
| 0104    | 1972 | 4     | 18  | 15   | 8      | 16.93  | 29.8570   | 0.6100   | 15    | mw    | 5.44      |
| 0105    | 1973 | 4     | 22  | 22   | 3      | 43.5   | 31.1750   | 3.9160   | 33    | mb    | 4.9       |
| 0106    | 1973 | 12    | 1   | 16   | 51     | 14     | 29.5170   | 0.6470   | 15    | mb    | 4.8       |
| 0107    | 1974 | 4     | 25  | 0    | 3      | 49.1   | 30.0910   | 0.9950   | 33    | mb    | 5         |
| 0108    | 1977 | 1     | 6   | 18   | 33     | 43.5   | 28.7020   | -2.5090  | 21    | mb    | 5.3       |
| 0109    | 1977 | 1     | 14  | 2    | 52     | 34.7   | 28.9480   | -1.7100  | 33    | mb    | 4.8       |
| 0110    | 1977 | 4     | 14  | 14   | 36     | 23.4   | 28.9400   | -2.4560  | 33    | mb    | 5.2       |
| 0111    | 1977 | 12    | 28  | 18   | 29     | 46.9   | 31.1550   | 2.0300   | 33    | mb    | 5.2       |
| 0112    | 1977 | 12    | 29  | 11   | 50     | 38     | 29.6830   | 0.0130   | 33    | ms    | 5.4       |
| 0113    | 1978 | 5     | 23  | 9    | 2      | 37.1   | 36.1130   | 3.0040   | 10    | mb    | 4.6       |
| 0114    | 1978 | 10    | 6   | 4    | 12     | 2.4    | 28.9700   | -1.9610  | 33    | mb    | 4.9       |
| 0115    | 1979 | 2     | 26  | 4    | 40     | 35.9   | 30.9360   | 1.8580   | 10    | mb    | 4.9       |
| 0116    | 1979 | 3     | 9   | 10   | 1      | 18.7   | 30.5670   | 1.2520   | 35    | mb    | 5         |
| 0117    | 1979 | 12    | 4   | 7    | 34     | 44.8   | 31.2940   | 1.7540   | 33    | ms    | 5         |
| 0118    | 1980 | 9     | 26  | 7    | 45     | 51.2   | 30.0580   | 1.2250   | 33    | mb    | 4.1       |
| 0119    | 1981 | 3     | 4   | 1    | 58     | 55.82  | 30.5320   | 1.3920   | 33    | mb    | 4.8       |
| 0120    | 1982 | 1     | 9   | 17   | 30     | 27.1   | 28.3380   | -1.6710  | 33    | mb    | 5         |
| 0121    | 1982 | 7     | 24  | 3    | 51     | 41.62  | 30.1070   | 1.2200   | 10    | mb    | 4.5       |
| 0122    | 1982 | 10    | 15  | 8    | 37     | 53.76  | 31.7330   | 4.6670   | 10    | mb    | 5.1       |
| 0123    | 1983 | 1     | 15  | 16   | 34     | 7.88   | 30.1990   | 0.5130   | 10    | mb    | 5.2       |
| 0124    | 1983 | 9     | 24  | 23   | 26     | 21.64  | 28.3810   | -1.5630  | 10    | mb    | 5.2       |
| 0125    | 1984 | 7     | 17  | 9    | 23     | 50.2   | 29.6980   | -0.1900  | 5     | mb    | 4.7       |
| 0126    | 1985 | 6     | 28  | 22   | 46     | 19.8   | 28.9110   | -2.4650  | 10    | mw    | 5         |
| 0127    | 1985 | 8     | 20  | 5    | 46     | 0.47   | 36.1430   | 5.5180   | 10    | mw    | 5.4       |
| 0128    | 1985 | 12    | 18  | 2    | 15     | 34.5   | 33.1990   | 4.6950   | 10    | mb    | 4.3       |
| 0129    | 1986 | 3     | 23  | 15   | 26     | 46.9   | 30.2800   | 0.5150   | 10    | mb    | 4.7       |
| 0130    | 1986 | 6     | 28  | 17   | 3      | 45.91  | 34.0260   | -0.9590  | 10    | mb    | 4.2       |
| 0131    | 1986 | 7     | 20  | 20   | 5      | 5.37   | 29.8960   | 1.0770   | 10    | mb    | 4.4       |
| 0132    | 1987 | 1     | 16  | 19   | 40     | 3.36   | 28.7670   | -1.5810  | 10    | mb    | 4.8       |
| 0133    | 1987 | 10    | 9   | 3    | 49     | 17.67  | 35.9980   | 5.4700   | 10    | mb    | 4.7       |
| 0134    | 1988 | 1     | 2   | 9    | 5      | 52.21  | 30.1490   | 0.4820   | 10    | m     | 4.6       |
| 0135    | 1988 | 4     | 30  | 16   | 25     | 5.44   | 35.4000   | 4.7940   | 10    | mb    | 4.2       |
| 0136    | 1988 | 5     | 1   | 10   | 20     | 20.67  | 31.8360   | -2.5400  | 33    | mb    | 4         |
| 0137    | 1988 | 5     | 7   | 5    | 5      | 33.93  | 30.0060   | -0.4670  | 10    | mb    | 4.5       |
| 0138    | 1989 | 1     | 5   | 5    | 8      | 14.86  | 29.9620   | 0.2290   | 10    | mb    | 4.8       |
| 0139    | 1990 | 5     | 20  | 2    | 22     | 1.62   | 32.1450   | 5.1210   | 14.9  | mw    | 7.2       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0140    | 1990 | 5     | 20  | 6    | 41     | 23.48  | 32.1790   | 4.5410   | 10    | mb    | 4.6       |
| 0141    | 1990 | 5     | 20  | 19   | 30     | 44.5   | 31.9760   | 5.1430   | 10    | mb    | 4.5       |
| 0142    | 1990 | 5     | 23  | 12   | 26     | 49.73  | 31.6810   | 5.4940   | 10    | mb    | 4.9       |
| 0143    | 1990 | 5     | 24  | 19   | 34     | 44.24  | 31.8290   | 5.2770   | 16.5  | mw    | 6.5       |
| 0144    | 1990 | 5     | 24  | 20   | 0      | 8.19   | 31.8480   | 5.3580   | 16    | mw    | 7.1       |
| 0145    | 1990 | 5     | 24  | 22   | 16     | 3.38   | 31.8760   | 5.4360   | 10    | mb    | 5.5       |
| 0146    | 1990 | 5     | 25  | 0    | 42     | 31.97  | 31.8480   | 5.4250   | 10    | mb    | 5.3       |
| 0147    | 1990 | 5     | 25  | 2    | 49     | 2.32   | 31.3280   | 5.3580   | 10    | mb    | 4.8       |
| 0148    | 1990 | 5     | 25  | 6    | 12     | 44.88  | 31.4900   | 4.4900   | 10    | mb    | 4.8       |
| 0149    | 1990 | 5     | 25  | 15   | 14     | 3.94   | 31.7630   | 5.3750   | 10    | mb    | 4.7       |
| 0150    | 1990 | 5     | 26  | 5    | 53     | 50.6   | 32.0440   | 5.3210   | 10    | mb    | 4.8       |
| 0151    | 1990 | 5     | 26  | 14   | 22     | 40.89  | 31.7690   | 5.1340   | 10    | mb    | 5         |
| 0152    | 1990 | 5     | 26  | 14   | 39     | 51.57  | 33.6380   | 4.8350   | 10    | mb    | 4.6       |
| 0153    | 1990 | 5     | 27  | 7    | 29     | 32.64  | 31.7430   | 4.8040   | 10    | mb    | 5         |
| 0154    | 1990 | 5     | 28  | 1    | 11     | 57.21  | 31.8470   | 5.4620   | 10    | mb    | 4.8       |
| 0155    | 1990 | 5     | 29  | 4    | 37     | 29.8   | 32.5680   | 5.4670   | 10    | mb    | 4.7       |
| 0156    | 1990 | 6     | 2   | 20   | 7      | 23.52  | 31.2410   | 5.3600   | 10    | mb    | 4.4       |
| 0157    | 1990 | 6     | 3   | 12   | 49     | 43.96  | 32.3360   | 2.1930   | 10    | mb    | 4.7       |
| 0158    | 1990 | 6     | 3   | 16   | 23     | 39.14  | 32.1210   | 5.4420   | 10    | mb    | 5.1       |
| 0159    | 1990 | 6     | 3   | 20   | 41     | 52.28  | 31.8630   | 4.6200   | 10    | mb    | 4.6       |
| 0160    | 1990 | 6     | 9   | 8    | 6      | 3.39   | 32.0220   | 5.4450   | 10    | mb    | 4.7       |
| 0161    | 1990 | 6     | 16  | 3    | 47     | 59.68  | 31.8630   | 5.4740   | 10    | mb    | 4.1       |
| 0162    | 1990 | 6     | 18  | 10   | 12     | 4.63   | 31.9940   | 4.9430   | 10    | mb    | 4.5       |
| 0163    | 1990 | 6     | 20  | 18   | 47     | 58.95  | 31.7170   | 5.4120   | 15.6  | mb    | 5         |
| 0164    | 1990 | 7     | 7   | 18   | 42     | 7.89   | 31.4550   | 5.1850   | 10    | mb    | 4.1       |
| 0165    | 1990 | 7     | 8   | 2    | 29     | 23.73  | 31.8690   | 5.3060   | 10    | mb    | 4.4       |
| 0166    | 1990 | 7     | 9   | 15   | 11     | 20.38  | 31.6540   | 5.3950   | 12.6  | mw    | 6.6       |
| 0167    | 1990 | 7     | 15  | 15   | 8      | 28.38  | 32.1880   | 5.0020   | 10    | mb    | 4.5       |
| 0168    | 1990 | 7     | 19  | 17   | 6      | 7.64   | 31.5440   | 4.2560   | 10    | mb    | 4.6       |
| 0169    | 1990 | 7     | 27  | 20   | 41     | 31.09  | 32.0780   | 5.0720   | 10    | mb    | 4.8       |
| 0170    | 1990 | 7     | 28  | 6    | 54     | 45.65  | 32.1090   | 5.2920   | 10    | mb    | 4.3       |
| 0171    | 1990 | 7     | 28  | 16   | 46     | 2.7    | 32.6040   | 5.2250   | 10    | mw    | 5.4       |
| 0172    | 1990 | 7     | 28  | 17   | 17     | 33.39  | 32.3330   | 5.2340   | 10    | mb    | 4.4       |
| 0173    | 1990 | 7     | 29  | 7    | 48     | 40.16  | 31.9370   | 1.2850   | 10    | mb    | 4.3       |
| 0174    | 1990 | 8     | 11  | 2    | 34     | 22.27  | 33.1180   | 0.1650   | 33    | mb    | 4.5       |
| 0175    | 1990 | 8     | 13  | 2    | 47     | 4.5    | 31.8820   | 5.3350   | 10    | mb    | 4.7       |
| 0176    | 1990 | 9     | 4   | 1    | 48     | 0.76   | 29.0850   | -0.4790  | 10    | mw    | 5.4       |
| 0177    | 1990 | 9     | 7   | 0    | 12     | 26.21  | 31.6860   | 5.4430   | 10    | mw    | 5.6       |
| 0178    | 1990 | 9     | 29  | 1    | 23     | 44.66  | 31.9730   | 5.0920   | 10    | mb    | 4.5       |
| 0179    | 1990 | 12    | 11  | 5    | 9      | 8.58   | 32.6390   | 5.3500   | 10    | mb    | 5         |
| 0180    | 1990 | 12    | 15  | 20   | 56     | 51.3   | 29.5290   | 0.1800   | 18.2  | mb    | 4.7       |
| 0181    | 1990 | 12    | 20  | 18   | 37     | 44.19  | 29.4600   | -0.3180  | 33    | mb    | 4.5       |
| 0182    | 1991 | 1     | 5   | 15   | 47     | 49.16  | 32.0800   | 5.1400   | 33    | mb    | 4.9       |
| 0183    | 1991 | 1     | 8   | 16   | 9      | 30.63  | 32.5410   | 5.3650   | 10    | mb    | 4.8       |
| 0184    | 1991 | 1     | 10  | 7    | 6      | 26.2   | 31.8220   | 5.1140   | 11.4  | mb    | 5.2       |
| 0185    | 1991 | 1     | 31  | 6    | 13     | 10.7   | 32.6060   | 5.3070   | 10    | mb    | 4.6       |
| 0186    | 1991 | 2     | 3   | 14   | 46     | 43.64  | 32.4870   | 5.3620   | 10    | mb    | 4.6       |
| 0187    | 1991 | 2     | 9   | 8    | 45     | 55.4   | 32.4660   | 5.1960   | 10    | mb    | 4.8       |
| 0188    | 1991 | 2     | 24  | 19   | 31     | 53.14  | 28.7720   | -1.6800  | 10    | mb    | 4.6       |
| 0189    | 1991 | 3     | 15  | 8    | 22     | 54.15  | 32.3010   | 5.7150   | 10    | mb    | 4.8       |
| 0190    | 1991 | 3     | 27  | 11   | 54     | 24.31  | 31.9670   | 5.5660   | 10    | ms    | 4.5       |
| 0191    | 1991 | 3     | 29  | 9    | 6      | 6.44   | 32.6720   | 5.2100   | 10    | mw    | 5.4       |
| 0192    | 1991 | 3     | 29  | 16   | 54     | 31.26  | 32.9510   | 5.4050   | 10    | mb    | 4.8       |
| 0193    | 1991 | 5     | 9   | 17   | 0      | 40.24  | 31.5900   | 5.1290   | 10    | mb    | 4.8       |
| 0194    | 1991 | 7     | 16  | 7    | 28     | 42.65  | 29.8870   | 0.6440   | 33    | mb    | 4.1       |
| 0195    | 1991 | 9     | 6   | 16   | 8      | 34.25  | 32.1550   | 5.3410   | 10    | ms    | 4.9       |
| 0196    | 1991 | 9     | 8   | 7    | 49     | 13.24  | 31.8980   | 5.2260   | 10    | mb    | 4.5       |
| 0197    | 1991 | 10    | 9   | 17   | 22     | 5.4    | 31.2930   | 1.8040   | 33    | mw    | 5.6       |
| 0198    | 1992 | 3     | 1   | 11   | 15     | 12.4   | 29.1440   | -2.2390  | 10    | mb    | 4.5       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0199    | 1992 | 3     | 2   | 20   | 30     | 42.57  | 31.5780   | 5.2190   | 10    | mb    | 4.7       |
| 0200    | 1992 | 10    | 12  | 23   | 42     | 9.29   | 32.0210   | 5.0170   | 33    | mb    | 4.6       |
| 0201    | 1992 | 10    | 13  | 16   | 22     | 11.76  | 32.1080   | 4.7930   | 33    | mb    | 4.7       |
| 0202    | 1993 | 9     | 28  | 22   | 30     | 49.77  | 28.6020   | -2.5260  | 10    | mb    | 4.9       |
| 0203    | 1993 | 10    | 18  | 5    | 50     | 17.43  | 30.2150   | 0.6330   | 33    | mb    | 4.9       |
| 0204    | 1993 | 12    | 4   | 18   | 45     | 15.08  | 32.0910   | 5.4690   | 10    | mb    | 4.2       |
| 0205    | 1994 | 2     | 5   | 23   | 34     | 9.97   | 30.0370   | 0.5930   | 14.2  | mwb   | 6.2       |
| 0206    | 1994 | 2     | 7   | 1    | 32     | 14.69  | 30.1360   | 0.6110   | 10    | mb    | 4.3       |
| 0207    | 1994 | 2     | 8   | 10   | 16     | 25.12  | 30.2700   | 0.6550   | 33    | mb    | 4.4       |
| 0208    | 1994 | 3     | 9   | 8    | 25     | 5.58   | 29.7950   | -1.8030  | 33    | mb    | 4.8       |
| 0209    | 1994 | 3     | 20  | 2    | 12     | 35.12  | 30.1700   | 0.4620   | 19.4  | mb    | 4.9       |
| 0210    | 1994 | 3     | 29  | 22   | 59     | 21.19  | 30.1660   | 0.4870   | 10    | mb    | 4.5       |
| 0211    | 1994 | 5     | 22  | 0    | 50     | 20.28  | 29.9280   | 0.0110   | 10    | mb    | 4.6       |
| 0212    | 1994 | 8     | 22  | 19   | 56     | 50.19  | 35.0340   | 4.5250   | 10    | mb    | 4.7       |
| 0213    | 1994 | 8     | 31  | 14   | 59     | 56.9   | 31.0020   | 1.6030   | 10    | mb    | 5         |
| 0214    | 1995 | 4     | 29  | 11   | 50     | 52.56  | 28.6050   | -1.3150  | 10    | mb    | 5.1       |
| 0215    | 1995 | 5     | 26  | 11   | 29     | 7.7    | 30.5380   | 0.7690   | 10    | mb    | 4.5       |
| 0216    | 1995 | 8     | 26  | 14   | 27     | 47.51  | 31.3540   | 2.0730   | 33    | mb    | 4         |
| 0217    | 1996 | 3     | 24  | 8    | 24     | 24.37  | 30.1690   | 0.5650   | 10    | mwc   | 5.4       |
| 0218    | 1996 | 4     | 2   | 1    | 17     | 5.34   | 35.9450   | 3.0840   | 10    | mb    | 4.3       |
| 0219    | 1996 | 4     | 3   | 3    | 37     | 13.19  | 35.9400   | 3.1260   | 10    | mb    | 4.5       |
| 0220    | 1996 | 12    | 23  | 12   | 16     | 0.19   | 30.2870   | 1.2680   | 33    | mb    | 4.4       |
| 0221    | 1997 | 5     | 27  | 16   | 41     | 3.1    | 31.6040   | 2.5040   | 10    | mb    | 4.8       |
| 0222    | 1997 | 6     | 16  | 23   | 16     | 54.09  | 31.3690   | 2.3170   | 10    | mb    | 4.5       |
| 0223    | 1997 | 7     | 18  | 1    | 45     | 12.36  | 31.6090   | 2.4480   | 10    | mb    | 4.7       |
| 0224    | 1997 | 7     | 18  | 2    | 44     | 24.72  | 31.5610   | 2.3280   | 10    | mb    | 4.6       |
| 0225    | 1997 | 7     | 18  | 2    | 50     | 2.42   | 31.4910   | 2.4840   | 10    | mb    | 4.7       |
| 0226    | 1997 | 7     | 18  | 3    | 17     | 24.11  | 31.5700   | 2.3490   | 10    | mb    | 4.8       |
| 0227    | 1997 | 7     | 19  | 13   | 45     | 19.47  | 31.7230   | 2.5160   | 33    | mb    | 4.7       |
| 0228    | 1997 | 7     | 19  | 14   | 21     | 37.58  | 31.4120   | 2.1770   | 33    | mb    | 4.6       |
| 0229    | 1998 | 2     | 22  | 17   | 19     | 56.9   | 29.3230   | 0.5210   | 10    | mb    | 4.5       |
| 0230    | 1998 | 8     | 15  | 5    | 41     | 24.76  | 30.0480   | 0.9460   | 10    | mb    | 4.7       |
| 0231    | 1998 | 8     | 15  | 14   | 57     | 28.21  | 29.8410   | 1.2110   | 10    | mb    | 4.7       |
| 0232    | 1998 | 8     | 15  | 15   | 57     | 45.61  | 30.0510   | 1.8680   | 10    | mb    | 4.6       |
| 0233    | 1998 | 8     | 15  | 16   | 16     | 46.68  | 30.1680   | 0.3210   | 10    | mb    | 4.4       |
| 0234    | 1998 | 8     | 15  | 17   | 29     | 16.55  | 29.9560   | 0.7520   | 10    | mb    | 4.8       |
| 0235    | 1998 | 8     | 16  | 4    | 47     | 40.25  | 29.8990   | 0.8750   | 10    | mb    | 4.7       |
| 0236    | 1998 | 10    | 18  | 12   | 58     | 26.15  | 30.0170   | 0.8320   | 10    | mb    | 4.3       |
| 0237    | 1999 | 1     | 22  | 22   | 48     | 0.73   | 32.3250   | 4.9240   | 10    | mb    | 4.3       |
| 0238    | 1999 | 4     | 4   | 17   | 49     | 54.32  | 29.3980   | 0.5380   | 10    | mb    | 4.6       |
| 0239    | 2000 | 5     | 15  | 8    | 33     | 4.78   | 36.2280   | 5.6180   | 33    | mb    | 4.5       |
| 0240    | 2000 | 9     | 12  | 16   | 51     | 17.53  | 28.7390   | -2.2650  | 10    | mb    | 4.6       |
| 0241    | 2000 | 10    | 5   | 10   | 8      | 24.02  | 28.7100   | -1.1520  | 10    | mb    | 4.5       |
| 0242    | 2000 | 10    | 23  | 12   | 2      | 12.95  | 30.5920   | 1.5080   | 21.2  | mb    | 4.8       |
| 0243    | 2001 | 1     | 31  | 19   | 15     | 30.35  | 29.4940   | 0.4660   | 27.7  | mb    | 4.9       |
| 0244    | 2001 | 6     | 29  | 23   | 40     | 0.85   | 29.9720   | 0.2920   | 10    | mwc   | 5.3       |
| 0245    | 2001 | 9     | 24  | 1    | 29     | 7.43   | 35.9790   | 0.1040   | 10    | mb    | 4.7       |
| 0246    | 2002 | 1     | 4   | 13   | 2      | 18.85  | 29.7580   | -0.1360  | 10    | mb    | 4.8       |
| 0247    | 2002 | 1     | 17  | 14   | 26     | 59.72  | 29.1520   | -1.6290  | 10    | mb    | 4.3       |
| 0248    | 2002 | 1     | 17  | 20   | 1      | 29.26  | 29.0770   | -1.6840  | 15.4  | mb    | 4.7       |
| 0249    | 2002 | 1     | 18  | 8    | 7      | 57.37  | 29.0310   | -1.5780  | 10    | mb    | 4.2       |
| 0250    | 2002 | 1     | 18  | 15   | 14     | 2.04   | 29.0760   | -1.7800  | 10    | mb    | 4.3       |
| 0251    | 2002 | 1     | 18  | 21   | 8      | 53.32  | 28.8660   | -1.6620  | 10    | mb    | 4.2       |
| 0252    | 2002 | 1     | 19  | 17   | 9      | 29.17  | 29.5790   | -1.9310  | 10    | mb    | 4.6       |
| 0253    | 2002 | 1     | 19  | 20   | 38     | 55.55  | 29.0590   | -1.8790  | 10    | mb    | 4.2       |
| 0254    | 2002 | 1     | 20  | 0    | 14     | 44.39  | 28.9810   | -1.6810  | 10    | mwc   | 5.1       |
| 0255    | 2002 | 1     | 20  | 23   | 28     | 17.47  | 29.0500   | -1.5990  | 10    | mb    | 4.2       |
| 0256    | 2002 | 1     | 21  | 1    | 19     | 32.6   | 28.8540   | -1.7260  | 10    | mb    | 4.6       |
| 0257    | 2002 | 1     | 21  | 2    | 0      | 14     | 28.9410   | -1.5050  | 10    | mb    | 4.2       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0258    | 2002 | 1     | 21  | 4    | 39     | 21.62  | 29.0410   | -1.7760  | 10    | mwc   | 5.1       |
| 0259    | 2002 | 1     | 21  | 10   | 55     | 3.72   | 29.1170   | -1.9030  | 10    | mb    | 4.7       |
| 0260    | 2002 | 1     | 22  | 1    | 2      | 32.25  | 28.9710   | -1.7870  | 10    | mb    | 4         |
| 0261    | 2002 | 1     | 22  | 15   | 32     | 5.59   | 28.9930   | -1.5150  | 10    | mwc   | 5.2       |
| 0262    | 2002 | 1     | 22  | 16   | 22     | 22.34  | 28.9950   | -1.5510  | 10    | mb    | 4.4       |
| 0263    | 2002 | 1     | 22  | 16   | 51     | 0.38   | 29.2490   | -1.4610  | 10    | mb    | 4.2       |
| 0264    | 2002 | 1     | 27  | 13   | 42     | 43.74  | 29.7160   | 0.7750   | 10    | mb    | 4.7       |
| 0265    | 2002 | 1     | 30  | 0    | 33     | 9.14   | 28.8860   | -1.6330  | 10    | mblg  | 4.6       |
| 0266    | 2002 | 2     | 11  | 13   | 49     | 26.12  | 29.0100   | -1.3860  | 10    | mb    | 4.4       |
| 0267    | 2002 | 8     | 10  | 16   | 18     | 51.97  | 32.3580   | 3.3220   | 10    | mb    | 4         |
| 0268    | 2002 | 9     | 9   | 14   | 13     | 27.93  | 28.8670   | -2.5670  | 10    | mb    | 4.5       |
| 0269    | 2002 | 10    | 24  | 6    | 8      | 37.98  | 29.0040   | -1.8840  | 11    | mwc   | 6.2       |
| 0270    | 2002 | 10    | 24  | 7    | 12     | 18.4   | 28.9790   | -1.8220  | 10    | ms    | 5.5       |
| 0271    | 2002 | 10    | 24  | 8    | 3      | 15.81  | 29.0140   | -2.0130  | 10    | mb    | 5         |
| 0272    | 2002 | 10    | 24  | 10   | 19     | 22.03  | 28.9750   | -2.0200  | 10    | mb    | 4.8       |
| 0273    | 2002 | 10    | 24  | 11   | 40     | 17.83  | 28.9730   | -2.0150  | 10    | mb    | 4.7       |
| 0274    | 2002 | 10    | 26  | 12   | 56     | 47.71  | 29.1550   | -1.5720  | 10    | mb    | 4.7       |
| 0275    | 2002 | 12    | 13  | 13   | 24     | 25.94  | 29.0410   | -1.8520  | 10    | mb    | 4.7       |
| 0276    | 2002 | 12    | 23  | 2    | 50     | 38.27  | 34.9710   | -1.7240  | 10    | mwc   | 5.2       |
| 0277    | 2003 | 1     | 19  | 1    | 15     | 13.05  | 29.9470   | 0.9190   | 10    | mb    | 4.5       |
| 0278    | 2003 | 3     | 20  | 6    | 15     | 20.58  | 29.5600   | -2.4180  | 10    | mwc   | 5.2       |
| 0279    | 2003 | 5     | 3   | 3    | 48     | 31.59  | 29.6640   | 0.5120   | 10    | mb    | 4.5       |
| 0280    | 2003 | 6     | 6   | 17   | 31     | 35.31  | 32.1010   | 5.4000   | 10    | mb    | 4.6       |
| 0281    | 2003 | 7     | 17  | 11   | 49     | 15.42  | 28.8470   | -2.3580  | 10    | mb    | 4.3       |
| 0282    | 2003 | 8     | 5   | 18   | 56     | 50.71  | 29.4460   | -0.5210  | 10    | mwc   | 5.2       |
| 0283    | 2003 | 8     | 5   | 21   | 33     | 25.04  | 29.1340   | -0.3350  | 10    | mb    | 4.4       |
| 0284    | 2003 | 8     | 22  | 22   | 6      | 50.09  | 29.0330   | -1.9040  | 10    | mb    | 4.3       |
| 0285    | 2003 | 8     | 25  | 2    | 5      | 57.99  | 29.3090   | -0.5120  | 10    | mb    | 4.6       |
| 0286    | 2003 | 12    | 31  | 4    | 17     | 24.77  | 28.4940   | -2.5480  | 10    | mb    | 4.1       |
| 0287    | 2004 | 2     | 5   | 21   | 35     | 35.55  | 30.4510   | 0.9570   | 10    | mb    | 4.8       |
| 0288    | 2004 | 3     | 18  | 20   | 37     | 44.63  | 31.4010   | 2.0940   | 30    | mb    | 4.7       |
| 0289    | 2004 | 3     | 18  | 22   | 13     | 7.91   | 32.0460   | 5.3540   | 10    | mb    | 4.6       |
| 0290    | 2004 | 5     | 24  | 4    | 13     | 2.27   | 30.0540   | 0.1160   | 10    | mb    | 4.4       |
| 0291    | 2004 | 12    | 13  | 3    | 6      | 55.96  | 30.1710   | 0.6500   | 20    | mb    | 4.3       |
| 0292    | 2004 | 12    | 13  | 4    | 9      | 3.98   | 30.1690   | 0.7750   | 18.7  | mb    | 4.8       |
| 0293    | 2005 | 1     | 30  | 21   | 16     | 9.89   | 28.9650   | -1.9760  | 10    | mb    | 4.5       |
| 0294    | 2005 | 3     | 13  | 3    | 4      | 22.89  | 29.8830   | 0.1900   | 10    | mb    | 4.5       |
| 0295    | 2005 | 9     | 3   | 6    | 5      | 12.76  | 29.9030   | 0.0600   | 10    | mb    | 4.4       |
| 0296    | 2006 | 3     | 9   | 1    | 30     | 8.24   | 32.1770   | 5.3550   | 10    | mb    | 4.4       |
| 0297    | 2006 | 4     | 8   | 2    | 22     | 48.2   | 29.5930   | -2.4690  | 3.4   | mb    | 4.2       |
| 0298    | 2006 | 4     | 27  | 4    | 18     | 28.14  | 30.0780   | 0.3380   | 10    | mwc   | 5.2       |
| 0299    | 2006 | 4     | 27  | 17   | 54     | 42.39  | 30.0580   | 0.3330   | 10    | mb    | 4.4       |
| 0300    | 2006 | 5     | 29  | 15   | 30     | 37.85  | 30.1140   | 0.3430   | 23.9  | mwc   | 4.9       |
| 0301    | 2007 | 2     | 19  | 2    | 33     | 43.01  | 30.7580   | 1.7500   | 19    | mwc   | 5.6       |
| 0302    | 2007 | 4     | 29  | 19   | 44     | 4.36   | 30.7910   | 1.8830   | 10    | mb    | 4.5       |
| 0303    | 2007 | 6     | 15  | 18   | 49     | 53.39  | 30.8340   | 1.7190   | 24    | mwb   | 5.9       |
| 0304    | 2007 | 7     | 12  | 15   | 31     | 42.98  | 35.8680   | -2.2680  | 10    | mb    | 4.5       |
| 0305    | 2007 | 7     | 16  | 2    | 29     | 22.06  | 35.5500   | -2.2600  | 10    | mb    | 4.1       |
| 0306    | 2007 | 7     | 16  | 14   | 23     | 34.36  | 35.9910   | -2.6330  | 10    | mb    | 4.9       |
| 0307    | 2007 | 7     | 17  | 4    | 17     | 6.34   | 35.7580   | -2.5730  | 10    | mb    | 4.2       |
| 0308    | 2007 | 7     | 18  | 11   | 11     | 16.56  | 36.0020   | -2.6340  | 11.3  | mb    | 4.9       |
| 0309    | 2007 | 7     | 18  | 16   | 43     | 26.03  | 35.8040   | -2.5850  | 10    | ml    | 4.1       |
| 0310    | 2007 | 7     | 25  | 15   | 39     | 7.77   | 36.2180   | -2.5140  | 10    | mb    | 4.6       |
| 0311    | 2007 | 7     | 30  | 11   | 54     | 53.38  | 36.3950   | -2.3940  | 10    | mb    | 4.7       |
| 0312    | 2007 | 8     | 9   | 5    | 54     | 17.34  | 36.3700   | -2.5440  | 10    | mb    | 4.1       |
| 0313    | 2007 | 8     | 20  | 2    | 46     | 50.57  | 36.1910   | -2.5570  | 10    | mb    | 4.4       |
| 0314    | 2007 | 8     | 20  | 7    | 15     | 35.79  | 36.1200   | -2.6220  | 10    | mb    | 4.6       |
| 0315    | 2007 | 8     | 24  | 23   | 45     | 55     | 36.2240   | -2.6140  | 10    | mb    | 4.9       |
| 0316    | 2007 | 8     | 30  | 18   | 49     | 35.36  | 36.2450   | -2.6200  | 10    | mb    | 4.2       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0317    | 2007 | 9     | 7   | 23   | 20     | 0.52   | 28.7300   | -2.2390  | 10    | mb    | 4.6       |
| 0318    | 2007 | 9     | 8   | 14   | 15     | 33     | 36.1090   | -2.6440  | 10    | mwc   | 4.9       |
| 0319    | 2007 | 12    | 23  | 5    | 18     | 1.5    | 36.2280   | 4.7620   | 10    | mb    | 4.6       |
| 0320    | 2008 | 2     | 3   | 7    | 34     | 12.18  | 28.9000   | -2.2960  | 10    | mwb   | 5.9       |
| 0321    | 2008 | 2     | 3   | 10   | 56     | 9.74   | 28.9730   | -2.4030  | 10    | mwc   | 5         |
| 0322    | 2008 | 2     | 3   | 11   | 0      | 7.08   | 28.9830   | -2.2940  | 10    | mb    | 4.9       |
| 0323    | 2008 | 2     | 3   | 11   | 37     | 48.98  | 28.9810   | -2.5030  | 10    | mb    | 4.8       |
| 0324    | 2008 | 2     | 4   | 0    | 24     | 35.14  | 28.8800   | -2.4320  | 10    | mb    | 4.6       |
| 0325    | 2008 | 2     | 5   | 17   | 29     | 8.34   | 28.8900   | -2.5260  | 10    | mb    | 4.7       |
| 0326    | 2008 | 2     | 14  | 2    | 7      | 46.77  | 28.9180   | -2.4040  | 10    | mwc   | 5.3       |
| 0327    | 2008 | 2     | 15  | 4    | 4      | 53.05  | 28.8200   | -2.4230  | 10    | mb    | 4.7       |
| 0328    | 2008 | 2     | 27  | 2    | 7      | 59.14  | 28.9660   | -2.3920  | 10    | mb    | 4.6       |
| 0329    | 2008 | 5     | 11  | 10   | 34     | 10.37  | 29.5910   | 0.4780   | 10    | mb    | 4.4       |
| 0330    | 2008 | 7     | 10  | 23   | 55     | 1.05   | 35.8570   | -2.6540  | 10    | mb    | 4.4       |
| 0331    | 2008 | 8     | 26  | 14   | 56     | 57.03  | 30.9110   | 2.2730   | 10    | mb    | 4.4       |
| 0332    | 2008 | 10    | 1   | 14   | 15     | 53.51  | 33.7430   | -0.8060  | 24.7  | mb    | 4.7       |
| 0333    | 2008 | 10    | 5   | 0    | 2      | 12.63  | 29.1180   | -1.1260  | 4     | mwb   | 5.3       |
| 0334    | 2008 | 10    | 5   | 0    | 32     | 10.62  | 29.0950   | -1.4050  | 10    | mb    | 4         |
| 0335    | 2009 | 3     | 5   | 3    | 28     | 56.53  | 29.5500   | -0.2430  | 10    | mb    | 4.2       |
| 0336    | 2009 | 3     | 25  | 5    | 3      | 22.38  | 29.5200   | -2.4660  | 10    | mb    | 4         |
| 0337    | 2009 | 7     | 30  | 14   | 48     | 6.46   | 30.4960   | 1.2920   | 10    | mb    | 4.6       |
| 0338    | 2009 | 10    | 18  | 0    | 39     | 43.21  | 30.1450   | 0.5630   | 10    | mwc   | 4.9       |
| 0339    | 2010 | 1     | 28  | 23   | 52     | 30.52  | 29.1980   | -0.9010  | 10    | mwc   | 4.9       |
| 0340    | 2010 | 5     | 1   | 4    | 58     | 51.15  | 31.8290   | 5.4550   | 10    | mb    | 4.4       |
| 0341    | 2010 | 6     | 13  | 12   | 13     | 24.65  | 34.4890   | -0.2010  | 10    | mwc   | 5         |
| 0342    | 2010 | 6     | 16  | 21   | 51     | 7.43   | 34.6360   | -1.6640  | 10    | mb    | 4.3       |
| 0343    | 2010 | 7     | 9   | 18   | 30     | 51.88  | 29.5580   | -0.3970  | 10    | mb    | 4.4       |
| 0344    | 2010 | 10    | 8   | 23   | 40     | 57.01  | 30.5550   | 1.2420   | 26.2  | mb    | 4.6       |
| 0345    | 2010 | 10    | 23  | 11   | 8      | 21.76  | 36.1220   | 4.7320   | 10    | mwc   | 5         |
| 0346    | 2010 | 12    | 12  | 20   | 34     | 20.13  | 29.6700   | 0.8040   | 10    | mwc   | 4.9       |
| 0347    | 2010 | 12    | 27  | 22   | 10     | 8.35   | 33.3340   | 0.1750   | 10    | mb    | 4.5       |
| 0348    | 2011 | 1     | 17  | 8    | 22     | 27.58  | 30.7680   | 1.6000   | 10    | mb    | 4.8       |
| 0349    | 2011 | 3     | 15  | 3    | 25     | 19.41  | 31.2310   | 1.7460   | 10    | mwc   | 5         |
| 0350    | 2012 | 1     | 22  | 21   | 3      | 35.95  | 36.0910   | 3.6780   | 10    | mb    | 5.2       |
| 0351    | 2012 | 2     | 2   | 2    | 54     | 3.23   | 28.5750   | -1.3690  | 10    | mb    | 4.7       |
| 0352    | 2012 | 10    | 2   | 18   | 40     | 35.12  | 29.9920   | 0.4780   | 10    | mb    | 4.4       |
| 0353    | 2012 | 11    | 11  | 15   | 40     | 33.94  | 28.2370   | -0.3500  | 10    | mb    | 4.1       |
| 0354    | 2012 | 11    | 20  | 16   | 23     | 49.1   | 29.9280   | -0.3790  | 16.7  | mb    | 4.8       |
| 0355    | 2013 | 4     | 20  | 0    | 30     | 27.66  | 30.8670   | 1.5040   | 10    | mb    | 4.8       |
| 0356    | 2013 | 7     | 2   | 13   | 33     | 17.44  | 30.9070   | 1.6060   | 10    | mb    | 5.2       |
| 0357    | 2013 | 7     | 3   | 19   | 21     | 45.95  | 30.8940   | 1.5370   | 10.1  | mww   | 5.7       |
| 0358    | 2013 | 7     | 3   | 20   | 41     | 12.73  | 30.9760   | 1.5470   | 11.2  | mb    | 4.4       |
| 0359    | 2013 | 7     | 3   | 22   | 22     | 18.45  | 30.8180   | 1.5480   | 10    | mwb   | 5.1       |
| 0360    | 2013 | 7     | 5   | 13   | 42     | 21.2   | 29.8090   | -0.1910  | 10    | mb    | 4.6       |
| 0361    | 2013 | 7     | 30  | 3    | 34     | 19.63  | 30.1700   | 0.4450   | 15.3  | mb    | 4.4       |
| 0362    | 2013 | 8     | 5   | 6    | 2      | 31.26  | 31.0468   | 1.6295   | 9.93  | mb    | 4.6       |
| 0363    | 2013 | 8     | 5   | 7    | 33     | 56.47  | 31.0489   | 1.6318   | 10    | mb    | 4.7       |
| 0364    | 2013 | 8     | 5   | 11   | 39     | 21.88  | 30.7834   | 1.6584   | 10    | mb    | 4.1       |
| 0365    | 2013 | 10    | 8   | 8    | 40     | 16.33  | 30.5707   | 1.5264   | 24.95 | mb    | 4.6       |
| 0366    | 2013 | 12    | 19  | 21   | 26     | 40.95  | 32.3919   | -1.3831  | 10    | mb    | 4.3       |
| 0367    | 2014 | 2     | 11  | 8    | 33     | 29.86  | 34.7645   | 4.8693   | 10    | mb    | 4.4       |
| 0368    | 2014 | 9     | 21  | 10   | 18     | 26.67  | 30.2439   | 0.7538   | 10    | mb    | 4.4       |
| 0369    | 2014 | 10    | 31  | 1    | 5      | 2.41   | 29.9951   | 0.4918   | 10    | mb    | 4.5       |
| 0370    | 2014 | 11    | 20  | 23   | 56     | 1.64   | 29.5273   | -0.2425  | 10    | mb    | 4.4       |
| 0371    | 2015 | 2     | 13  | 8    | 35     | 23.79  | 29.6975   | -0.2766  | 10    | mb    | 4.4       |
| 0372    | 2015 | 3     | 17  | 0    | 54     | 2.89   | 35.8175   | 2.9905   | 10    | mb    | 4.2       |
| 0373    | 2015 | 6     | 29  | 14   | 11     | 18.64  | 31.2302   | 2.7582   | 10    | mb    | 4.5       |
| 0374    | 2015 | 7     | 17  | 18   | 32     | 53.89  | 30.2731   | 1.1663   | 10.08 | mb    | 4.4       |
| 0375    | 2015 | 8     | 7   | 1    | 25     | 2.54   | 28.8973   | -2.1412  | 11    | mww   | 5.8       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0376    | 2015 | 8     | 7   | 1    | 28     | 37.12  | 28.9515   | -2.0913  | 10    | mwc   | 5.5       |
| 0377    | 2015 | 8     | 7   | 1    | 50     | 26.77  | 28.8493   | -2.2754  | 10    | mb    | 4.3       |
| 0378    | 2015 | 9     | 12  | 12   | 32     | 4.29   | 29.6640   | 0.3971   | 18.36 | mb    | 4.5       |
| 0379    | 2015 | 11    | 24  | 17   | 47     | 37.86  | 31.0764   | 1.4548   | 10    | mb    | 4.2       |
| 0380    | 2015 | 11    | 25  | 9    | 38     | 12.57  | 29.7271   | -0.1635  | 10    | mb    | 4.7       |
| 0381    | 2016 | 2     | 4   | 12   | 43     | 59.71  | 28.4181   | -1.5703  | 10    | mb    | 5.1       |
| 0382    | 2016 | 6     | 11  | 1    | 5      | 16.95  | 29.4435   | -0.5957  | 10    | mb    | 4         |
| 0383    | 2016 | 9     | 10  | 12   | 27     | 33.41  | 31.6181   | -1.0355  | 40    | mww   | 5.9       |
| 0384    | 2016 | 9     | 23  | 16   | 11     | 56.61  | 29.0598   | -2.6498  | 10    | mb    | 4.8       |
| 0385    | 2016 | 10    | 24  | 23   | 30     | 0.71   | 29.0218   | -2.6056  | 10    | mb    | 4.7       |
| 0386    | 2017 | 2     | 18  | 3    | 37     | 14.71  | 30.7252   | 1.4576   | 10    | mb    | 4.2       |
| 0387    | 2017 | 2     | 25  | 17   | 19     | 35.22  | 31.1166   | 1.4127   | 10    | mb    | 4.7       |
| 0388    | 2017 | 4     | 10  | 8    | 17     | 33.66  | 29.8514   | -0.1582  | 15.08 | mb    | 4.5       |
| 0389    | 2017 | 4     | 29  | 22   | 28     | 30.44  | 31.5973   | -1.1579  | 10.12 | mb    | 4.3       |
| 0390    | 2017 | 7     | 30  | 7    | 2      | 29.17  | 29.7824   | -0.2200  | 10    | mww   | 5.3       |
| 0391    | 2017 | 11    | 30  | 21   | 48     | 35.64  | 28.7075   | -2.6188  | 10    | mww   | 5         |
| 0392    | 2018 | 1     | 9   | 9    | 1      | 0.81   | 28.4483   | -1.6551  | 10    | mb    | 4.5       |
| 0393    | 2018 | 9     | 13  | 23   | 52     | 47.83  | 29.9281   | 0.6273   | 10    | mb    | 4.5       |
| 0394    | 2018 | 10    | 1   | 5    | 58     | 4.16   | 29.2650   | -0.9071  | 10    | mb    | 4.4       |
| 0395    | 2018 | 12    | 1   | 18   | 36     | 49.21  | 29.4658   | -0.0184  | 12.75 | mb    | 4.3       |
| 0396    | 2019 | 1     | 5   | 18   | 13     | 45.19  | 31.4019   | 3.0909   | 10    | mb    | 4.8       |
| 0397    | 2019 | 4     | 3   | 19   | 40     | 51.29  | 31.1843   | 1.7749   | 10    | mb    | 4.5       |
| 0398    | 2019 | 4     | 7   | 3    | 17     | 4.09   | 28.1972   | -0.0700  | 10    | mb    | 4.3       |
| 0399    | 2019 | 8     | 5   | 9    | 37     | 13.54  | 29.4790   | -0.8645  | 10    | mb    | 4.4       |
| 0400    | 2019 | 8     | 6   | 16   | 58     | 31.11  | 30.1201   | 0.0359   | 10    | mb    | 4.6       |
| 0401    | 2019 | 9     | 6   | 6    | 15     | 35.09  | 30.2972   | 1.0589   | 10    | mb    | 4.6       |
| 0402    | 2019 | 12    | 3   | 10   | 25     | 41.97  | 30.3405   | 0.2825   | 10    | mb    | 4.4       |
| 0403    | 2020 | 1     | 8   | 17   | 54     | 36.13  | 29.6288   | 0.5503   | 10    | mb    | 4.5       |
| 0404    | 2020 | 1     | 11  | 17   | 4      | 27.49  | 28.8008   | -2.3827  | 10    | mb    | 4.3       |
| 0405    | 2020 | 1     | 28  | 22   | 32     | 6.04   | 29.7646   | -0.2431  | 10    | mb    | 4.6       |
| 0406    | 2020 | 1     | 30  | 13   | 1      | 10.39  | 30.1568   | -0.0420  | 24.43 | mb    | 4.4       |
| 0407    | 2020 | 3     | 19  | 22   | 35     | 49.1   | 29.7626   | -0.7920  | 10    | mb    | 4.3       |
| 0408    | 2020 | 5     | 3   | 19   | 36     | 55.64  | 36.0596   | 2.8543   | 10    | mww   | 5         |
| 0409    | 2020 | 6     | 8   | 22   | 34     | 15.67  | 30.8804   | 1.6150   | 10    | mb    | 4.5       |
| 0410    | 2020 | 6     | 21  | 13   | 56     | 49.04  | 28.5490   | -1.5756  | 10    | mb    | 4.2       |
| 0411    | 2020 | 6     | 21  | 21   | 54     | 58.4   | 29.9312   | 0.8089   | 10    | mb    | 4.3       |
| 0412    | 2020 | 8     | 6   | 2    | 17     | 46.83  | 29.9632   | 0.1063   | 10    | mb    | 4.4       |
| 0413    | 2020 | 8     | 20  | 11   | 23     | 30.17  | 28.4953   | -0.3979  | 10    | mb    | 4.6       |
| 0414    | 2020 | 10    | 4   | 6    | 47     | 32.84  | 29.7489   | 0.8556   | 10    | mb    | 4.2       |
| 0415    | 2020 | 10    | 25  | 22   | 46     | 17.58  | 31.7671   | 5.0759   | 10    | mb    | 4.5       |
| 0416    | 2021 | 2     | 9   | 23   | 25     | 47.18  | 28.6712   | -1.1904  | 10    | mb    | 4.5       |
| 0417    | 2021 | 2     | 25  | 14   | 29     | 44.07  | 28.7561   | -1.9861  | 10    | mb    | 4.4       |
| 0418    | 2021 | 3     | 11  | 1    | 47     | 13.77  | 34.2551   | -1.5683  | 10    | mb    | 4.8       |
| 0419    | 2021 | 3     | 20  | 17   | 7      | 27.09  | 31.1874   | 2.4985   | 10    | mb    | 4.2       |
| 0420    | 2021 | 4     | 14  | 2    | 20     | 28.25  | 30.3849   | 1.1719   | 10    | mb    | 4.6       |
| 0421    | 2021 | 5     | 22  | 23   | 54     | 55.99  | 29.2111   | -1.7503  | 10    | mb    | 4.3       |
| 0422    | 2021 | 5     | 23  | 11   | 51     | 53.65  | 29.6147   | -1.9652  | 10    | mb    | 4.2       |
| 0423    | 2021 | 5     | 23  | 13   | 7      | 55.73  | 29.3863   | -1.8121  | 10    | mb    | 4.5       |
| 0424    | 2021 | 5     | 23  | 16   | 52     | 25.48  | 29.4389   | -1.8280  | 13.06 | mb    | 4.3       |
| 0425    | 2021 | 5     | 23  | 20   | 38     | 56.9   | 29.2368   | -1.6519  | 10    | mb    | 4.5       |
| 0426    | 2021 | 5     | 23  | 22   | 52     | 56.47  | 29.4069   | -1.6468  | 10    | mb    | 4.3       |
| 0427    | 2021 | 5     | 24  | 8    | 37     | 25.45  | 29.2293   | -1.5912  | 10    | mb    | 4.7       |
| 0428    | 2021 | 5     | 25  | 8    | 19     | 55.52  | 29.3804   | -1.7687  | 10    | mb    | 4.5       |
| 0429    | 2021 | 5     | 25  | 9    | 3      | 0.25   | 29.4806   | -1.5761  | 10    | mb    | 4.7       |
| 0430    | 2021 | 5     | 25  | 9    | 41     | 17.05  | 29.3197   | -1.7569  | 10    | mb    | 4.4       |
| 0431    | 2021 | 5     | 25  | 10   | 40     | 45.45  | 29.3986   | -1.7467  | 10    | mb    | 4.3       |
| 0432    | 2021 | 5     | 25  | 12   | 16     | 27.11  | 29.2667   | -1.7560  | 10    | mb    | 4.4       |
| 0433    | 2021 | 5     | 25  | 20   | 38     | 11.78  | 29.4184   | -1.6688  | 10    | mb    | 4.3       |
| 0434    | 2021 | 5     | 26  | 3    | 46     | 31.63  | 29.4006   | -1.7237  | 10    | mb    | 4.7       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0435    | 2021 | 5     | 26  | 7    | 1      | 18     | 29.4858   | -1.8137  | 10    | mb    | 4.2       |
| 0436    | 2021 | 5     | 26  | 8    | 51     | 59.39  | 29.2514   | -1.7157  | 10    | mb    | 4.4       |
| 0437    | 2021 | 5     | 26  | 11   | 41     | 18.64  | 29.3085   | -1.6522  | 10    | mb    | 4.4       |
| 0438    | 2021 | 5     | 26  | 16   | 7      | 17.58  | 29.3040   | -1.7731  | 10    | mb    | 4.5       |
| 0439    | 2021 | 5     | 26  | 17   | 32     | 56.19  | 29.2551   | -1.7394  | 12.65 | mb    | 4.5       |
| 0440    | 2021 | 5     | 26  | 23   | 19     | 33.29  | 29.3238   | -1.7819  | 12.91 | mb    | 4.5       |
| 0441    | 2021 | 5     | 26  | 23   | 26     | 58.08  | 29.2957   | -1.8550  | 12.86 | mb    | 4.5       |
| 0442    | 2021 | 5     | 27  | 3    | 23     | 52.23  | 29.3872   | -1.6168  | 10    | mb    | 4.3       |
| 0443    | 2021 | 5     | 27  | 9    | 33     | 54.31  | 29.3823   | -1.7149  | 10    | mb    | 4.5       |
| 0444    | 2021 | 6     | 17  | 17   | 49     | 8.03   | 33.4060   | -0.6614  | 10    | mb    | 4.6       |
| 0445    | 2021 | 6     | 26  | 21   | 11     | 40.89  | 31.2114   | 4.1011   | 10    | mb    | 4.4       |
| 0446    | 2021 | 9     | 7   | 1    | 48     | 21.52  | 28.8862   | -2.1446  | 10    | mb    | 4.5       |
| 0447    | 2021 | 10    | 16  | 0    | 23     | 26.73  | 29.7956   | -0.3396  | 10    | mb    | 4.7       |
| 0448    | 2021 | 10    | 16  | 4    | 46     | 5.74   | 29.9453   | -0.3636  | 10    | mb    | 4.5       |

## Appendix A-3: ISC Reviewed Bulletin

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0449    | 1912 | 7     | 9   | 8    | 18     | 10.31  | 33.5660   | 3.3324   | 10    | ms    | 5.9       |
| 0450    | 1928 | 1     | 6   | 19   | 31     | 59.51  | 35.8599   | 0.3404   | 15    | ms    | 7         |
| 0451    | 1928 | 1     | 10  | 2    | 25     | 37.46  | 35.4191   | 0.3832   | 10    | ms    | 6.2       |
| 0452    | 1945 | 3     | 18  | 8    | 1      | 26     | 32.0000   | 0.0000   | 35    | ms    | 6         |
| 0453    | 1952 | 6     | 30  | 21   | 4      | 30.87  | 29.9139   | -0.3604  | 15    | ms    | 6.4       |
| 0454    | 1954 | 6     | 13  | 15   | 41     | 55     | 29.0000   | -1.0000  |       | m     | 5.5       |
| 0455    | 1955 | 7     | 22  | 4    | 0      | 2.9    | 30.5200   | 1.4200   |       | m     | 5         |
| 0456    | 1955 | 9     | 4   | 22   | 12     | 50.41  | 30.9407   | 1.5604   | 15    | m     | 6.3       |
| 0457    | 1957 | 7     | 9   | 22   | 24     | 46     | 29.0000   | 0.0000   |       | m     | 4.8       |
| 0458    | 1958 | 4     | 15  | 22   | 20     | 35     | 30.5000   | 0.0000   |       | m     | 5         |
| 0459    | 1959 | 1     | 15  | 23   | 2      | 30     | 29.7500   | -0.2500  |       | m     | 4.5       |
| 0460    | 1959 | 1     | 23  | 9    | 46     | 18     | 35.0000   | 3.0000   |       | m     | 4.9       |
| 0461    | 1959 | 1     | 27  | 5    | 44     | 0      | 31.0000   | 1.0000   |       | m     | 4.2       |
| 0462    | 1959 | 6     | 19  | 11   | 58     | 51.6   | 29.3800   | -0.1700  |       | m     | 5.4       |
| 0463    | 1959 | 8     | 9   | 11   | 17     | 0      | 29.0000   | 0.5000   |       | m     | 5.1       |
| 0464    | 1959 | 9     | 22  | 6    | 43     | 26.6   | 29.7600   | 0.9100   |       | m     | 4.5       |
| 0465    | 1960 | 5     | 4   | 2    | 17     | 33.4   | 32.4600   | -1.2100  |       | m     | 5.7       |
| 0466    | 1961 | 11    | 12  | 2    | 15     | 18.48  | 29.4364   | 0.3746   | 30    | ms    | 5.5       |
| 0467    | 1965 | 4     | 25  | 10   | 1      | 10     | 28.9071   | -2.5379  | 12    | mb    | 5.1       |
| 0468    | 1965 | 12    | 28  | 11   | 30     | 8.6    | 29.4639   | -1.4534  | 10    | mb    | 4.6       |
| 0469    | 1966 | 3     | 9   | 3    | 12     | 46.24  | 31.3895   | 2.1361   | 10    | mb    | 4.5       |
| 0470    | 1966 | 3     | 9   | 3    | 29     | 37.05  | 31.2448   | 1.9204   | 10    | mb    | 4.4       |
| 0471    | 1966 | 3     | 18  | 6    | 14     | 31.16  | 30.6951   | 0.7510   | 10    | m     | 4.4       |
| 0472    | 1966 | 3     | 18  | 7    | 13     | 29.6   | 30.7093   | -0.4353  | 10    | m     | 4         |
| 0473    | 1966 | 3     | 19  | 23   | 4      | 42.91  | 29.9581   | 0.4605   | 14    | m     | 4.4       |
| 0474    | 1966 | 3     | 20  | 1    | 42     | 52.44  | 29.8142   | 0.7621   | 27.4  | mb    | 6.1       |
| 0475    | 1966 | 3     | 20  | 2    | 17     | 0      | 30.1000   | -0.3000  | 0     | m     | 4.5       |
| 0476    | 1966 | 3     | 20  | 2    | 24     | 0      | 30.1000   | -0.3000  | 0     | m     | 4.1       |
| 0477    | 1966 | 3     | 20  | 2    | 39     | 43.37  | 29.9236   | 0.9964   | 21    | mb    | 5.3       |
| 0478    | 1966 | 3     | 20  | 2    | 51     | 0      | 30.1000   | -0.3000  | 0     | m     | 4.2       |
| 0479    | 1966 | 3     | 20  | 2    | 57     | 0      | 30.1000   | -0.3000  | 0     | m     | 4         |
| 0480    | 1966 | 3     | 20  | 3    | 22     | 47.65  | 29.9157   | 0.8633   | 21    | mb    | 5.2       |
| 0481    | 1966 | 3     | 20  | 7    | 58     | 0      | 30.1000   | -0.3000  | 0     | m     | 4         |
| 0482    | 1966 | 3     | 20  | 8    | 31     | 0      | 30.1000   | -0.3000  | 0     | m     | 4.1       |
| 0483    | 1966 | 3     | 20  | 8    | 55     | 38.75  | 29.7667   | 0.7863   | 21    | mb    | 5.3       |
| 0484    | 1966 | 3     | 20  | 15   | 25     | 59.52  | 30.3336   | -0.3518  | 10    | m     | 4         |
| 0485    | 1966 | 3     | 20  | 16   | 20     | 0      | 30.1000   | -0.3000  | 0     | m     | 4         |
| 0486    | 1966 | 3     | 20  | 16   | 24     | 0      | 30.1000   | -0.3000  | 0     | m     | 4         |
| 0487    | 1966 | 3     | 20  | 18   | 14     | 0      | 30.1000   | -0.3000  | 0     | m     | 4         |
| 0488    | 1966 | 3     | 20  | 19   | 34     | 0      | 30.1000   | -0.3000  | 0     | m     | 4.1       |
| 0489    | 1966 | 3     | 21  | 1    | 30     | 41.68  | 29.8399   | 0.6822   | 21    | mb    | 5.4       |
| 0490    | 1966 | 3     | 21  | 9    | 23     | 53.24  | 29.9543   | 0.6338   | 21    | mb    | 5.1       |
| 0491    | 1966 | 3     | 24  | 13   | 6      | 0      | 30.1000   | -0.3000  | 0     | m     | 4.3       |
| 0492    | 1966 | 3     | 25  | 2    | 30     | 0      | 30.1000   | -0.3000  | 0     | m     | 4.2       |
| 0493    | 1966 | 3     | 25  | 13   | 49     | 47.82  | 30.6850   | 0.4836   | 10    | mb    | 4.6       |
| 0494    | 1966 | 3     | 25  | 21   | 57     | 36.52  | 30.2071   | 1.0240   | 10    | m     | 4.3       |
| 0495    | 1966 | 3     | 29  | 17   | 24     | 11.05  | 30.1988   | 1.0429   | 21    | mb    | 4.8       |
| 0496    | 1966 | 3     | 29  | 17   | 27     | 0      | 30.1000   | -0.3000  | 0     | m     | 4.4       |
| 0497    | 1966 | 4     | 1   | 7    | 59     | 36.97  | 29.8346   | 0.8265   | 10    | mb    | 4.5       |
| 0498    | 1966 | 4     | 6   | 1    | 17     | 52.7   | 29.8009   | 0.4869   | 14    | mb    | 4.4       |
| 0499    | 1966 | 4     | 7   | 0    | 9      | 10.52  | 29.8728   | 0.3257   | 14    | mb    | 4.4       |
| 0500    | 1966 | 4     | 12  | 7    | 35     | 15.43  | 30.0312   | 1.0736   | 21    | mb    | 4.8       |
| 0501    | 1966 | 4     | 13  | 2    | 14     | 20.8   | 30.1498   | 0.9882   | 21    | mb    | 5         |
| 0502    | 1966 | 4     | 13  | 9    | 43     | 3.75   | 30.2059   | 1.0877   | 10    | mb    | 4.6       |
| 0503    | 1966 | 4     | 14  | 13   | 16     | 20.26  | 29.8719   | 0.9658   | 21    | m     | 4.5       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0504    | 1966 | 4     | 15  | 3    | 8      | 16.57  | 29.9357   | 0.6282   | 21    | mb    | 5.3       |
| 0505    | 1966 | 4     | 16  | 14   | 43     | 21.01  | 29.9581   | 0.6421   | 21    | mb    | 5.2       |
| 0506    | 1966 | 4     | 30  | 20   | 38     | 47.22  | 29.7574   | 0.4717   | 14    | mb    | 4.9       |
| 0507    | 1966 | 5     | 12  | 0    | 40     | 54.27  | 30.5943   | 0.1686   | 10    | m     | 4.2       |
| 0508    | 1966 | 5     | 16  | 5    | 44     | 18.9   | 30.1624   | 0.5596   | 14    | mb    | 4.8       |
| 0509    | 1966 | 5     | 17  | 7    | 3      | 32.56  | 30.0769   | 0.6421   | 14.7  | mb    | 5.4       |
| 0510    | 1966 | 5     | 18  | 1    | 46     | 33.84  | 29.7157   | 0.7355   | 14    | mb    | 4         |
| 0511    | 1966 | 5     | 29  | 2    | 26     | 13.55  | 29.9172   | 0.5298   | 14    | mb    | 4.8       |
| 0512    | 1966 | 6     | 3   | 7    | 14     | 40.47  | 29.5868   | 0.4827   | 10    | mb    | 5         |
| 0513    | 1966 | 6     | 4   | 19   | 2      | 3.36   | 29.7712   | 0.7386   | 21    | mb    | 4.8       |
| 0514    | 1966 | 6     | 14  | 15   | 37     | 46.15  | 30.1921   | -0.3107  | 10    | m     | 4.5       |
| 0515    | 1966 | 6     | 14  | 23   | 50     | 42.39  | 29.9734   | 0.9947   | 21    | mb    | 4.8       |
| 0516    | 1966 | 6     | 17  | 18   | 31     | 55.19  | 29.8967   | 0.6744   | 21    | mb    | 5.1       |
| 0517    | 1966 | 6     | 19  | 0    | 54     | 51.24  | 29.8488   | 0.6378   | 14    | mb    | 4.9       |
| 0518    | 1966 | 7     | 2   | 11   | 21     | 30.55  | 30.0512   | 0.6528   | 21    | mb    | 4.7       |
| 0519    | 1966 | 7     | 6   | 2    | 58     | 37.9   | 30.0652   | 0.4002   | 10    | mb    | 5.2       |
| 0520    | 1966 | 7     | 12  | 17   | 45     | 40.37  | 29.5453   | 1.2095   | 10    | mb    | 4.7       |
| 0521    | 1966 | 7     | 14  | 4    | 34     | 47.03  | 29.7949   | 0.6885   | 21    | mb    | 5.3       |
| 0522    | 1966 | 7     | 22  | 2    | 51     | 23.36  | 29.6362   | 0.6096   | 10    | mb    | 4.6       |
| 0523    | 1966 | 7     | 30  | 6    | 24     | 36.85  | 30.3108   | 0.6968   | 10    | m     | 4.3       |
| 0524    | 1966 | 7     | 31  | 15   | 17     | 18.53  | 30.0597   | 0.6108   | 14    | mb    | 5         |
| 0525    | 1966 | 8     | 1   | 17   | 16     | 41.14  | 29.8838   | 0.7302   | 14    | m     | 4.2       |
| 0526    | 1966 | 9     | 2   | 0    | 9      | 18.07  | 30.2428   | 0.8339   | 21    | m     | 4.2       |
| 0527    | 1966 | 9     | 2   | 7    | 51     | 0      | 31.6000   | 0.6000   | 0     | m     | 4         |
| 0528    | 1966 | 9     | 26  | 23   | 24     | 8.82   | 29.9655   | 0.0861   | 16    | m     | 4         |
| 0529    | 1966 | 10    | 5   | 8    | 34     | 41.19  | 29.8501   | 0.0292   | 24    | mb    | 5.2       |
| 0530    | 1966 | 10    | 26  | 8    | 4      | 1.31   | 30.2745   | 0.2673   | 10    | m     | 4         |
| 0531    | 1966 | 10    | 29  | 5    | 10     | 7.14   | 29.6738   | -1.6698  | 10    | m     | 4.3       |
| 0532    | 1966 | 11    | 17  | 20   | 26     | 2.32   | 30.3635   | 0.0269   | 10    | m     | 4.2       |
| 0533    | 1966 | 11    | 23  | 4    | 17     | 41.53  | 31.1938   | 3.7220   | 10    | m     | 4.3       |
| 0534    | 1966 | 11    | 25  | 21   | 28     | 59.72  | 29.9576   | 0.7275   | 21    | m     | 4.3       |
| 0535    | 1966 | 12    | 14  | 17   | 58     | 0      | 31.0000   | 2.0000   | 0     | m     | 4.1       |
| 0536    | 1966 | 12    | 29  | 16   | 48     | 19.62  | 29.8755   | 0.8481   | 21    | m     | 4.1       |
| 0537    | 1967 | 1     | 12  | 22   | 22     | 10.88  | 31.0667   | 2.1308   | 10    | mb    | 4.5       |
| 0538    | 1967 | 2     | 7   | 6    | 20     | 16.09  | 30.5791   | -0.5854  | 10    | m     | 4.6       |
| 0539    | 1967 | 2     | 14  | 2    | 6      | 38.48  | 30.1815   | 0.4494   | 10    | m     | 4         |
| 0540    | 1967 | 2     | 24  | 14   | 23     | 32.3   | 30.1993   | -0.0340  | 16    | m     | 4.1       |
| 0541    | 1967 | 3     | 10  | 12   | 41     | 13.79  | 30.1591   | 0.4916   | 14    | mb    | 5.5       |
| 0542    | 1967 | 5     | 8   | 13   | 58     | 29.18  | 35.6341   | 3.8812   | 10    | m     | 4.3       |
| 0543    | 1967 | 5     | 28  | 12   | 19     | 31.55  | 31.1837   | 1.6413   | 24.5  | mb    | 5         |
| 0544    | 1967 | 6     | 8   | 18   | 39     | 45     | 30.8000   | -0.1000  | 0     | m     | 4         |
| 0545    | 1967 | 6     | 19  | 16   | 43     | 5.32   | 30.1078   | 0.5015   | 14    | mb    | 4.6       |
| 0546    | 1967 | 7     | 5   | 16   | 0      | 53     | 28.9000   | -2.3000  | 0     | m     | 4.1       |
| 0547    | 1967 | 7     | 24  | 3    | 13     | 15.04  | 28.5434   | -1.0968  | 10    | m     | 4.7       |
| 0548    | 1967 | 8     | 19  | 9    | 47     | 24.18  | 29.7609   | 0.4758   | 21    | m     | 4.7       |
| 0549    | 1967 | 9     | 9   | 22   | 35     | 55.02  | 32.5386   | 3.7962   | 10    | mb    | 4.9       |
| 0550    | 1967 | 10    | 30  | 19   | 55     | 37.53  | 31.2691   | 1.9215   | 10    | m     | 4.2       |
| 0551    | 1967 | 10    | 30  | 21   | 22     | 38.65  | 31.1143   | 2.0476   | 10    | m     | 4.2       |
| 0552    | 1967 | 10    | 31  | 13   | 51     | 3.45   | 31.1338   | 1.8659   | 10    | m     | 4.7       |
| 0553    | 1967 | 11    | 2   | 15   | 20     | 46.2   | 30.3256   | 1.5227   | 10    | m     | 4.1       |
| 0554    | 1967 | 11    | 11  | 2    | 28     | 43.26  | 31.3906   | 2.0109   | 10    | mb    | 5.2       |
| 0555    | 1967 | 11    | 13  | 20   | 29     | 3.33   | 31.5694   | 1.7871   | 10    | mb    | 5.3       |
| 0556    | 1967 | 11    | 29  | 5    | 27     | 13.87  | 31.1246   | 1.8656   | 10    | m     | 4.3       |
| 0557    | 1967 | 11    | 29  | 5    | 32     | 14.33  | 31.4092   | 1.7700   | 10    | m     | 4.9       |
| 0558    | 1967 | 12    | 29  | 13   | 4      | 35.08  | 32.1426   | -0.2375  | 10    | m     | 4.2       |
| 0559    | 1967 | 12    | 29  | 13   | 46     | 44.82  | 31.5959   | 2.0027   | 10    | m     | 4.1       |
| 0560    | 1967 | 12    | 29  | 15   | 43     | 7.42   | 31.2965   | 2.4265   | 10    | m     | 4.1       |
| 0561    | 1967 | 12    | 29  | 16   | 7      | 3      | 34.0000   | 1.3000   | 0     | m     | 4.1       |
| 0562    | 1967 | 12    | 29  | 23   | 39     | 13     | 34.0000   | 1.3000   | 0     | m     | 4         |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0563    | 1968 | 1     | 23  | 19   | 11     | 10     | 34.0000   | 5.0000   | 0     | m     | 4.7       |
| 0564    | 1968 | 3     | 14  | 19   | 44     | 17.56  | 33.1313   | -1.5284  | 10    | m     | 4.1       |
| 0565    | 1968 | 3     | 16  | 7    | 0      | 29.18  | 34.4171   | -0.9194  | 10    | m     | 4.7       |
| 0566    | 1968 | 3     | 20  | 19   | 2      | 49.97  | 34.4579   | -0.9116  | 10    | m     | 4.6       |
| 0567    | 1968 | 3     | 21  | 2    | 59     | 35.71  | 34.4417   | -0.9234  | 10    | m     | 4.5       |
| 0568    | 1968 | 3     | 21  | 3    | 26     | 2      | 34.2000   | -0.5000  | 0     | m     | 4         |
| 0569    | 1968 | 3     | 21  | 3    | 35     | 3      | 34.3000   | -0.5000  | 0     | m     | 4         |
| 0570    | 1968 | 3     | 21  | 12   | 49     | 26.52  | 34.4464   | -1.1801  | 10    | m     | 4.7       |
| 0571    | 1968 | 3     | 21  | 23   | 22     | 7.74   | 34.4420   | -0.5505  | 10    | m     | 4.1       |
| 0572    | 1968 | 4     | 1   | 3    | 56     | 10.2   | 34.5205   | -1.0778  | 10    | m     | 4.9       |
| 0573    | 1968 | 5     | 10  | 8    | 4      | 16.65  | 34.4238   | -1.0368  | 10    | m     | 4.9       |
| 0574    | 1968 | 6     | 13  | 16   | 53     | 47.19  | 34.2689   | 1.9032   | 10    | m     | 4.3       |
| 0575    | 1968 | 6     | 24  | 1    | 6      | 32.28  | 29.7232   | -0.5148  | 10    | m     | 4.1       |
| 0576    | 1968 | 6     | 24  | 1    | 19     | 19.73  | 30.0498   | -0.8757  | 10    | m     | 4.1       |
| 0577    | 1968 | 6     | 24  | 3    | 21     | 59.49  | 29.7911   | -0.4080  | 10    | mb    | 5.1       |
| 0578    | 1968 | 6     | 29  | 11   | 48     | 17.9   | 29.2596   | -1.0615  | 10    | mb    | 5.2       |
| 0579    | 1968 | 7     | 2   | 11   | 0      | 27.19  | 29.8398   | -0.1275  | 16    | m     | 4.1       |
| 0580    | 1968 | 7     | 2   | 11   | 1      | 25     | 30.0000   | 0.0000   | 0     | m     | 4.4       |
| 0581    | 1968 | 9     | 21  | 23   | 41     | 54.86  | 30.2239   | 0.8379   | 21    | m     | 4.4       |
| 0582    | 1968 | 10    | 30  | 0    | 39     | 43.26  | 30.1032   | 0.0509   | 10    | m     | 4.3       |
| 0583    | 1968 | 11    | 6   | 23   | 26     | 57.22  | 35.7612   | 3.3045   | 10    | m     | 4.2       |
| 0584    | 1968 | 11    | 13  | 16   | 44     | 17.6   | 31.3012   | 1.8780   | 10    | m     | 5         |
| 0585    | 1968 | 11    | 26  | 18   | 49     | 12.66  | 29.8589   | 0.7823   | 21    | m     | 4.5       |
| 0586    | 1969 | 3     | 7   | 20   | 26     | 13.7   | 29.2134   | -2.5864  | 12    | m     | 5         |
| 0587    | 1969 | 3     | 13  | 18   | 7      | 45     | 30.6000   | 0.6000   | 0     | m     | 4         |
| 0588    | 1969 | 3     | 14  | 23   | 10     | 19.83  | 29.8160   | -0.7920  | 10    | m     | 4.3       |
| 0589    | 1969 | 4     | 5   | 15   | 23     | 47.12  | 31.6870   | 4.6327   | 10    | m     | 4.7       |
| 0590    | 1969 | 4     | 7   | 4    | 44     | 17     | 29.3000   | -0.6000  | 0     | m     | 4.3       |
| 0591    | 1969 | 4     | 22  | 21   | 59     | 11.02  | 31.4086   | 1.8544   | 10    | m     | 5         |
| 0592    | 1969 | 4     | 29  | 19   | 54     | 43.72  | 30.7739   | -0.9028  | 10    | mb    | 4.9       |
| 0593    | 1969 | 6     | 3   | 17   | 0      | 29.44  | 28.9048   | -1.9652  | 12    | m     | 4         |
| 0594    | 1969 | 7     | 15  | 16   | 33     | 27.72  | 31.3903   | 3.6008   | 10    | mb    | 5.5       |
| 0595    | 1969 | 8     | 23  | 16   | 6      | 39.58  | 29.6672   | -0.2302  | 10    | m     | 4.3       |
| 0596    | 1969 | 8     | 26  | 13   | 1      | 31.48  | 30.1234   | 0.3476   | 14    | m     | 4.1       |
| 0597    | 1969 | 9     | 5   | 18   | 54     | 15.07  | 30.9821   | -0.3676  | 10    | m     | 4.1       |
| 0598    | 1969 | 12    | 14  | 6    | 55     | 39.89  | 34.1380   | -1.0630  | 10    | m     | 4.5       |
| 0599    | 1970 | 2     | 14  | 15   | 48     | 41.45  | 31.6780   | 5.5643   | 10    | mb    | 4.2       |
| 0600    | 1970 | 3     | 13  | 18   | 30     | 20.37  | 29.2664   | -1.0953  | 10    | m     | 4.5       |
| 0601    | 1971 | 1     | 3   | 3    | 10     | 8.49   | 30.6143   | 1.7448   | 10    | m     | 4         |
| 0602    | 1971 | 1     | 4   | 15   | 14     | 37.6   | 32.3437   | 3.4333   | 10    | mb    | 4.4       |
| 0603    | 1971 | 1     | 16  | 9    | 0      | 20.21  | 28.4235   | -1.5273  | 10    | m     | 5         |
| 0604    | 1971 | 4     | 18  | 0    | 34     | 33.46  | 29.9647   | 0.2859   | 14    | mb    | 4.6       |
| 0605    | 1971 | 4     | 18  | 5    | 49     | 49.32  | 30.1784   | 0.0505   | 16    | mb    | 4.7       |
| 0606    | 1971 | 4     | 21  | 18   | 40     | 54.43  | 29.8458   | 0.1192   | 16    | mb    | 4.3       |
| 0607    | 1971 | 9     | 14  | 20   | 43     | 57.09  | 29.4168   | -1.2683  | 10    | m     | 4.3       |
| 0608    | 1972 | 1     | 8   | 17   | 27     | 51.13  | 30.0946   | 0.5202   | 14    | mb    | 5         |
| 0609    | 1972 | 4     | 18  | 15   | 8      | 16.26  | 29.8697   | 0.5876   | 14    | mb    | 5.3       |
| 0610    | 1972 | 8     | 8   | 4    | 24     | 59.11  | 28.2147   | -1.3403  | 22.9  | mb    | 4.4       |
| 0611    | 1972 | 9     | 10  | 8    | 45     | 11.03  | 35.2944   | 0.0497   | 10    | m     | 4.6       |
| 0612    | 1973 | 4     | 22  | 22   | 3      | 43.11  | 31.1837   | 3.9365   | 10    | mb    | 4.7       |
| 0613    | 1973 | 11    | 19  | 6    | 28     | 26.62  | 31.2703   | 4.3225   | 10    | m     | 5.4       |
| 0614    | 1973 | 12    | 1   | 16   | 51     | 15.35  | 29.6825   | 0.5824   | 10    | mb    | 4.5       |
| 0615    | 1974 | 1     | 10  | 16   | 2      | 46.32  | 29.9455   | 0.4496   | 14    | m     | 4.7       |
| 0616    | 1974 | 1     | 17  | 3    | 55     | 6.01   | 29.8728   | -0.2193  | 16    | m     | 4.5       |
| 0617    | 1974 | 4     | 25  | 0    | 3      | 48.07  | 30.0810   | 1.0448   | 8.9   | mb    | 5.1       |
| 0618    | 1974 | 4     | 25  | 10   | 45     | 33.01  | 29.8981   | 1.1980   | 10    | m     | 4.5       |
| 0619    | 1974 | 12    | 25  | 22   | 37     | 21.96  | 28.8642   | -2.0549  | 12    | mb    | 4.8       |
| 0620    | 1975 | 3     | 5   | 11   | 0      | 8.25   | 31.0324   | 4.2976   | 10    | m     | 5.3       |
| 0621    | 1976 | 1     | 16  | 3    | 25     | 14.93  | 31.2825   | 2.0690   | 10    | m     | 5         |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0622    | 1976 | 7     | 31  | 3    | 7      | 16     | 30.4000   | 0.6000   |       | m     | 4.6       |
| 0623    | 1977 | 1     | 1   | 17   | 56     | 3.29   | 28.7924   | -2.1203  | 12    | m     | 4.5       |
| 0624    | 1977 | 1     | 6   | 18   | 33     | 43.68  | 28.7034   | -2.5979  | 11.7  | mb    | 5.3       |
| 0625    | 1977 | 1     | 14  | 2    | 52     | 33.11  | 28.9776   | -1.5965  | 10    | mb    | 4.8       |
| 0626    | 1977 | 4     | 14  | 14   | 36     | 22.75  | 28.7541   | -2.5222  | 12    | mb    | 4.7       |
| 0627    | 1977 | 4     | 21  | 4    | 9      | 25.28  | 28.8207   | -2.3591  | 12    | m     | 4.8       |
| 0628    | 1977 | 5     | 5   | 11   | 8      | 9      | 29.4000   | -2.6000  |       | m     | 4.2       |
| 0629    | 1977 | 10    | 7   | 8    | 40     | 44.19  | 30.5957   | 0.7609   | 10    | m     | 4.7       |
| 0630    | 1977 | 12    | 28  | 18   | 29     | 45.78  | 31.0701   | 1.8530   | 10    | mb    | 5.2       |
| 0631    | 1977 | 12    | 29  | 11   | 50     | 37.5   | 29.4506   | -0.2025  | 10    | mb    | 4.6       |
| 0632    | 1978 | 2     | 17  | 6    | 3      | 18     | 28.2000   | -1.6000  |       | m     | 4.1       |
| 0633    | 1978 | 5     | 23  | 9    | 2      | 38.42  | 36.1852   | 2.9428   | 10    | mb    | 4.5       |
| 0634    | 1978 | 7     | 13  | 19   | 35     | 22.3   | 31.0459   | 0.7538   | 10    | m     | 4.6       |
| 0635    | 1978 | 8     | 18  | 19   | 44     | 52.46  | 29.6462   | -2.3213  | 10    | m     | 4.4       |
| 0636    | 1978 | 10    | 6   | 4    | 12     | 1.9    | 28.6985   | -1.9974  | 10    | mb    | 4.9       |
| 0637    | 1979 | 1     | 19  | 2    | 52     | 3.27   | 36.1784   | 5.3207   | 10    | mb    | 4.4       |
| 0638    | 1979 | 2     | 26  | 4    | 40     | 38.64  | 30.7575   | 1.8176   | 10    | mb    | 4.9       |
| 0639    | 1979 | 3     | 9   | 10   | 1      | 20.29  | 30.4977   | 1.2596   | 31.2  | mb    | 5         |
| 0640    | 1979 | 3     | 16  | 15   | 3      | 1.79   | 29.6657   | -2.6431  | 10    | m     | 4.7       |
| 0641    | 1979 | 4     | 4   | 1    | 13     | 8.26   | 28.9919   | -0.9097  | 10    | m     | 4.2       |
| 0642    | 1979 | 4     | 15  | 2    | 44     | 8.84   | 30.6914   | 0.2717   | 10    | m     | 4.7       |
| 0643    | 1979 | 6     | 26  | 13   | 43     | 32.67  | 30.2171   | 3.5969   | 10    | m     | 5.2       |
| 0644    | 1979 | 12    | 4   | 7    | 34     | 45.66  | 31.2403   | 1.5819   | 29.9  | mb    | 5.1       |
| 0645    | 1980 | 2     | 10  | 20   | 22     | 17.65  | 29.2534   | -1.1912  | 10    | m     | 4.7       |
| 0646    | 1980 | 6     | 9   | 0    | 9      | 13.84  | 30.0360   | 0.6819   | 14    | m     | 4.4       |
| 0647    | 1980 | 6     | 13  | 8    | 11     | 20     | 31.0000   | -2.0000  |       | m     | 4.4       |
| 0648    | 1980 | 9     | 23  | 9    | 23     | 35.26  | 30.4667   | 1.4350   | 10    | m     | 4.6       |
| 0649    | 1980 | 9     | 26  | 7    | 45     | 53.3   | 29.9067   | 1.1017   | 21    | mb    | 4.1       |
| 0650    | 1980 | 12    | 11  | 17   | 27     | 55     | 30.2000   | -1.0000  |       | m     | 4.2       |
| 0651    | 1980 | 12    | 12  | 18   | 16     | 35.31  | 29.8989   | 0.1964   | 14    | m     | 4.7       |
| 0652    | 1981 | 2     | 7   | 0    | 12     | 26.29  | 30.8765   | 1.8304   | 10    | m     | 4.3       |
| 0653    | 1981 | 3     | 4   | 1    | 58     | 55.83  | 30.6739   | 1.2197   | 17.6  | mb    | 5         |
| 0654    | 1981 | 7     | 20  | 12   | 15     | 42.51  | 29.3731   | -0.6568  | 10    | m     | 4.3       |
| 0655    | 1982 | 1     | 9   | 17   | 30     | 27.5   | 28.3416   | -1.6505  | 19.7  | mb    | 5.3       |
| 0656    | 1982 | 7     | 22  | 9    | 23     | 1.3    | 29.6477   | -0.6711  | 10    | m     | 4.4       |
| 0657    | 1982 | 7     | 24  | 3    | 51     | 44.82  | 30.0719   | 1.0677   | 21    | m     | 4.1       |
| 0658    | 1982 | 10    | 15  | 8    | 37     | 54.49  | 31.8592   | 4.8944   | 17    | mb    | 5.1       |
| 0659    | 1983 | 1     | 15  | 16   | 34     | 9.1    | 29.9705   | 0.4143   | 9.8   | mb    | 5.2       |
| 0660    | 1983 | 9     | 24  | 23   | 26     | 23.13  | 28.2851   | -1.7128  | 10.4  | mb    | 5.2       |
| 0661    | 1983 | 11    | 21  | 1    | 35     | 49     | 28.6000   | -0.4000  |       | m     | 4.3       |
| 0662    | 1984 | 7     | 1   | 20   | 2      | 54.16  | 33.0259   | -1.0159  | 10    | m     | 4         |
| 0663    | 1984 | 7     | 17  | 9    | 23     | 52.64  | 29.7204   | -0.3040  | 10    | mb    | 4.7       |
| 0664    | 1984 | 8     | 22  | 1    | 57     | 54.36  | 30.6220   | -1.9070  | 10    | m     | 4         |
| 0665    | 1985 | 6     | 28  | 22   | 46     | 22.18  | 28.9528   | -2.4036  | 12    | mb    | 5         |
| 0666    | 1985 | 8     | 20  | 5    | 46     | 2.8    | 36.0338   | 5.4254   | 9.4   | mb    | 5.5       |
| 0667    | 1985 | 9     | 3   | 9    | 49     | 23.69  | 29.0973   | -1.2673  | 10    | m     | 4.7       |
| 0668    | 1985 | 11    | 13  | 23   | 26     | 57     | 31.2000   | 0.5000   |       | m     | 4.2       |
| 0669    | 1985 | 12    | 18  | 2    | 15     | 36.7   | 33.1747   | 4.7160   | 10    | mb    | 4.3       |
| 0670    | 1986 | 2     | 8   | 21   | 35     | 13     | 29.9000   | 0.2000   |       | m     | 4.1       |
| 0671    | 1986 | 3     | 23  | 15   | 26     | 49.18  | 30.1098   | 0.3656   | 10    | mb    | 4.7       |
| 0672    | 1986 | 6     | 28  | 17   | 3      | 46.45  | 33.9804   | -0.9973  | 10    | mb    | 4.2       |
| 0673    | 1986 | 7     | 20  | 20   | 5      | 9.15   | 29.8857   | 0.9707   | 21    | m     | 4.3       |
| 0674    | 1987 | 1     | 16  | 19   | 40     | 5      | 28.5550   | -1.6620  | 10    | mb    | 4.9       |
| 0675    | 1987 | 2     | 21  | 20   | 19     | 55.71  | 30.4590   | 2.5720   | 10    | m     | 4.4       |
| 0676    | 1987 | 9     | 13  | 2    | 30     | 55.2   | 35.8500   | -0.9200  | 10    | m     | 4.5       |
| 0677    | 1987 | 10    | 9   | 3    | 49     | 20.04  | 35.9651   | 5.6048   | 10    | mb    | 4.5       |
| 0678    | 1987 | 12    | 20  | 14   | 19     | 14     | 31.0000   | 0.5000   |       | m     | 4.2       |
| 0679    | 1988 | 1     | 2   | 9    | 5      | 55.68  | 30.2309   | 0.7310   | 14    | m     | 4.6       |
| 0680    | 1988 | 4     | 30  | 16   | 25     | 7.39   | 35.4665   | 4.7940   | 10    | m     | 4.5       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0681    | 1988 | 5     | 1   | 10   | 20     | 19.04  | 31.8622   | -2.5608  | 10    | mb    | 4         |
| 0682    | 1988 | 5     | 7   | 5    | 5      | 35.55  | 30.0122   | -0.7189  | 10    | mb    | 4.5       |
| 0683    | 1988 | 8     | 3   | 11   | 27     | 41.4   | 30.4112   | 1.1721   | 10    | m     | 4.2       |
| 0684    | 1988 | 8     | 18  | 15   | 31     | 6.04   | 33.6497   | -1.9080  | 10    | m     | 4.3       |
| 0685    | 1989 | 1     | 5   | 5    | 8      | 16.86  | 30.1028   | 0.1633   | 16    | mb    | 4.7       |
| 0686    | 1989 | 5     | 26  | 10   | 34     | 40.12  | 33.2341   | -1.1422  | 10    | m     | 4.5       |
| 0687    | 1989 | 5     | 29  | 18   | 58     | 42.68  | 31.3358   | -1.3866  | 10    | m     | 4.4       |
| 0688    | 1990 | 5     | 20  | 2    | 22     | 3.5    | 32.1863   | 5.1383   | 13.8  | mb    | 6.7       |
| 0689    | 1990 | 5     | 20  | 6    | 41     | 25.8   | 32.1693   | 4.5667   | 10    | mb    | 4.6       |
| 0690    | 1990 | 5     | 20  | 19   | 30     | 47.01  | 31.9535   | 5.0793   | 17    | mb    | 4.5       |
| 0691    | 1990 | 5     | 23  | 0    | 19     | 43.03  | 31.9756   | 4.6932   | 10    | m     | 4.9       |
| 0692    | 1990 | 5     | 23  | 12   | 26     | 50.41  | 31.8879   | 5.1991   | 17    | mb    | 4.9       |
| 0693    | 1990 | 5     | 24  | 19   | 34     | 48.16  | 31.9620   | 5.3585   | 25.8  | Mb    | 6.1       |
| 0694    | 1990 | 5     | 24  | 20   | 0      | 11.35  | 31.8563   | 5.3122   | 25.5  | mb    | 6.5       |
| 0695    | 1990 | 5     | 24  | 22   | 16     | 6.34   | 31.9533   | 5.4544   | 14.9  | mb    | 5.5       |
| 0696    | 1990 | 5     | 24  | 22   | 50     | 19.73  | 31.5696   | 4.7910   | 10    | mb    | 4.7       |
| 0697    | 1990 | 5     | 25  | 0    | 42     | 34.3   | 31.9108   | 5.3174   | 15    | mb    | 5.4       |
| 0698    | 1990 | 5     | 25  | 2    | 49     | 4.71   | 31.3823   | 5.3295   | 10    | mb    | 4.8       |
| 0699    | 1990 | 5     | 25  | 6    | 12     | 45.4   | 31.4971   | 4.1464   | 10    | mb    | 4.8       |
| 0700    | 1990 | 5     | 25  | 6    | 38     | 47     | 32.0000   | 5.1000   |       | m     | 4.8       |
| 0701    | 1990 | 5     | 25  | 13   | 23     | 35.37  | 31.5063   | 4.4697   | 10    | mb    | 4.5       |
| 0702    | 1990 | 5     | 25  | 15   | 14     | 5.85   | 31.7144   | 5.3423   | 10    | mb    | 4.7       |
| 0703    | 1990 | 5     | 26  | 5    | 53     | 53.36  | 32.0957   | 5.2009   | 20    | mb    | 4.8       |
| 0704    | 1990 | 5     | 26  | 14   | 22     | 42.47  | 31.6656   | 5.1107   | 10    | mb    | 5.1       |
| 0705    | 1990 | 5     | 26  | 14   | 39     | 57.66  | 31.6152   | 4.6238   | 10    | mb    | 4.6       |
| 0706    | 1990 | 5     | 27  | 7    | 29     | 35.46  | 31.9576   | 4.5907   | 16.4  | mb    | 5         |
| 0707    | 1990 | 5     | 28  | 1    | 12     | 0.46   | 31.7799   | 5.4685   | 15    | mb    | 4.8       |
| 0708    | 1990 | 5     | 29  | 4    | 37     | 31.48  | 32.3425   | 5.4260   | 10    | mb    | 4.7       |
| 0709    | 1990 | 6     | 2   | 20   | 7      | 25.4   | 31.2246   | 5.4098   | 10    | mb    | 4.3       |
| 0710    | 1990 | 6     | 3   | 12   | 50     | 9.38   | 31.7683   | 5.3352   | 17    | mb    | 4.7       |
| 0711    | 1990 | 6     | 3   | 16   | 23     | 44.4   | 32.2184   | 5.3441   | 32.2  | mb    | 5         |
| 0712    | 1990 | 6     | 3   | 17   | 21     | 14.22  | 31.8766   | 5.3699   | 17    | m     | 4.5       |
| 0713    | 1990 | 6     | 3   | 20   | 41     | 53.15  | 31.8833   | 4.3490   | 10    | mb    | 4.6       |
| 0714    | 1990 | 6     | 9   | 8    | 6      | 6.23   | 32.0348   | 5.3569   | 19.2  | mb    | 4.7       |
| 0715    | 1990 | 6     | 16  | 3    | 48     | 3.25   | 31.7691   | 5.4526   | 20    | mb    | 4.1       |
| 0716    | 1990 | 6     | 17  | 1    | 37     | 20.41  | 31.3321   | 5.4229   | 10    | mb    | 4.2       |
| 0717    | 1990 | 6     | 18  | 10   | 12     | 7.58   | 31.6516   | 4.9461   | 10    | mb    | 4.4       |
| 0718    | 1990 | 6     | 19  | 19   | 25     | 29.33  | 31.7018   | 4.5899   | 17    | m     | 4.6       |
| 0719    | 1990 | 6     | 20  | 18   | 48     | 0.44   | 31.6709   | 5.3821   | 15    | mb    | 5         |
| 0720    | 1990 | 6     | 29  | 8    | 44     | 58.48  | 31.9707   | 5.4416   | 10    | m     | 4.6       |
| 0721    | 1990 | 6     | 30  | 10   | 17     | 47.41  | 32.3474   | 5.2698   | 10    | m     | 4.6       |
| 0722    | 1990 | 7     | 7   | 18   | 42     | 11.04  | 31.4017   | 5.1518   | 10    | mb    | 4.1       |
| 0723    | 1990 | 7     | 8   | 2    | 29     | 25.32  | 31.5671   | 5.2175   | 10    | mb    | 4.4       |
| 0724    | 1990 | 7     | 9   | 15   | 11     | 23.5   | 31.6786   | 5.4244   | 17.5  | mb    | 6         |
| 0725    | 1990 | 7     | 15  | 15   | 8      | 31.69  | 32.1857   | 4.9519   | 17    | mb    | 4.5       |
| 0726    | 1990 | 7     | 19  | 17   | 6      | 9.43   | 31.5481   | 4.3027   | 10    | mb    | 4.6       |
| 0727    | 1990 | 7     | 27  | 20   | 41     | 34.21  | 32.2596   | 4.8873   | 24.5  | mb    | 4.8       |
| 0728    | 1990 | 7     | 28  | 6    | 54     | 49.49  | 32.0075   | 5.1512   | 20    | mb    | 4.4       |
| 0729    | 1990 | 7     | 28  | 16   | 46     | 6.69   | 32.5982   | 5.2283   | 29.2  | mb    | 5.5       |
| 0730    | 1990 | 7     | 28  | 17   | 17     | 34.33  | 32.3996   | 5.1032   | 10    | mb    | 4.4       |
| 0731    | 1990 | 8     | 6   | 10   | 11     | 0.3    | 32.0946   | 5.1444   | 17    | m     | 4.9       |
| 0732    | 1990 | 8     | 11  | 2    | 34     | 20.46  | 32.9163   | -0.0499  | 10    | mb    | 4.5       |
| 0733    | 1990 | 8     | 13  | 2    | 47     | 7.24   | 31.8303   | 5.2540   | 20    | mb    | 4.6       |
| 0734    | 1990 | 8     | 15  | 12   | 55     | 19     | 30.0000   | 4.9000   |       | m     | 4.5       |
| 0735    | 1990 | 9     | 4   | 1    | 48     | 3.55   | 29.0671   | -0.4869  | 14.2  | mb    | 5         |
| 0736    | 1990 | 9     | 7   | 0    | 12     | 28.83  | 31.5428   | 5.3787   | 16.9  | mb    | 5.3       |
| 0737    | 1990 | 9     | 29  | 1    | 23     | 48.01  | 31.8671   | 5.1052   | 17    | mb    | 4.4       |
| 0738    | 1990 | 12    | 11  | 5    | 9      | 12.83  | 32.7097   | 5.8117   | 10    | mb    | 4.9       |
| 0739    | 1990 | 12    | 15  | 20   | 56     | 53.88  | 29.5062   | 0.1979   | 17.9  | mb    | 4.7       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0740    | 1990 | 12    | 20  | 18   | 37     | 45.96  | 29.5677   | -0.0803  | 10    | mb    | 4.5       |
| 0741    | 1991 | 1     | 5   | 15   | 47     | 49.57  | 32.0976   | 5.1127   | 17    | mb    | 4.9       |
| 0742    | 1991 | 1     | 8   | 16   | 9      | 32.21  | 32.4790   | 5.2465   | 10    | mb    | 4.9       |
| 0743    | 1991 | 1     | 10  | 7    | 6      | 27.55  | 31.7396   | 5.0338   | 7.3   | mb    | 5.2       |
| 0744    | 1991 | 1     | 31  | 6    | 13     | 11.19  | 32.7535   | 5.2443   | 7.3   | mb    | 4.7       |
| 0745    | 1991 | 2     | 3   | 14   | 46     | 44.97  | 32.4660   | 5.2109   | 10    | mb    | 4.6       |
| 0746    | 1991 | 2     | 4   | 21   | 23     | 57.9   | 29.4900   | 1.6870   | 15    | mb    | 4         |
| 0747    | 1991 | 2     | 7   | 23   | 11     | 40.4   | 34.9480   | 3.9560   | 15    | mb    | 4.3       |
| 0748    | 1991 | 2     | 9   | 8    | 45     | 57.36  | 32.4379   | 5.2656   | 10    | mb    | 4.6       |
| 0749    | 1991 | 2     | 24  | 19   | 31     | 54.25  | 28.6047   | -1.6451  | 10    | mb    | 4.6       |
| 0750    | 1991 | 3     | 15  | 8    | 22     | 55.82  | 32.0851   | 5.5594   | 10    | mb    | 4.8       |
| 0751    | 1991 | 3     | 27  | 11   | 54     | 26.94  | 31.9357   | 5.4192   | 20    | mb    | 4.9       |
| 0752    | 1991 | 3     | 29  | 9    | 6      | 8.4    | 32.6024   | 5.1960   | 12    | mb    | 5.5       |
| 0753    | 1991 | 3     | 29  | 16   | 54     | 32.87  | 32.8267   | 5.3711   | 11.4  | mb    | 4.9       |
| 0754    | 1991 | 5     | 9   | 17   | 0      | 42.23  | 31.4782   | 5.0343   | 10    | mb    | 4.7       |
| 0755    | 1991 | 7     | 16  | 7    | 28     | 42.26  | 30.0517   | 0.5618   | 14    | mb    | 4.1       |
| 0756    | 1991 | 7     | 29  | 14   | 31     | 49.3   | 33.3869   | -1.5907  | 10    | m     | 4.3       |
| 0757    | 1991 | 8     | 1   | 13   | 10     | 12     | 30.0000   | -1.0000  |       | m     | 4.2       |
| 0758    | 1991 | 9     | 6   | 16   | 8      | 37.22  | 32.1533   | 5.2751   | 10    | mb    | 4.8       |
| 0759    | 1991 | 9     | 8   | 7    | 49     | 16.63  | 32.0566   | 5.2072   | 17    | mb    | 4.3       |
| 0760    | 1991 | 10    | 9   | 17   | 22     | 3.98   | 31.2999   | 1.7893   | 9.8   | mb    | 5.8       |
| 0761    | 1991 | 10    | 24  | 6    | 8      | 41.4   | 31.4907   | 5.1312   | 10    | mb    | 4.5       |
| 0762    | 1992 | 2     | 13  | 18   | 13     | 54     | 33.7000   | -0.9000  |       | m     | 4.3       |
| 0763    | 1992 | 2     | 27  | 6    | 49     | 34     | 32.0000   | -1.9000  |       | m     | 4.5       |
| 0764    | 1992 | 3     | 1   | 11   | 15     | 13.61  | 29.0576   | -2.4013  | 8.6   | mb    | 4.5       |
| 0765    | 1992 | 3     | 2   | 20   | 30     | 43.93  | 31.3967   | 5.0143   | 10    | mb    | 4.4       |
| 0766    | 1992 | 10    | 12  | 23   | 42     | 8.65   | 32.2168   | 4.9942   | 17    | mb    | 4.6       |
| 0767    | 1992 | 10    | 13  | 16   | 22     | 12.16  | 31.7663   | 5.1563   | 17    | mb    | 4.7       |
| 0768    | 1993 | 2     | 8   | 12   | 25     | 34.25  | 34.3083   | -0.8962  | 10    | m     | 4.7       |
| 0769    | 1993 | 9     | 14  | 19   | 19     | 19.08  | 34.6817   | -2.1213  | 10    | mb    | 4.7       |
| 0770    | 1993 | 9     | 28  | 22   | 31     | 10.7   | 29.9427   | 0.5028   | 10.4  | mb    | 4.9       |
| 0771    | 1993 | 10    | 18  | 5    | 50     | 16.01  | 30.2062   | 0.4579   | 14.6  | mb    | 4.9       |
| 0772    | 1993 | 11    | 16  | 2    | 55     | 27.45  | 28.5564   | -1.4681  | 10    | mb    | 4.3       |
| 0773    | 1993 | 12    | 4   | 18   | 45     | 14.63  | 31.8749   | 5.0768   | 10    | mb    | 4.2       |
| 0774    | 1994 | 2     | 5   | 23   | 34     | 11.32  | 30.1385   | 0.5041   | 12.5  | mb    | 5.9       |
| 0775    | 1994 | 2     | 6   | 0    | 13     | 27.71  | 30.0296   | 0.3189   | 9.3   | mb    | 4.9       |
| 0776    | 1994 | 2     | 6   | 1    | 39     | 34.4   | 30.5267   | 0.8287   | 10    | mb    | 4.4       |
| 0777    | 1994 | 2     | 7   | 1    | 32     | 15.08  | 30.1404   | 0.3419   | 14    | mb    | 4.3       |
| 0778    | 1994 | 2     | 7   | 22   | 50     | 58.88  | 29.9142   | 0.2484   | 10    | mb    | 4.3       |
| 0779    | 1994 | 2     | 8   | 10   | 16     | 23.26  | 30.2406   | 0.4143   | 14    | mb    | 4.5       |
| 0780    | 1994 | 3     | 9   | 8    | 25     | 27.07  | 29.4752   | 1.4076   | 10    | mb    | 4.8       |
| 0781    | 1994 | 3     | 12  | 1    | 19     | 3.5    | 29.3290   | 0.3560   | 14.7  | mb    | 4.1       |
| 0782    | 1994 | 3     | 20  | 2    | 12     | 36.86  | 30.0793   | 0.4934   | 14    | mb    | 4.9       |
| 0783    | 1994 | 3     | 29  | 22   | 59     | 21.05  | 30.0427   | 0.2486   | 7.1   | mb    | 4.5       |
| 0784    | 1994 | 4     | 4   | 2    | 42     | 29.8   | 29.3830   | -1.4490  | 13.2  | mb    | 4         |
| 0785    | 1994 | 5     | 22  | 0    | 50     | 23.93  | 29.9709   | 0.1556   | 16    | mb    | 4.7       |
| 0786    | 1994 | 8     | 22  | 19   | 56     | 51.03  | 34.8874   | 4.3203   | 9.9   | mb    | 4.7       |
| 0787    | 1994 | 8     | 31  | 14   | 59     | 59.29  | 30.9397   | 1.4865   | 9.9   | mb    | 4.9       |
| 0788    | 1994 | 9     | 5   | 7    | 45     | 56.4   | 30.2550   | 0.4750   | 18    | mb    | 4         |
| 0789    | 1994 | 9     | 12  | 18   | 56     | 57.7   | 34.2460   | -0.7880  | 9     | mb    | 4         |
| 0790    | 1994 | 12    | 19  | 15   | 48     | 26.23  | 34.4427   | -0.1554  | 10    | mb    | 4.3       |
| 0791    | 1994 | 12    | 21  | 3    | 59     | 54.9   | 35.5320   | 0.3740   | 1.2   | mb    | 4.2       |
| 0792    | 1995 | 1     | 23  | 15   | 18     | 20     | 36.2830   | 2.6610   | 0     | mb    | 4         |
| 0793    | 1995 | 2     | 15  | 10   | 54     | 28.5   | 31.9760   | 2.7670   | 3.6   | mb    | 4         |
| 0794    | 1995 | 3     | 22  | 23   | 20     | 0.16   | 30.1100   | -0.0800  | 0     | mb    | 4         |
| 0795    | 1995 | 4     | 5   | 12   | 15     | 40.21  | 30.4400   | 0.0300   | 8.9   | mb    | 4.2       |
| 0796    | 1995 | 4     | 29  | 11   | 50     | 54     | 28.6072   | -1.1940  | 6.4   | mb    | 5.1       |
| 0797    | 1995 | 5     | 26  | 11   | 29     | 10.5   | 30.2575   | 0.9090   | 10    | mb    | 4.5       |
| 0798    | 1995 | 7     | 7   | 16   | 18     | 51.8   | 36.2590   | 1.9410   | 38    | mb    | 4         |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0799    | 1995 | 8     | 17  | 22   | 30     | 47     | 31.4010   | 2.9430   | 38    | mb    | 4.2       |
| 0800    | 1995 | 8     | 26  | 14   | 27     | 46.34  | 31.2254   | 2.1313   | 10    | mb    | 4.1       |
| 0801    | 1995 | 9     | 1   | 20   | 35     | 36.77  | 36.0263   | -1.9540  | 10    | mb    | 4.1       |
| 0802    | 1995 | 11    | 12  | 22   | 29     | 43.4   | 29.7000   | -1.2300  | 10    | mb    | 4         |
| 0803    | 1995 | 12    | 23  | 5    | 49     | 38.4   | 33.9600   | -2.2900  | 18    | mb    | 4         |
| 0804    | 1996 | 2     | 9   | 0    | 23     | 8.48   | 29.5811   | -0.0838  | 10    | ml    | 4.8       |
| 0805    | 1996 | 2     | 12  | 12   | 44     | 36.6   | 30.2400   | 3.6500   | 0     | mb    | 4.5       |
| 0806    | 1996 | 3     | 23  | 16   | 20     | 17.6   | 35.3980   | 4.9640   | 10    | mb    | 4         |
| 0807    | 1996 | 3     | 24  | 8    | 24     | 25.87  | 29.7936   | 0.4308   | 2.9   | mb    | 5         |
| 0808    | 1996 | 3     | 24  | 11   | 20     | 46     | 30.1950   | 0.4590   |       | ml    | 5.3       |
| 0809    | 1996 | 3     | 24  | 22   | 52     | 42.3   | 30.3790   | 0.6050   | 9.4   | ml    | 4.9       |
| 0810    | 1996 | 4     | 2   | 1    | 17     | 7.36   | 36.0198   | 3.1166   | 10    | mb    | 4.3       |
| 0811    | 1996 | 4     | 3   | 3    | 37     | 15.76  | 36.0178   | 3.3155   | 10    | mb    | 4.5       |
| 0812    | 1996 | 5     | 22  | 2    | 48     | 46.87  | 29.8129   | 0.2506   | 14    | ml    | 4.4       |
| 0813    | 1996 | 7     | 8   | 21   | 22     | 3.3    | 29.5050   | -1.5610  | 13.1  | ml    | 4.8       |
| 0814    | 1996 | 8     | 28  | 7    | 58     | 34.2   | 29.0170   | -2.2870  | 13.1  | ml    | 4.4       |
| 0815    | 1996 | 10    | 20  | 0    | 33     | 51.4   | 31.8920   | 4.4570   | 10    | ml    | 4.5       |
| 0816    | 1996 | 12    | 23  | 12   | 15     | 58.63  | 30.2056   | 0.8313   | 25.3  | mb    | 4.2       |
| 0817    | 1996 | 12    | 27  | 2    | 23     | 54.9   | 35.4600   | 1.8500   | 0     | mb    | 4.2       |
| 0818    | 1997 | 1     | 1   | 0    | 15     | 57.2   | 33.4270   | -1.1880  | 10    | ml    | 4.7       |
| 0819    | 1997 | 1     | 8   | 12   | 5      | 5.8    | 30.0640   | 0.7100   |       | ml    | 5.1       |
| 0820    | 1997 | 1     | 10  | 7    | 21     | 31     | 33.4590   | -1.0170  |       | ml    | 4.3       |
| 0821    | 1997 | 1     | 18  | 21   | 21     | 23.4   | 33.4630   | -1.2170  | 9.4   | ml    | 4.5       |
| 0822    | 1997 | 2     | 5   | 1    | 29     | 33.5   | 33.7650   | -0.8750  | 11.5  | ml    | 4         |
| 0823    | 1997 | 2     | 11  | 7    | 38     | 41.41  | 29.2217   | -2.2860  | 10    | mb    | 4.4       |
| 0824    | 1997 | 3     | 19  | 22   | 4      | 45.9   | 30.2840   | 0.1250   | 0     | ml    | 4.7       |
| 0825    | 1997 | 3     | 22  | 0    | 55     | 9.3    | 30.3490   | 0.2510   | 0     | ml    | 4.5       |
| 0826    | 1997 | 4     | 13  | 22   | 42     | 49.6   | 30.0820   | -0.7070  | 9.3   | ml    | 5         |
| 0827    | 1997 | 5     | 27  | 16   | 18     | 40.56  | 31.3029   | 2.6303   | 10    | mb    | 4.1       |
| 0828    | 1997 | 5     | 27  | 16   | 41     | 7.08   | 31.4020   | 2.3136   | 28.1  | mb    | 4.9       |
| 0829    | 1997 | 5     | 27  | 17   | 21     | 42.49  | 31.3213   | 1.8242   | 10    | mb    | 4.2       |
| 0830    | 1997 | 5     | 27  | 23   | 46     | 33.6   | 31.3960   | 2.1670   | 10    | ml    | 5.2       |
| 0831    | 1997 | 5     | 28  | 0    | 5      | 2.08   | 31.2930   | 1.8603   | 10    | mb    | 4.1       |
| 0832    | 1997 | 5     | 28  | 2    | 6      | 40     | 33.2710   | 3.4260   | 14.1  | ml    | 4.9       |
| 0833    | 1997 | 5     | 29  | 2    | 18     | 32.2   | 31.9820   | 2.7760   | 9     | ml    | 4.4       |
| 0834    | 1997 | 5     | 29  | 14   | 28     | 42.1   | 31.3110   | 1.8560   | 13    | ml    | 4.6       |
| 0835    | 1997 | 5     | 31  | 13   | 24     | 20.04  | 31.3924   | 2.1732   | 10    | mb    | 4         |
| 0836    | 1997 | 6     | 1   | 14   | 44     | 23.5   | 31.5960   | 1.7050   | 10    | ml    | 4.9       |
| 0837    | 1997 | 6     | 16  | 23   | 16     | 56     | 31.4055   | 2.3048   | 10    | mb    | 4.5       |
| 0838    | 1997 | 7     | 18  | 1    | 45     | 13.97  | 31.6549   | 2.3854   | 10    | mb    | 4.6       |
| 0839    | 1997 | 7     | 18  | 2    | 44     | 26.53  | 31.3743   | 2.3553   | 10    | mb    | 4.3       |
| 0840    | 1997 | 7     | 18  | 2    | 50     | 2.4    | 31.6103   | 2.1498   | 10    | mb    | 4.6       |
| 0841    | 1997 | 7     | 18  | 3    | 17     | 26.16  | 31.4072   | 2.3797   | 10    | mb    | 4.8       |
| 0842    | 1997 | 7     | 19  | 13   | 45     | 18.02  | 31.8641   | 2.4077   | 10    | mb    | 4.6       |
| 0843    | 1997 | 7     | 19  | 14   | 21     | 36.11  | 31.5056   | 2.0389   | 10    | mb    | 4.5       |
| 0844    | 1997 | 7     | 30  | 20   | 16     | 29.8   | 31.4880   | 1.5580   | 10    | ml    | 4.2       |
| 0845    | 1997 | 9     | 18  | 17   | 50     | 56.1   | 33.4910   | -1.1240  | 7.4   | ml    | 4.1       |
| 0846    | 1997 | 9     | 23  | 16   | 56     | 9.9    | 33.5630   | -0.9970  | 4     | ml    | 4.3       |
| 0847    | 1997 | 9     | 24  | 9    | 21     | 32.3   | 34.0320   | -0.8370  | 14    | ml    | 4.1       |
| 0848    | 1997 | 9     | 25  | 20   | 29     | 45.4   | 30.3670   | -0.3340  | 2.1   | ml    | 4.9       |
| 0849    | 1998 | 2     | 22  | 17   | 19     | 58.86  | 29.5251   | 0.5426   | 10    | mb    | 4.2       |
| 0850    | 1998 | 7     | 1   | 17   | 16     | 56.9   | 30.7780   | -0.5910  | 18.3  | ml    | 4.2       |
| 0851    | 1998 | 7     | 2   | 20   | 7      | 40.2   | 29.2350   | 1.3140   | 10    | ml    | 5         |
| 0852    | 1998 | 7     | 23  | 11   | 2      | 22.7   | 30.7690   | 1.3320   | 38.1  | ml    | 4.1       |
| 0853    | 1998 | 8     | 3   | 10   | 59     | 17.6   | 29.9810   | -1.0930  | 10    | ml    | 5.5       |
| 0854    | 1998 | 8     | 14  | 4    | 44     | 49.8   | 29.7190   | 0.2220   | 15    | ml    | 5.5       |
| 0855    | 1998 | 8     | 15  | 5    | 41     | 25.21  | 30.1046   | 0.7186   | 11.3  | mb    | 4.6       |
| 0856    | 1998 | 8     | 15  | 14   | 57     | 30.96  | 29.9556   | 1.1716   | 21    | mb    | 4.5       |
| 0857    | 1998 | 8     | 15  | 15   | 57     | 47.22  | 29.8906   | 1.8314   | 10    | mb    | 4.4       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0858    | 1998 | 8     | 15  | 16   | 16     | 47.92  | 30.2602   | 0.2290   | 10    | mb    | 4         |
| 0859    | 1998 | 8     | 15  | 17   | 29     | 18.6   | 30.0194   | 0.6994   | 14.3  | mb    | 4.8       |
| 0860    | 1998 | 8     | 16  | 4    | 47     | 41.5   | 29.9394   | 0.8017   | 9.5   | mb    | 4.6       |
| 0861    | 1998 | 8     | 16  | 5    | 32     | 30.6   | 29.9460   | -0.9160  | 0     | ml    | 4.4       |
| 0862    | 1998 | 8     | 17  | 2    | 38     | 19     | 30.2940   | -0.2280  | 18.4  | ml    | 4.3       |
| 0863    | 1998 | 8     | 20  | 14   | 42     | 42.9   | 28.6460   | -0.4340  | 0.1   | ml    | 4.8       |
| 0864    | 1998 | 8     | 20  | 21   | 17     | 41     | 31.0660   | -1.0510  | 6.5   | ml    | 4.9       |
| 0865    | 1998 | 10    | 18  | 12   | 58     | 28.31  | 30.1699   | 0.7688   | 14    | mb    | 4.2       |
| 0866    | 1998 | 10    | 22  | 15   | 13     | 39.75  | 28.9966   | -1.8783  | 12    | mb    | 4         |
| 0867    | 1998 | 10    | 23  | 8    | 33     | 46.81  | 36.0887   | 3.0406   | 10    | mb    | 4.3       |
| 0868    | 1999 | 1     | 1   | 9    | 5      | 48.37  | 31.4330   | 4.6094   | 10    | mb    | 4.1       |
| 0869    | 1999 | 1     | 22  | 22   | 48     | 2.15   | 32.3685   | 4.8124   | 10    | mb    | 4.2       |
| 0870    | 1999 | 4     | 4   | 17   | 49     | 53.9   | 29.4907   | -0.1992  | 25.3  | mb    | 4.6       |
| 0871    | 1999 | 4     | 23  | 22   | 34     | 32.6   | 29.8430   | 0.1280   | 0     | ml    | 5.2       |
| 0872    | 1999 | 5     | 12  | 2    | 36     | 16.5   | 30.1420   | -0.3450  | 0     | ml    | 4.5       |
| 0873    | 1999 | 5     | 28  | 20   | 55     | 3.3    | 29.8620   | 1.0190   | 0     | ml    | 5         |
| 0874    | 2000 | 3     | 2   | 2    | 44     | 52.9   | 28.1509   | -2.5284  | 11    | mb    | 5.3       |
| 0875    | 2000 | 5     | 15  | 8    | 33     | 3.21   | 36.2299   | 5.5711   | 10    | mb    | 4.4       |
| 0876    | 2000 | 9     | 12  | 16   | 51     | 19.32  | 28.5223   | -2.2944  | 10    | mb    | 4.5       |
| 0877    | 2000 | 10    | 5   | 10   | 8      | 26.16  | 28.6668   | -1.1752  | 10    | mb    | 4.5       |
| 0878    | 2000 | 10    | 11  | 3    | 55     | 12.63  | 28.5476   | -1.5459  | 10    | mb    | 4.1       |
| 0879    | 2000 | 10    | 23  | 12   | 2      | 14.05  | 30.4942   | 1.5099   | 10    | mb    | 4.7       |
| 0880    | 2001 | 1     | 31  | 19   | 15     | 31.11  | 29.4811   | 0.3543   | 22.9  | mb    | 4.9       |
| 0881    | 2001 | 4     | 30  | 16   | 2      | 12.28  | 31.4852   | 5.2422   | 10    | mb    | 4.2       |
| 0882    | 2001 | 6     | 29  | 23   | 40     | 2.7    | 30.0782   | 0.0824   | 13.6  | mb    | 5         |
| 0883    | 2001 | 9     | 24  | 1    | 29     | 9.77   | 35.8713   | 0.1370   | 10    | mb    | 4.7       |
| 0884    | 2002 | 1     | 4   | 13   | 2      | 20.95  | 29.7625   | -0.2896  | 9.1   | mb    | 4.8       |
| 0885    | 2002 | 1     | 17  | 14   | 27     | 0.56   | 29.2384   | -1.6110  | 10    | mb    | 4.3       |
| 0886    | 2002 | 1     | 17  | 20   | 1      | 30.6   | 29.2933   | -1.8006  | 12.9  | mb    | 4.8       |
| 0887    | 2002 | 1     | 18  | 8    | 7      | 58.77  | 28.9872   | -1.4772  | 10    | mb    | 4.4       |
| 0888    | 2002 | 1     | 18  | 15   | 14     | 4.1    | 28.9184   | -1.5379  | 10    | mb    | 4.2       |
| 0889    | 2002 | 1     | 18  | 21   | 8      | 54.71  | 29.0648   | -1.4958  | 10    | mb    | 4.2       |
| 0890    | 2002 | 1     | 19  | 4    | 26     | 21.82  | 29.0430   | -1.6247  | 10    | mb    | 4.1       |
| 0891    | 2002 | 1     | 19  | 17   | 9      | 30.43  | 29.4169   | -1.8550  | 10    | mb    | 4.5       |
| 0892    | 2002 | 1     | 19  | 20   | 38     | 57.87  | 29.0977   | -1.7693  | 12    | mb    | 4         |
| 0893    | 2002 | 1     | 20  | 0    | 14     | 45.91  | 29.0910   | -1.7481  | 8.9   | mb    | 5         |
| 0894    | 2002 | 1     | 20  | 5    | 17     | 20.05  | 29.0157   | -1.5405  | 10    | mN    | 4.4       |
| 0895    | 2002 | 1     | 20  | 23   | 28     | 17.9   | 29.0451   | -1.7054  | 10    | mb    | 4.3       |
| 0896    | 2002 | 1     | 20  | 23   | 31     | 46.71  | 29.2783   | -1.7849  | 10    | mN    | 4.2       |
| 0897    | 2002 | 1     | 20  | 23   | 45     | 30.49  | 29.0760   | -1.4373  | 10    | mb    | 4.2       |
| 0898    | 2002 | 1     | 21  | 1    | 19     | 34.36  | 28.8905   | -1.7378  | 10    | mb    | 4.8       |
| 0899    | 2002 | 1     | 21  | 2    | 0      | 15.34  | 28.8449   | -1.5362  | 10    | mb    | 4.1       |
| 0900    | 2002 | 1     | 21  | 4    | 39     | 24.25  | 28.9646   | -1.8218  | 12    | mb    | 5         |
| 0901    | 2002 | 1     | 21  | 10   | 55     | 5.54   | 29.0931   | -1.9363  | 12    | mb    | 4.9       |
| 0902    | 2002 | 1     | 21  | 14   | 29     | 48.91  | 28.7325   | -1.2732  | 0     | mb    | 4         |
| 0903    | 2002 | 1     | 22  | 1    | 2      | 33.41  | 28.8854   | -1.5632  | 10    | mb    | 5         |
| 0904    | 2002 | 1     | 22  | 2    | 1      | 2.67   | 29.1232   | -1.7258  | 10    | m     | 4.5       |
| 0905    | 2002 | 1     | 22  | 15   | 32     | 7.26   | 29.1427   | -1.6756  | 14    | mb    | 5         |
| 0906    | 2002 | 1     | 22  | 16   | 22     | 23.41  | 28.9583   | -1.6145  | 10    | mb    | 4.3       |
| 0907    | 2002 | 1     | 22  | 16   | 51     | 1.59   | 28.9645   | -1.4418  | 10    | mb    | 4.3       |
| 0908    | 2002 | 1     | 27  | 13   | 42     | 46.4   | 29.7162   | 0.6471   | 21    | mb    | 4.7       |
| 0909    | 2002 | 1     | 30  | 0    | 33     | 9.98   | 28.9990   | -1.6536  | 10    | mb    | 4         |
| 0910    | 2002 | 2     | 11  | 13   | 49     | 27.31  | 29.0752   | -1.3997  | 10    | mb    | 4.1       |
| 0911    | 2002 | 5     | 12  | 4    | 2      | 39.62  | 34.6281   | -1.2479  | 0     | mb    | 4         |
| 0912    | 2002 | 5     | 12  | 12   | 6      | 49.21  | 31.4868   | 5.0164   | 10    | mb    | 4.2       |
| 0913    | 2002 | 6     | 22  | 23   | 53     | 37.9   | 30.9442   | 1.4572   | 10    | mb    | 4.1       |
| 0914    | 2002 | 8     | 10  | 16   | 18     | 57.52  | 32.5231   | 3.2599   | 28.2  | mb    | 4.2       |
| 0915    | 2002 | 9     | 9   | 14   | 13     | 29.95  | 28.7830   | -2.4180  | 12    | mb    | 4.4       |
| 0916    | 2002 | 10    | 24  | 6    | 8      | 39.58  | 28.9159   | -1.9436  | 14.2  | mb    | 5.9       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0917    | 2002 | 10    | 24  | 7    | 12     | 19.51  | 28.9044   | -1.9335  | 9.4   | mb    | 5.3       |
| 0918    | 2002 | 10    | 24  | 8    | 3      | 17.35  | 28.9659   | -2.0812  | 12    | mb    | 4.8       |
| 0919    | 2002 | 10    | 24  | 10   | 19     | 23.51  | 28.9110   | -2.0591  | 12    | mb    | 4.7       |
| 0920    | 2002 | 10    | 24  | 11   | 12     | 54.91  | 28.7376   | -1.9219  | 0     | mblg  | 4.1       |
| 0921    | 2002 | 10    | 24  | 11   | 40     | 19.67  | 28.9032   | -1.8432  | 12    | mb    | 4.6       |
| 0922    | 2002 | 10    | 25  | 14   | 21     | 24.51  | 31.6842   | 5.3152   | 0     | mblg  | 4         |
| 0923    | 2002 | 10    | 26  | 12   | 56     | 48.68  | 29.0884   | -1.5778  | 10    | mb    | 4.7       |
| 0924    | 2002 | 12    | 13  | 13   | 24     | 28.3   | 29.1002   | -1.7734  | 12    | mb    | 4.5       |
| 0925    | 2002 | 12    | 23  | 2    | 50     | 40.53  | 35.0213   | -1.8075  | 13.3  | mb    | 5         |
| 0926    | 2003 | 1     | 19  | 1    | 15     | 15.7   | 29.7619   | 0.6535   | 22.5  | mb    | 4.4       |
| 0927    | 2003 | 3     | 20  | 6    | 15     | 22.95  | 29.6047   | -2.4692  | 15.9  | mb    | 5.2       |
| 0928    | 2003 | 5     | 3   | 3    | 48     | 32.66  | 29.6707   | 0.4506   | 7.1   | mb    | 4.6       |
| 0929    | 2003 | 6     | 6   | 16   | 18     | 40.79  | 31.7027   | 5.3317   | 10    | mb    | 4.1       |
| 0930    | 2003 | 6     | 6   | 17   | 31     | 38.35  | 31.9319   | 5.4395   | 20    | mb    | 4.5       |
| 0931    | 2003 | 7     | 17  | 11   | 49     | 17.31  | 28.8816   | -2.3186  | 12    | mb    | 4.2       |
| 0932    | 2003 | 8     | 5   | 18   | 56     | 54.31  | 29.4669   | -0.6938  | 23.4  | mb    | 5.3       |
| 0933    | 2003 | 8     | 5   | 21   | 33     | 26.73  | 29.1154   | -0.4506  | 10    | mb    | 4.4       |
| 0934    | 2003 | 8     | 22  | 22   | 6      | 52.2   | 28.9826   | -1.9186  | 12    | mb    | 4.1       |
| 0935    | 2003 | 8     | 25  | 2    | 6      | 0.11   | 29.1257   | -0.5523  | 10    | mb    | 4.5       |
| 0936    | 2003 | 11    | 2   | 12   | 47     | 20.46  | 30.1381   | 0.3137   | 14    | mb    | 4.3       |
| 0937    | 2003 | 12    | 31  | 4    | 17     | 24.97  | 28.6963   | -2.6393  | 10    | mb    | 4.1       |
| 0938    | 2004 | 2     | 5   | 21   | 35     | 35.16  | 30.5419   | 0.8655   | 10    | mb    | 4.4       |
| 0939    | 2004 | 3     | 18  | 20   | 37     | 44.32  | 31.3580   | 2.0309   | 30.7  | mb    | 4.7       |
| 0940    | 2004 | 3     | 18  | 22   | 13     | 9.01   | 31.9697   | 5.2735   | 20    | mb    | 4.6       |
| 0941    | 2004 | 5     | 24  | 4    | 13     | 2.99   | 30.2393   | 0.0738   | 16    | mb    | 4.1       |
| 0942    | 2004 | 6     | 7   | 7    | 47     | 31.3   | 31.7378   | 3.3328   | 10    | mb    | 4.2       |
| 0943    | 2004 | 12    | 13  | 3    | 6      | 54.71  | 30.2131   | 0.6068   | 14    | mb    | 4.3       |
| 0944    | 2004 | 12    | 13  | 4    | 9      | 3.37   | 30.1559   | 0.7570   | 14.5  | mb    | 4.7       |
| 0945    | 2004 | 12    | 28  | 7    | 3      | 20.28  | 34.5364   | -2.2308  | 0     | mb    | 4         |
| 0946    | 2005 | 1     | 30  | 21   | 16     | 8.87   | 29.0572   | -2.0056  | 12    | mb    | 4.5       |
| 0947    | 2005 | 3     | 13  | 3    | 4      | 22.68  | 29.8118   | 0.0884   | 16    | mb    | 4.1       |
| 0948    | 2005 | 9     | 3   | 6    | 5      | 13.52  | 29.8996   | -0.0066  | 16    | mb    | 4.4       |
| 0949    | 2006 | 3     | 9   | 1    | 30     | 9.7    | 32.1235   | 5.3517   | 20    | mb    | 4.2       |
| 0950    | 2006 | 4     | 8   | 2    | 22     | 46.6   | 29.7201   | -2.5914  | 10    | mblg  | 4.2       |
| 0951    | 2006 | 4     | 27  | 4    | 18     | 29.15  | 30.0462   | 0.3534   | 14.5  | mb    | 5.3       |
| 0952    | 2006 | 4     | 27  | 17   | 54     | 43.11  | 30.0676   | 0.2772   | 14    | mb    | 4.3       |
| 0953    | 2006 | 5     | 29  | 15   | 30     | 36.81  | 30.0563   | 0.3080   | 15.9  | mb    | 4.7       |
| 0954    | 2006 | 11    | 3   | 0    | 29     | 27.6   | 29.5243   | -0.3100  | 10    | mblg  | 4         |
| 0955    | 2006 | 11    | 27  | 17   | 49     | 50.91  | 29.1423   | -1.5334  | 10    | mb    | 4         |
| 0956    | 2007 | 2     | 19  | 2    | 33     | 44.01  | 30.8212   | 1.7256   | 27.5  | mb    | 5.6       |
| 0957    | 2007 | 4     | 29  | 19   | 44     | 5.04   | 30.6977   | 1.8514   | 15.9  | mb    | 4.5       |
| 0958    | 2007 | 6     | 15  | 18   | 49     | 51.49  | 30.7911   | 1.7136   | 14.7  | mb    | 5.7       |
| 0959    | 2007 | 7     | 12  | 15   | 31     | 43.83  | 35.9993   | -2.1801  | 10    | mb    | 4.4       |
| 0960    | 2007 | 7     | 17  | 4    | 17     | 5.7    | 36.0239   | -2.6286  | 7.7   | mb    | 4.3       |
| 0961    | 2007 | 7     | 18  | 11   | 11     | 16.34  | 36.0259   | -2.6147  | 10    | mb    | 4.4       |
| 0962    | 2007 | 7     | 30  | 11   | 54     | 52.98  | 36.3280   | -2.4786  | 10    | mb    | 4.1       |
| 0963    | 2007 | 8     | 20  | 2    | 46     | 50.79  | 36.1753   | -2.5430  | 10    | mb    | 4.1       |
| 0964    | 2007 | 8     | 20  | 6    | 38     | 43.29  | 36.2560   | -2.3172  | 10    | mb    | 4.5       |
| 0965    | 2007 | 8     | 20  | 7    | 34     | 9.57   | 36.1798   | -2.4792  | 10    | mb    | 4         |
| 0966    | 2007 | 8     | 24  | 23   | 45     | 54.6   | 36.1618   | -2.6294  | 10    | mb    | 4.8       |
| 0967    | 2007 | 9     | 7   | 23   | 20     | 0.78   | 28.8508   | -2.3130  | 10    | mb    | 4.6       |
| 0968    | 2008 | 2     | 3   | 7    | 34     | 12.22  | 28.8844   | -2.3311  | 12.1  | mb    | 6.1       |
| 0969    | 2008 | 2     | 3   | 10   | 56     | 9.91   | 29.0030   | -2.4099  | 10.9  | mb    | 5.1       |
| 0970    | 2008 | 2     | 3   | 11   | 0      | 7.66   | 28.9788   | -2.2968  | 12    | mb    | 4.8       |
| 0971    | 2008 | 2     | 3   | 11   | 37     | 49.4   | 29.0196   | -2.5387  | 17    | mb    | 4.8       |
| 0972    | 2008 | 2     | 4   | 0    | 24     | 35.38  | 28.9509   | -2.4839  | 12    | mb    | 4.5       |
| 0973    | 2008 | 2     | 5   | 17   | 29     | 8.35   | 28.8946   | -2.5930  | 12    | mb    | 4.1       |
| 0974    | 2008 | 2     | 11  | 23   | 59     | 57.44  | 28.9907   | -2.5034  | 12    | ml    | 4         |
| 0975    | 2008 | 2     | 14  | 2    | 7      | 47.19  | 28.9546   | -2.3743  | 10.6  | mb    | 5.4       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 0976    | 2008 | 2     | 15  | 4    | 4      | 53.2   | 28.8740   | -2.4823  | 12    | mb    | 4.6       |
| 0977    | 2008 | 2     | 27  | 2    | 7      | 59.61  | 29.0493   | -2.4262  | 12    | mb    | 4         |
| 0978    | 2008 | 3     | 14  | 23   | 40     | 17.34  | 28.2186   | -1.4246  | 10    | mblg  | 4         |
| 0979    | 2008 | 5     | 11  | 10   | 34     | 10.83  | 29.7115   | 0.5198   | 10    | mb    | 4.4       |
| 0980    | 2008 | 8     | 26  | 14   | 56     | 56.58  | 30.8823   | 2.2732   | 10    | mb    | 4         |
| 0981    | 2008 | 8     | 29  | 16   | 36     | 13.56  | 29.6809   | -0.0561  | 0     | mb    | 4         |
| 0982    | 2008 | 10    | 1   | 14   | 15     | 53.2   | 33.6311   | -0.8622  | 26.6  | mb    | 4.6       |
| 0983    | 2008 | 10    | 5   | 0    | 2      | 14.09  | 29.0900   | -1.2148  | 13.8  | mb    | 5.1       |
| 0984    | 2008 | 10    | 5   | 0    | 32     | 9.64   | 29.1054   | -1.4825  | 10    | mblg  | 4         |
| 0985    | 2008 | 12    | 23  | 18   | 21     | 3.06   | 29.5575   | -0.5479  | 10    | mb    | 4         |
| 0986    | 2009 | 2     | 2   | 4    | 24     | 33.3   | 30.1260   | 0.3690   | 10    | ml    | 4.1       |
| 0987    | 2009 | 2     | 3   | 18   | 33     | 31.37  | 28.8710   | -2.1759  | 12    | ml    | 4.3       |
| 0988    | 2009 | 3     | 5   | 3    | 28     | 56.65  | 29.5203   | -0.1944  | 10    | mblg  | 4         |
| 0989    | 2009 | 3     | 25  | 5    | 3      | 21.56  | 29.4847   | -2.5901  | 10    | mb    | 4         |
| 0990    | 2009 | 7     | 30  | 14   | 48     | 6.02   | 30.5584   | 1.2214   | 10    | mb    | 4.3       |
| 0991    | 2009 | 9     | 2   | 11   | 9      | 14.4   | 30.7600   | 0.7020   | 10    | ml    | 4         |
| 0992    | 2009 | 10    | 1   | 2    | 37     | 32.01  | 30.0507   | 0.7220   | 0     | ms    | 4.9       |
| 0993    | 2009 | 10    | 2   | 12   | 27     | 25.29  | 30.0010   | 0.3281   | 0     | mblg  | 4.1       |
| 0994    | 2009 | 10    | 12  | 2    | 0      | 9.74   | 29.3010   | -1.3724  | 10    | mb    | 4.1       |
| 0995    | 2009 | 10    | 18  | 0    | 39     | 44.1   | 30.1867   | 0.4498   | 13.5  | mb    | 4.9       |
| 0996    | 2009 | 10    | 18  | 1    | 8      | 57.1   | 29.8431   | -0.5223  | 10    | ml    | 4         |
| 0997    | 2009 | 10    | 18  | 6    | 17     | 6.6    | 35.1740   | 2.4710   | 10    | ml    | 4.4       |
| 0998    | 2009 | 11    | 3   | 10   | 53     | 48.7   | 30.1283   | 0.3756   | 14    | mblg  | 4         |
| 0999    | 2010 | 1     | 28  | 23   | 52     | 31.21  | 29.2574   | -0.9383  | 12.5  | mb    | 5         |
| 1000    | 2010 | 1     | 28  | 23   | 57     | 23.98  | 29.3178   | -0.5962  | 10    | mb    | 4.1       |
| 1001    | 2010 | 5     | 1   | 4    | 58     | 52.65  | 31.9423   | 5.4378   | 20    | mb    | 4.3       |
| 1002    | 2010 | 6     | 13  | 12   | 13     | 24.23  | 34.4944   | -0.2843  | 10    | mb    | 5         |
| 1003    | 2010 | 6     | 16  | 21   | 51     | 7.19   | 34.6106   | -1.6757  | 10    | mb    | 4         |
| 1004    | 2010 | 7     | 9   | 18   | 30     | 51.73  | 29.5461   | -0.4156  | 10    | mb    | 4.2       |
| 1005    | 2010 | 10    | 8   | 23   | 40     | 54.48  | 30.6585   | 1.2111   | 10    | mb    | 4.1       |
| 1006    | 2010 | 10    | 23  | 11   | 8      | 22.21  | 36.0867   | 4.7794   | 10.1  | mb    | 4.9       |
| 1007    | 2010 | 12    | 12  | 20   | 34     | 21.8   | 29.7920   | 0.7765   | 21    | mb    | 4.8       |
| 1008    | 2010 | 12    | 27  | 22   | 10     | 8.82   | 33.2823   | 0.2550   | 10    | mb    | 4         |
| 1009    | 2011 | 1     | 17  | 8    | 22     | 27.15  | 30.8157   | 1.4963   | 10    | mb    | 4.6       |
| 1010    | 2011 | 3     | 15  | 3    | 25     | 19.19  | 31.2751   | 1.6294   | 10    | mb    | 5         |
| 1011    | 2012 | 1     | 22  | 21   | 3      | 37.36  | 36.1039   | 3.7342   | 19.4  | mb    | 5.2       |
| 1012    | 2012 | 2     | 2   | 2    | 54     | 3.49   | 28.5727   | -1.3680  | 10    | mb    | 4.5       |
| 1013    | 2012 | 6     | 12  | 3    | 30     | 15.26  | 31.8030   | 5.1397   | 17    | mblg  | 4         |
| 1014    | 2012 | 10    | 2   | 18   | 40     | 35.76  | 30.2338   | 0.5066   | 14    | mb    | 4.2       |
| 1015    | 2012 | 11    | 11  | 15   | 40     | 33.88  | 28.4424   | -0.3241  | 10    | mb    | 4         |
| 1016    | 2012 | 11    | 20  | 16   | 23     | 50.05  | 29.9425   | -0.4472  | 14.7  | mb    | 4.8       |
| 1017    | 2012 | 12    | 6   | 2    | 43     | 6.48   | 36.0173   | 0.4087   | 10    | mblg  | 4.1       |
| 1018    | 2013 | 4     | 20  | 0    | 30     | 27.62  | 30.8165   | 1.4861   | 10    | mb    | 4.8       |
| 1019    | 2013 | 7     | 2   | 13   | 33     | 18.38  | 30.9588   | 1.5154   | 17.3  | mb    | 5         |
| 1020    | 2013 | 7     | 3   | 19   | 21     | 46.61  | 30.8894   | 1.5496   | 15.7  | mb    | 5.7       |
| 1021    | 2013 | 7     | 3   | 20   | 1      | 48.98  | 31.2600   | 2.1191   | 10    | ms    | 4.4       |
| 1022    | 2013 | 7     | 3   | 20   | 41     | 12.35  | 31.1109   | 1.4928   | 10    | ml    | 4.3       |
| 1023    | 2013 | 7     | 3   | 22   | 22     | 19.59  | 30.9103   | 1.5165   | 16.9  | mb    | 5.2       |
| 1024    | 2013 | 7     | 5   | 13   | 42     | 20.58  | 29.8701   | -0.3950  | 10    | mb    | 4.2       |
| 1025    | 2013 | 7     | 12  | 2    | 45     | 20.42  | 30.8393   | 1.5395   | 10    | mb    | 4         |
| 1026    | 2013 | 7     | 30  | 3    | 34     | 19.59  | 30.2307   | 0.4078   | 14    | mb    | 4.3       |
| 1027    | 2013 | 8     | 5   | 6    | 2      | 30.9   | 31.1148   | 1.5220   | 10    | mb    | 4.4       |
| 1028    | 2013 | 8     | 5   | 7    | 33     | 56.04  | 31.1504   | 1.4652   | 10    | mb    | 4.6       |
| 1029    | 2013 | 8     | 5   | 11   | 39     | 21.26  | 30.6656   | 1.6071   | 10    | mb    | 4         |
| 1030    | 2013 | 10    | 8   | 8    | 40     | 13.96  | 30.6786   | 1.4902   | 10    | mb    | 4.4       |
| 1031    | 2013 | 12    | 11  | 7    | 29     | 57.73  | 30.5190   | 0.2692   | 10    | mb    | 4.1       |
| 1032    | 2013 | 12    | 19  | 21   | 26     | 41.1   | 32.3945   | -1.2500  | 10    | mb    | 4         |
| 1033    | 2014 | 2     | 11  | 8    | 33     | 29.73  | 34.7847   | 4.8491   | 10    | mb    | 4.2       |
| 1034    | 2014 | 9     | 21  | 10   | 18     | 26.78  | 30.1294   | 0.6550   | 14    | mb    | 4.1       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1035    | 2014 | 10    | 31  | 1    | 5      | 2.61   | 30.2374   | 0.4948   | 14    | mb    | 4.4       |
| 1036    | 2014 | 11    | 20  | 23   | 56     | 1.23   | 29.6535   | -0.3857  | 10    | mb    | 4.2       |
| 1037    | 2015 | 2     | 13  | 8    | 35     | 23.89  | 29.7330   | -0.2714  | 10    | mb    | 4.2       |
| 1038    | 2015 | 3     | 17  | 0    | 54     | 3.39   | 35.8837   | 3.1136   | 10    | mb    | 4.1       |
| 1039    | 2015 | 6     | 29  | 14   | 11     | 17.69  | 31.1498   | 2.6628   | 10    | mb    | 4.3       |
| 1040    | 2015 | 7     | 17  | 18   | 32     | 52.5   | 30.3164   | 1.1515   | 1.1   | mb    | 4.4       |
| 1041    | 2015 | 8     | 7   | 1    | 25     | 1.42   | 28.9329   | -2.1425  | 8.8   | mb    | 5.5       |
| 1042    | 2015 | 8     | 7   | 1    | 28     | 35.31  | 28.9339   | -2.1104  | 3.1   | mb    | 5.5       |
| 1043    | 2015 | 8     | 7   | 1    | 50     | 27.24  | 28.7634   | -2.1307  | 8.4   | mb    | 4.3       |
| 1044    | 2015 | 9     | 12  | 12   | 32     | 3.17   | 29.6446   | 0.3698   | 16.4  | mb    | 4.3       |
| 1045    | 2015 | 10    | 7   | 17   | 45     | 5.96   | 30.2688   | 0.2036   | 10    | mb    | 4.2       |
| 1046    | 2015 | 11    | 8   | 8    | 6      | 36.47  | 29.2061   | -1.0535  | 10    | mblg  | 4         |
| 1047    | 2015 | 11    | 24  | 17   | 47     | 37.4   | 31.0708   | 1.4139   | 10    | mb    | 4         |
| 1048    | 2015 | 11    | 25  | 9    | 38     | 13.11  | 29.8475   | -0.1964  | 16    | mb    | 4.3       |
| 1049    | 2016 | 2     | 4   | 12   | 43     | 58.83  | 28.4584   | -1.5478  | 8.2   | mb    | 5         |
| 1050    | 2016 | 2     | 4   | 14   | 27     | 29.64  | 28.4161   | -1.8407  | 10    | mb    | 4.4       |
| 1051    | 2016 | 6     | 11  | 1    | 5      | 16.54  | 29.4158   | -0.5749  | 10    | mb    | 4         |
| 1052    | 2016 | 8     | 30  | 18   | 58     | 9.4    | 34.6350   | 5.1510   | 15    | ml    | 4.3       |
| 1053    | 2016 | 9     | 10  | 12   | 27     | 32.11  | 31.5514   | -1.0669  | 34.6  | mb    | 5.7       |
| 1054    | 2016 | 9     | 23  | 16   | 11     | 57.47  | 29.0147   | -2.5395  | 12    | mb    | 4.7       |
| 1055    | 2016 | 10    | 1   | 9    | 57     | 16.63  | 29.8449   | 0.4875   | 19.4  | mb    | 4.2       |
| 1056    | 2016 | 10    | 6   | 9    | 50     | 53.62  | 30.1527   | 0.1668   | 27.4  | mb    | 4         |
| 1057    | 2016 | 10    | 24  | 23   | 29     | 59.45  | 28.9747   | -2.6058  | 12    | mb    | 4.6       |
| 1058    | 2017 | 2     | 18  | 3    | 37     | 15.26  | 30.8891   | 1.3843   | 10    | mb    | 4.2       |
| 1059    | 2017 | 2     | 25  | 17   | 19     | 33.34  | 31.0981   | 1.3849   | 5.3   | mb    | 4.5       |
| 1060    | 2017 | 4     | 10  | 8    | 17     | 33.7   | 29.8556   | -0.0801  | 16    | mb    | 4.3       |
| 1061    | 2017 | 4     | 29  | 22   | 28     | 29.44  | 31.6121   | -1.2710  | 10    | mb    | 4         |
| 1062    | 2017 | 7     | 4   | 6    | 31     | 37.76  | 29.7872   | 0.3798   | 0     | mb    | 4         |
| 1063    | 2017 | 7     | 30  | 7    | 2      | 29.8   | 29.7594   | -0.2257  | 16.8  | mb    | 5.2       |
| 1064    | 2017 | 9     | 16  | 4    | 44     | 42.44  | 28.8517   | -2.4573  | 12    | mb    | 4         |
| 1065    | 2017 | 11    | 13  | 14   | 8      | 19.49  | 36.2478   | 5.3323   | 10    | ml    | 4.3       |
| 1066    | 2017 | 11    | 30  | 21   | 48     | 35.92  | 28.8316   | -2.6451  | 12    | mb    | 4.9       |
| 1067    | 2018 | 1     | 9   | 9    | 0      | 59.89  | 28.4065   | -1.6707  | 10    | mb    | 4.4       |
| 1068    | 2018 | 9     | 13  | 23   | 52     | 48.19  | 29.9274   | 0.5962   | 14    | mb    | 4.2       |
| 1069    | 2018 | 10    | 1   | 5    | 58     | 3.62   | 29.3281   | -0.8129  | 10    | mb    | 4.3       |
| 1070    | 2018 | 12    | 1   | 18   | 36     | 48.95  | 29.5378   | -0.1497  | 10    | mb    | 4.2       |
| 1071    | 2019 | 1     | 5   | 18   | 13     | 45.12  | 31.4055   | 3.0918   | 10.8  | mb    | 4.7       |
| 1072    | 2019 | 4     | 3   | 19   | 40     | 50.74  | 31.1765   | 1.7843   | 10    | mb    | 4.4       |
| 1073    | 2019 | 4     | 7   | 3    | 17     | 3.04   | 28.2219   | -0.0735  | 10    | mb    | 4.2       |
| 1074    | 2019 | 4     | 19  | 8    | 56     | 49.51  | 29.0206   | -2.5806  | 10    | mb    | 4.2       |
| 1075    | 2019 | 8     | 5   | 9    | 37     | 13.76  | 29.5295   | -1.0325  | 10    | mb    | 4.3       |
| 1076    | 2019 | 8     | 6   | 16   | 58     | 31.95  | 30.0428   | 0.0325   | 16    | mb    | 4.4       |
| 1077    | 2019 | 9     | 6   | 6    | 15     | 34.48  | 30.3064   | 1.0815   | 10    | mb    | 4.5       |
| 1078    | 2019 | 9     | 17  | 15   | 51     | 28.15  | 30.2627   | 0.5999   | 10    | ml    | 4.1       |
| 1079    | 2019 | 12    | 3   | 10   | 25     | 41.34  | 30.2783   | 0.2984   | 10    | mb    | 4.3       |
| 1080    | 2020 | 1     | 8   | 17   | 54     | 35.35  | 29.6078   | 0.5596   | 10    | mb    | 4.1       |
| 1081    | 2020 | 1     | 11  | 17   | 4      | 27.37  | 28.9243   | -2.2637  | 12    | mb    | 4.1       |
| 1082    | 2020 | 1     | 28  | 22   | 32     | 5.2    | 29.7223   | -0.2615  | 10    | mb    | 4.5       |
| 1083    | 2020 | 1     | 30  | 13   | 1      | 9.42   | 30.1133   | -0.1297  | 16    | mb    | 4.2       |
| 1084    | 2020 | 3     | 19  | 22   | 35     | 48.8   | 29.6617   | -0.8077  | 10    | mb    | 4.3       |

**Appendix A-4: DGSM Catalogue**

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1228    | 1970 | 03    | 13  | 18   | 30     | 15     | 29.5000   | -0.8000  | 10.0  | ms    | 4.6       |
| 1229    | 1971 | 01    | 03  | 03   | 10     | 09     | 30.6551   | 1.8517   | 10.0  | ms    | 4.0       |
| 1230    | 1971 | 09    | 14  | 20   | 43     | 52     | 29.5058   | -1.0891  | 10.0  | ms    | 4.3       |
| 1231    | 1971 | 04    | 21  | 18   | 40     | 50     | 29.8648   | 0.1963   | 10.0  | ms    | 4.3       |
| 1232    | 1971 | 01    | 04  | 15   | 14     | 31     | 32.6309   | 3.8866   | 10.0  | ms    | 4.4       |
| 1233    | 1971 | 04    | 18  | 00   | 34     | 30     | 30.0331   | 0.2883   | 10.0  | ms    | 4.6       |
| 1234    | 1971 | 04    | 18  | 05   | 49     | 49     | 30.0569   | 0.2017   | 0.0   | ms    | 4.7       |
| 1235    | 1972 | 09    | 10  | 08   | 45     | 12     | 35.1172   | -0.2988  | 10.0  | ms    | 4.6       |
| 1236    | 1972 | 01    | 08  | 17   | 27     | 51     | 30.0844   | 0.5827   | 0.0   | ms    | 4.8       |
| 1237    | 1972 | 04    | 18  | 15   | 08     | 13     | 29.8223   | 0.6652   | 10.0  | ms    | 5.4       |
| 1238    | 1973 | 12    | 01  | 16   | 51     | 14     | 29.6192   | 0.7162   | 10.0  | ms    | 4.8       |
| 1239    | 1973 | 04    | 22  | 22   | 03     | 41     | 31.3180   | 4.1488   | 11.5  | ms    | 4.9       |
| 1240    | 1973 | 11    | 19  | 06   | 28     | 23     | 31.3262   | 4.2852   | 10.0  | ms    | 5.4       |
| 1241    | 1974 | 04    | 25  | 10   | 45     | 30     | 30.1038   | 1.2730   | 0.0   | ms    | 4.5       |
| 1242    | 1974 | 01    | 17  | 03   | 55     | 01     | 30.0964   | -0.1738  | 3.6   | ms    | 4.5       |
| 1243    | 1974 | 01    | 10  | 16   | 02     | 43     | 29.9070   | 0.4989   | 15.0  | ms    | 4.7       |
| 1244    | 1974 | 04    | 25  | 00   | 03     | 46     | 30.0491   | 1.1084   | 9.0   | ms    | 5.0       |
| 1245    | 1975 | 03    | 05  | 11   | 00     | 05     | 31.0908   | 4.3474   | 18.0  | ms    | 5.3       |
| 1246    | 1976 | 01    | 16  | 03   | 25     | 11     | 31.4406   | 2.1166   | 13.2  | ms    | 5.0       |
| 1247    | 1977 | 10    | 07  | 08   | 40     | 40     | 30.6033   | 0.9076   | 15.0  | ms    | 4.7       |
| 1248    | 1977 | 12    | 29  | 11   | 50     | 41     | 29.2799   | 0.2718   | 37.6  | ms    | 4.8       |
| 1249    | 1977 | 12    | 28  | 18   | 29     | 45     | 31.1897   | 2.0213   | 10.0  | ms    | 5.2       |
| 1250    | 1978 | 07    | 13  | 19   | 35     | 28     | 30.4335   | 0.2278   | 10.0  | ms    | 4.6       |
| 1251    | 1979 | 04    | 04  | 01   | 13     | 07     | 29.1767   | -1.0067  | 10.0  | ms    | 4.2       |
| 1252    | 1979 | 04    | 15  | 02   | 43     | 56     | 30.3078   | 1.1091   | 10.0  | ms    | 4.7       |
| 1253    | 1979 | 02    | 26  | 04   | 40     | 35     | 30.9370   | 1.8451   | 10.0  | ms    | 4.9       |
| 1254    | 1979 | 03    | 09  | 10   | 01     | 18     | 30.5105   | 1.2974   | 10.0  | ms    | 5.0       |
| 1255    | 1979 | 06    | 26  | 13   | 43     | 27     | 30.4751   | 4.1424   | 10.0  | ms    | 5.2       |
| 1256    | 1980 | 09    | 26  | 07   | 45     | 53     | 29.9398   | 1.0214   | 10.0  | ms    | 4.1       |
| 1257    | 1980 | 09    | 23  | 09   | 23     | 31     | 30.6708   | 1.7528   | 38.1  | ms    | 4.3       |
| 1258    | 1980 | 06    | 09  | 00   | 09     | 10     | 30.1424   | 0.7447   | 14.0  | ms    | 4.4       |
| 1259    | 1980 | 12    | 12  | 18   | 16     | 33     | 30.1708   | 0.3928   | 7.4   | ms    | 4.7       |
| 1260    | 1980 | 02    | 10  | 20   | 22     | 17     | 29.2582   | -1.1088  | 10.0  | ms    | 4.7       |
| 1261    | 1981 | 07    | 20  | 12   | 15     | 38     | 29.3892   | -0.3896  | 10.0  | ms    | 4.3       |
| 1262    | 1981 | 03    | 04  | 01   | 58     | 55     | 30.5431   | 1.3781   | 39.5  | ms    | 4.8       |
| 1263    | 1981 | 02    | 07  | 00   | 12     | 22     | 30.8635   | 1.8491   | 14.7  | ms    | 4.8       |
| 1264    | 1982 | 07    | 22  | 09   | 22     | 58     | 29.7025   | -0.4105  | 33.0  | ms    | 4.4       |
| 1265    | 1982 | 07    | 24  | 03   | 51     | 44     | 30.0165   | 0.9799   | 0.0   | ms    | 4.5       |
| 1266    | 1983 | 01    | 15  | 16   | 34     | 08     | 30.0919   | 0.5330   | 33.0  | ms    | 5.2       |
| 1267    | 1984 | 07    | 17  | 09   | 23     | 50     | 29.6896   | -0.1902  | 10.0  | ms    | 4.7       |
| 1268    | 1985 | 11    | 13  | 23   | 26     | 57     | 33.7000   | 0.5000   | 10.0  | ms    | 4.2       |
| 1269    | 1985 | 09    | 03  | 09   | 49     | 23     | 29.1646   | -0.9566  | 10.0  | ms    | 4.5       |
| 1270    | 1986 | 02    | 08  | 21   | 35     | 07     | 29.5888   | 0.2980   | 10.0  | ms    | 4.1       |
| 1271    | 1986 | 06    | 28  | 17   | 03     | 46     | 34.0241   | -0.8628  | 10.0  | ms    | 4.2       |
| 1272    | 1986 | 07    | 20  | 20   | 05     | 05     | 29.8914   | 1.0866   | 10.0  | ms    | 4.4       |
| 1273    | 1986 | 03    | 23  | 15   | 26     | 47     | 30.2987   | 0.5413   | 18.3  | ms    | 4.7       |
| 1274    | 1987 | 12    | 20  | 14   | 19     | 21     | 29.6236   | 0.2229   | 10.0  | ms    | 4.2       |
| 1275    | 1987 | 02    | 21  | 20   | 19     | 51     | 30.4328   | 2.8616   | 38.0  | ms    | 5.1       |
| 1276    | 1988 | 08    | 03  | 11   | 27     | 45     | 30.5000   | 1.0000   | 38.0  | ms    | 4.2       |
| 1277    | 1988 | 05    | 07  | 05   | 05     | 34     | 30.0007   | -0.4459  | 10.0  | ms    | 4.5       |
| 1278    | 1988 | 01    | 02  | 09   | 05     | 52     | 30.1451   | 0.4937   | 10.0  | ms    | 4.6       |
| 1279    | 1989 | 05    | 29  | 18   | 58     | 44     | 30.1082   | -0.0174  | 10.0  | ms    | 4.3       |
| 1280    | 1989 | 05    | 26  | 10   | 34     | 41     | 33.4607   | -1.0628  | 0.0   | ms    | 4.5       |
| 1281    | 1989 | 01    | 05  | 05   | 08     | 15     | 30.0139   | 0.2227   | 0.0   | ms    | 4.8       |
| 1282    | 1990 | 12    | 20  | 18   | 37     | 47     | 29.6667   | 0.0851   | 10.0  | ms    | 4.5       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1283    | 1990 | 08    | 11  | 02   | 34     | 21     | 32.9859   | -0.0264  | 10.0  | ms    | 4.5       |
| 1284    | 1990 | 07    | 19  | 17   | 06     | 07     | 31.5364   | 4.2620   | 13.3  | ms    | 4.6       |
| 1285    | 1990 | 12    | 15  | 20   | 56     | 52     | 29.5333   | 0.3841   | 10.0  | ms    | 4.7       |
| 1286    | 1990 | 09    | 04  | 01   | 48     | 01     | 29.1639   | -0.3752  | 20.0  | ms    | 5.0       |
| 1287    | 1991 | 02    | 04  | 21   | 23     | 57     | 29.4900   | 1.6870   | 10.0  | ms    | 4.0       |
| 1288    | 1991 | 07    | 16  | 07   | 28     | 42     | 29.8169   | 0.6453   | 10.0  | ms    | 4.1       |
| 1289    | 1991 | 07    | 29  | 14   | 31     | 47     | 33.4340   | -1.5845  | 10.0  | ms    | 4.3       |
| 1290    | 1991 | 02    | 07  | 23   | 11     | 40     | 34.9480   | 3.9560   | 18.4  | ms    | 4.3       |
| 1291    | 1991 | 10    | 09  | 17   | 22     | 02     | 31.2437   | 1.8442   | 4.9   | ms    | 5.7       |
| 1292    | 1993 | 02    | 08  | 12   | 25     | 34     | 34.2000   | -0.7000  | 4.0   | ms    | 4.7       |
| 1293    | 1993 | 10    | 18  | 05   | 50     | 14     | 30.1756   | 0.5607   | 10.0  | ms    | 4.9       |
| 1294    | 1993 | 09    | 28  | 22   | 31     | 09     | 29.8823   | 0.6632   | 15.0  | ms    | 4.9       |
| 1295    | 1994 | 11    | 03  | 00   | 36     | 19     | 31.8130   | 2.8390   | 15.0  | ms    | 4.0       |
| 1296    | 1994 | 09    | 12  | 18   | 56     | 57     | 34.2460   | -0.7880  | 10.0  | ms    | 4.0       |
| 1297    | 1994 | 09    | 05  | 07   | 45     | 56     | 30.2550   | 0.4750   | 0.0   | ms    | 4.0       |
| 1298    | 1994 | 04    | 04  | 02   | 42     | 29     | 29.3830   | -1.4490  | 15.0  | ms    | 4.0       |
| 1299    | 1994 | 03    | 12  | 01   | 19     | 03     | 29.3290   | 0.3560   | 10.0  | ms    | 4.1       |
| 1300    | 1994 | 12    | 19  | 15   | 48     | 23     | 34.4350   | 0.2350   | 0.0   | ms    | 4.3       |
| 1301    | 1994 | 02    | 07  | 01   | 32     | 14     | 30.1300   | 0.6171   | 0.0   | ms    | 4.3       |
| 1302    | 1994 | 02    | 08  | 10   | 16     | 23     | 30.1716   | 0.4317   | 0.0   | ms    | 4.4       |
| 1303    | 1994 | 02    | 07  | 22   | 50     | 58     | 29.8953   | -0.0041  | 0.0   | ms    | 4.4       |
| 1304    | 1994 | 03    | 29  | 22   | 59     | 21     | 30.1357   | 0.4782   | 10.0  | ms    | 4.5       |
| 1305    | 1994 | 02    | 06  | 01   | 39     | 31     | 30.4577   | 0.9111   | 10.0  | ms    | 4.5       |
| 1306    | 1994 | 05    | 22  | 00   | 50     | 20     | 30.0363   | 0.1425   | 1.1   | ms    | 4.6       |
| 1307    | 1994 | 08    | 22  | 19   | 56     | 50     | 34.8414   | 4.3567   | 10.0  | ms    | 4.7       |
| 1308    | 1994 | 03    | 09  | 08   | 25     | 27     | 29.5146   | 1.2907   | 10.0  | ms    | 4.8       |
| 1309    | 1994 | 03    | 20  | 02   | 12     | 38     | 30.1687   | 0.5736   | 14.0  | ms    | 4.9       |
| 1310    | 1994 | 02    | 06  | 00   | 13     | 26     | 30.0220   | 0.4786   | 14.0  | ms    | 4.9       |
| 1311    | 1994 | 08    | 31  | 14   | 59     | 58     | 30.8760   | 1.7050   | 10.0  | ms    | 5.0       |
| 1312    | 1994 | 02    | 05  | 23   | 34     | 09     | 30.0267   | 0.5918   | 14.0  | ms    | 6.2       |
| 1313    | 1995 | 11    | 12  | 22   | 29     | 43     | 29.7000   | -1.2300  | 10.0  | ms    | 4.0       |
| 1314    | 1995 | 08    | 26  | 14   | 27     | 43     | 31.1990   | 2.1466   | 10.0  | ms    | 4.0       |
| 1315    | 1995 | 02    | 15  | 10   | 54     | 28     | 31.9760   | 2.7670   | 10.0  | ms    | 4.0       |
| 1316    | 1995 | 05    | 06  | 02   | 09     | 22     | 31.9330   | 0.5220   | 10.0  | ms    | 4.1       |
| 1317    | 1995 | 08    | 17  | 22   | 30     | 47     | 31.4010   | 2.9430   | 10.0  | ms    | 4.2       |
| 1318    | 1995 | 04    | 05  | 12   | 15     | 35     | 29.9350   | 0.7570   | 10.0  | ms    | 4.2       |
| 1319    | 1995 | 09    | 19  | 01   | 34     | 14     | 33.6010   | 1.0720   | 10.0  | ms    | 4.3       |
| 1320    | 1995 | 05    | 26  | 11   | 29     | 08     | 30.3046   | 0.8357   | 10.0  | ms    | 4.5       |
| 1321    | 1995 | 01    | 17  | 17   | 19     | 36     | 34.8800   | -0.9500  | 0.0   | ms    | 4.5       |
| 1322    | 1995 | 03    | 21  | 07   | 03     | 34     | 33.3800   | -0.1300  | 10.0  | ms    | 5.2       |
| 1323    | 1996 | 12    | 23  | 12   | 15     | 57     | 30.2792   | 0.8239   | 9.0   | ms    | 4.4       |
| 1324    | 1996 | 02    | 12  | 12   | 44     | 36     | 30.2400   | 3.6500   | 33.8  | ms    | 4.5       |
| 1325    | 1996 | 07    | 08  | 21   | 22     | 03     | 29.5050   | -1.5610  | 25.9  | ms    | 4.8       |
| 1326    | 1996 | 03    | 24  | 22   | 52     | 42     | 30.3790   | 0.6050   | 10.0  | ms    | 4.9       |
| 1327    | 1996 | 03    | 24  | 08   | 24     | 25     | 29.9353   | 0.5498   | 10.0  | ms    | 5.0       |
| 1328    | 1997 | 02    | 05  | 01   | 29     | 33     | 33.7650   | -0.8750  | 10.0  | ms    | 4.0       |
| 1329    | 1997 | 09    | 24  | 09   | 21     | 32     | 34.0320   | -0.8370  | 0.0   | ms    | 4.1       |
| 1330    | 1997 | 09    | 18  | 17   | 50     | 56     | 33.4910   | -1.1240  | 0.0   | ms    | 4.1       |
| 1331    | 1997 | 05    | 28  | 00   | 05     | 01     | 31.4166   | 2.1878   | 10.0  | ms    | 4.1       |
| 1332    | 1997 | 05    | 27  | 16   | 18     | 38     | 31.3665   | 2.5654   | 10.0  | ms    | 4.1       |
| 1333    | 1997 | 07    | 30  | 20   | 16     | 29     | 31.4880   | 1.5580   | 10.0  | ms    | 4.2       |
| 1334    | 1997 | 09    | 23  | 16   | 56     | 09     | 33.5630   | -0.9970  | 18.4  | ms    | 4.3       |
| 1335    | 1997 | 05    | 27  | 17   | 21     | 41     | 31.3780   | 2.0724   | 10.0  | ms    | 4.3       |
| 1336    | 1997 | 05    | 29  | 02   | 18     | 32     | 31.9820   | 2.7760   | 14.0  | ms    | 4.4       |
| 1337    | 1997 | 06    | 16  | 23   | 16     | 53     | 31.5035   | 2.3490   | 10.0  | ms    | 4.5       |
| 1338    | 1997 | 03    | 22  | 00   | 55     | 09     | 30.3490   | 0.2510   | 10.0  | ms    | 4.5       |
| 1339    | 1997 | 01    | 18  | 21   | 21     | 23     | 33.4630   | -1.2170  | 16.5  | ms    | 4.5       |
| 1340    | 1997 | 07    | 19  | 14   | 21     | 38     | 31.5634   | 2.2953   | 10.0  | ms    | 4.6       |
| 1341    | 1997 | 07    | 18  | 02   | 44     | 24     | 31.5261   | 2.3370   | 25.0  | ms    | 4.6       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1342    | 1997 | 05    | 29  | 14   | 28     | 42     | 31.3110   | 1.8560   | 0.0   | ms    | 4.6       |
| 1343    | 1997 | 07    | 19  | 13   | 45     | 15     | 31.6732   | 2.4435   | 2.6   | ms    | 4.7       |
| 1344    | 1997 | 07    | 18  | 02   | 50     | 01     | 31.5933   | 2.3960   | 10.0  | ms    | 4.7       |
| 1345    | 1997 | 07    | 18  | 01   | 45     | 12     | 31.6069   | 2.4317   | 0.0   | ms    | 4.7       |
| 1346    | 1997 | 03    | 19  | 22   | 04     | 45     | 30.2840   | 0.1250   | 9.4   | ms    | 4.7       |
| 1347    | 1997 | 01    | 01  | 00   | 15     | 57     | 33.4270   | -1.1880  | 0.0   | ms    | 4.7       |
| 1348    | 1997 | 07    | 18  | 03   | 17     | 24     | 31.6003   | 2.4458   | 10.0  | ms    | 4.8       |
| 1349    | 1997 | 05    | 27  | 16   | 41     | 03     | 31.6455   | 2.5480   | 0.0   | ms    | 4.8       |
| 1350    | 1997 | 09    | 25  | 20   | 29     | 45     | 30.3670   | -0.3340  | 10.0  | ms    | 4.9       |
| 1351    | 1997 | 06    | 01  | 14   | 44     | 23     | 31.5960   | 1.7050   | 10.0  | ms    | 4.9       |
| 1352    | 1997 | 05    | 28  | 02   | 06     | 40     | 33.2710   | 3.4260   | 33.0  | ms    | 4.9       |
| 1353    | 1997 | 04    | 13  | 22   | 42     | 49     | 30.0820   | -0.7070  | 10.0  | ms    | 5.0       |
| 1354    | 1997 | 05    | 27  | 23   | 46     | 33     | 31.3960   | 2.1670   | 10.0  | ms    | 5.2       |
| 1355    | 1998 | 07    | 23  | 11   | 02     | 22     | 30.7690   | 1.3320   | 10.0  | ms    | 4.1       |
| 1356    | 1998 | 07    | 01  | 17   | 16     | 56     | 30.7780   | -0.5910  | 33.0  | ms    | 4.2       |
| 1357    | 1998 | 10    | 18  | 12   | 58     | 26     | 30.0580   | 0.8338   | 10.0  | ms    | 4.3       |
| 1358    | 1998 | 08    | 17  | 02   | 38     | 19     | 30.2940   | -0.2280  | 0.0   | ms    | 4.3       |
| 1359    | 1998 | 08    | 16  | 04   | 50     | 19     | 30.0080   | -1.2860  | 0.0   | ms    | 4.3       |
| 1360    | 1998 | 08    | 16  | 05   | 32     | 30     | 29.9460   | -0.9160  | 10.0  | ms    | 4.4       |
| 1361    | 1998 | 08    | 15  | 16   | 16     | 45     | 30.5194   | 0.1976   | 10.0  | ms    | 4.4       |
| 1362    | 1998 | 02    | 22  | 17   | 19     | 55     | 29.4143   | 0.5647   | 10.0  | ms    | 4.5       |
| 1363    | 1998 | 08    | 15  | 15   | 57     | 45     | 30.0765   | 1.8783   | 10.0  | ms    | 4.6       |
| 1364    | 1998 | 08    | 16  | 04   | 47     | 39     | 29.9651   | 0.8009   | 10.0  | ms    | 4.7       |
| 1365    | 1998 | 08    | 15  | 14   | 57     | 28     | 29.8960   | 1.2295   | 10.0  | ms    | 4.7       |
| 1366    | 1998 | 08    | 15  | 05   | 41     | 22     | 30.0952   | 0.6329   | 10.0  | ms    | 4.7       |
| 1367    | 1998 | 08    | 15  | 17   | 29     | 16     | 30.0781   | 0.7130   | 10.0  | ms    | 4.8       |
| 1368    | 1998 | 08    | 20  | 21   | 17     | 41     | 31.0660   | -1.0510  | 10.0  | ms    | 4.9       |
| 1369    | 1998 | 07    | 02  | 20   | 07     | 40     | 29.2350   | 1.3140   | 9.7   | ms    | 5.0       |
| 1370    | 1999 | 02    | 25  | 16   | 27     | 37     | 32.5930   | 0.2610   | 10.0  | ms    | 4.0       |
| 1371    | 1999 | 03    | 29  | 22   | 30     | 46     | 31.1880   | -1.1730  | 33.0  | ms    | 4.1       |
| 1372    | 1999 | 01    | 01  | 09   | 05     | 46     | 31.3880   | 4.4120   | 10.0  | ms    | 4.1       |
| 1373    | 1999 | 02    | 18  | 19   | 28     | 44     | 31.1300   | -1.1360  | 13.0  | ms    | 4.2       |
| 1374    | 1999 | 01    | 26  | 22   | 23     | 55     | 30.9760   | -1.3580  | 8.1   | ms    | 4.2       |
| 1375    | 1999 | 02    | 28  | 22   | 20     | 57     | 31.2750   | -1.3180  | 10.0  | ms    | 4.3       |
| 1376    | 1999 | 02    | 26  | 11   | 08     | 01     | 30.6680   | -1.4770  | 10.0  | ms    | 4.3       |
| 1377    | 1999 | 05    | 12  | 02   | 36     | 16     | 30.1420   | -0.3450  | 0.0   | ms    | 4.5       |
| 1378    | 1999 | 04    | 04  | 17   | 49     | 50     | 29.5430   | 0.0440   | 0.0   | ms    | 4.6       |
| 1379    | 1999 | 02    | 22  | 13   | 20     | 59     | 31.7390   | 3.3810   | 0.0   | ms    | 4.6       |
| 1380    | 1999 | 02    | 10  | 04   | 12     | 34     | 30.8420   | -1.5160  | 0.0   | ms    | 4.8       |
| 1381    | 1999 | 05    | 28  | 20   | 55     | 03     | 29.8620   | 1.0190   | 10.0  | ms    | 5.0       |
| 1382    | 1999 | 03    | 05  | 10   | 26     | 12     | 30.0680   | 0.5560   | 10.0  | ms    | 5.0       |
| 1383    | 1999 | 01    | 29  | 12   | 04     | 04     | 30.9120   | -1.4580  | 10.0  | ms    | 5.2       |
| 1384    | 2000 | 10    | 23  | 12   | 02     | 12     | 30.6070   | 1.4630   | 10.0  | ms    | 4.8       |
| 1385    | 2001 | 01    | 31  | 19   | 15     | 30     | 29.4750   | 0.4110   | 26.7  | ms    | 4.9       |
| 1386    | 2001 | 06    | 29  | 23   | 40     | 00     | 29.9880   | 0.2150   | 10.0  | ms    | 5.2       |
| 1387    | 2002 | 08    | 10  | 16   | 18     | 51     | 32.3460   | 3.3210   | 18.3  | ms    | 4.0       |
| 1388    | 2002 | 05    | 12  | 04   | 02     | 39     | 34.6281   | -1.2479  | 10.0  | ms    | 4.0       |
| 1389    | 2002 | 01    | 20  | 23   | 45     | 28     | 29.0590   | -1.4730  | 10.0  | ms    | 4.0       |
| 1390    | 2002 | 06    | 22  | 23   | 53     | 37     | 30.9740   | 1.7760   | 10.0  | ms    | 4.1       |
| 1391    | 2002 | 10    | 26  | 12   | 56     | 47     | 29.1607   | -1.5641  | 10.0  | ms    | 4.7       |
| 1392    | 2002 | 01    | 27  | 13   | 42     | 44     | 29.8010   | 0.7630   | 10.0  | ms    | 4.7       |
| 1393    | 2002 | 01    | 04  | 13   | 02     | 18     | 29.7790   | -0.1410  | 10.0  | ms    | 4.8       |
| 1394    | 2003 | 08    | 05  | 21   | 33     | 25     | 29.1218   | -0.3284  | 0.0   | ms    | 4.4       |
| 1395    | 2003 | 05    | 03  | 03   | 48     | 31     | 29.6879   | 0.5027   | 10.0  | ms    | 4.5       |
| 1396    | 2003 | 01    | 19  | 01   | 15     | 15     | 29.9400   | 0.9735   | 10.0  | ms    | 4.5       |
| 1397    | 2003 | 08    | 25  | 02   | 05     | 58     | 29.2317   | -0.4056  | 10.0  | ms    | 4.6       |
| 1398    | 2003 | 08    | 05  | 18   | 56     | 54     | 29.6627   | -0.6931  | 18.2  | ms    | 5.2       |
| 1399    | 2004 | 12    | 13  | 03   | 06     | 54     | 30.1436   | 0.6820   | 10.0  | ms    | 4.3       |
| 1400    | 2004 | 05    | 24  | 04   | 13     | 00     | 30.0699   | 0.1237   | 5.0   | ms    | 4.4       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1401    | 2004 | 12    | 13  | 04   | 09     | 01     | 30.1799   | 0.7765   | 0.0   | ms    | 4.8       |
| 1402    | 2004 | 02    | 05  | 21   | 35     | 33     | 30.4846   | 1.0145   | 33.0  | ms    | 4.8       |
| 1403    | 2005 | 09    | 03  | 06   | 05     | 11     | 29.8687   | 0.0911   | 0.0   | ms    | 4.4       |
| 1404    | 2005 | 03    | 13  | 03   | 04     | 21     | 29.8673   | 0.1901   | 0.0   | ms    | 4.5       |
| 1405    | 2006 | 04    | 27  | 17   | 54     | 43     | 29.9428   | 0.3645   | 0.0   | ms    | 4.4       |
| 1406    | 2006 | 05    | 29  | 15   | 30     | 36     | 30.0696   | 0.3660   | 32.0  | ms    | 5.0       |
| 1407    | 2006 | 04    | 27  | 04   | 18     | 29     | 29.9919   | 0.3666   | 17.2  | ms    | 5.2       |
| 1408    | 2007 | 04    | 29  | 19   | 44     | 04     | 30.6435   | 1.8507   | 10.0  | ms    | 4.5       |
| 1409    | 2007 | 02    | 19  | 02   | 33     | 43     | 30.7077   | 1.6445   | 14.7  | ms    | 5.6       |
| 1410    | 2007 | 06    | 15  | 18   | 49     | 53     | 30.7607   | 1.7232   | 10.0  | ms    | 5.8       |
| 1411    | 2008 | 12    | 23  | 18   | 21     | 03     | 29.6824   | -0.4491  | 19.6  | ms    | 4.0       |
| 1412    | 2008 | 10    | 05  | 00   | 32     | 10     | 29.0956   | -1.4056  | 10.0  | ms    | 4.0       |
| 1413    | 2008 | 08    | 29  | 16   | 36     | 13     | 29.6809   | -0.0561  | 10.0  | ms    | 4.0       |
| 1414    | 2008 | 08    | 26  | 14   | 56     | 57     | 30.8587   | 2.3041   | 21.2  | ms    | 4.4       |
| 1415    | 2008 | 05    | 11  | 10   | 34     | 10     | 29.6611   | 0.4453   | 10.0  | ms    | 4.4       |
| 1416    | 2008 | 10    | 01  | 14   | 15     | 53     | 33.6801   | -0.8003  | 10.0  | ms    | 4.7       |
| 1417    | 2008 | 10    | 05  | 00   | 02     | 14     | 29.0657   | -1.2061  | 10.0  | ms    | 5.3       |
| 1418    | 2009 | 10    | 18  | 01   | 08     | 57     | 29.8870   | -0.4733  | 10.0  | ms    | 4.0       |
| 1419    | 2009 | 09    | 02  | 11   | 09     | 14     | 30.7600   | 0.7020   | 13.1  | ms    | 4.0       |
| 1420    | 2009 | 10    | 12  | 02   | 00     | 09     | 29.1995   | -1.4263  | 33.0  | ms    | 4.1       |
| 1421    | 2009 | 02    | 02  | 04   | 24     | 33     | 30.1260   | 0.3690   | 10.0  | ms    | 4.1       |
| 1422    | 2009 | 03    | 05  | 03   | 28     | 56     | 29.5658   | -0.2604  | 23.6  | ms    | 4.2       |
| 1423    | 2009 | 10    | 18  | 06   | 17     | 12     | 35.0814   | 1.9947   | 0.0   | ms    | 4.4       |
| 1424    | 2009 | 07    | 30  | 14   | 48     | 06     | 30.5714   | 1.2882   | 33.0  | ms    | 4.6       |
| 1425    | 2009 | 10    | 18  | 00   | 39     | 44     | 30.1395   | 0.4658   | 15.0  | ms    | 4.9       |
| 1426    | 2010 | 01    | 28  | 23   | 57     | 23     | 29.3178   | -0.5963  | 33.0  | ms    | 4.1       |
| 1427    | 2010 | 07    | 09  | 18   | 30     | 51     | 29.5469   | -0.4156  | 21.0  | ms    | 4.4       |
| 1428    | 2010 | 12    | 27  | 22   | 10     | 08     | 33.2823   | 0.2550   | 16.1  | ms    | 4.5       |
| 1429    | 2010 | 10    | 08  | 23   | 40     | 54     | 30.6642   | 1.2214   | 16.3  | ms    | 4.6       |
| 1430    | 2010 | 12    | 12  | 20   | 34     | 21     | 29.8050   | 0.7552   | 27.7  | ms    | 4.9       |
| 1431    | 2010 | 01    | 28  | 23   | 52     | 31     | 29.1991   | -0.9448  | 6.5   | ms    | 4.9       |
| 1432    | 2010 | 06    | 13  | 12   | 13     | 24     | 34.4902   | -0.2523  | 2.1   | ms    | 5.0       |
| 1433    | 2011 | 01    | 17  | 08   | 22     | 27     | 30.8157   | 1.4963   | 10.0  | ms    | 4.8       |
| 1434    | 2011 | 03    | 15  | 03   | 25     | 19     | 31.2751   | 1.6294   | 14.1  | ms    | 5.0       |
| 1435    | 2012 | 10    | 02  | 18   | 40     | 35     | 30.2338   | 0.5066   | 9.4   | ms    | 4.4       |
| 1436    | 2012 | 11    | 20  | 16   | 23     | 50     | 29.9425   | -0.4472  | 38.4  | ms    | 4.8       |
| 1437    | 2013 | 07    | 12  | 02   | 45     | 20     | 30.8393   | 1.5395   | 10.0  | ms    | 4.0       |
| 1438    | 2013 | 12    | 11  | 07   | 29     | 57     | 30.5190   | 0.2692   | 15.0  | ms    | 4.1       |
| 1439    | 2013 | 08    | 05  | 11   | 39     | 21     | 30.6656   | 1.6071   | 10.0  | ms    | 4.1       |
| 1440    | 2013 | 12    | 19  | 21   | 26     | 41     | 32.3945   | -1.2500  | 6.0   | ms    | 4.3       |
| 1441    | 2013 | 07    | 30  | 03   | 34     | 19     | 30.2307   | 0.4078   | 0.0   | ms    | 4.4       |
| 1442    | 2013 | 07    | 03  | 20   | 41     | 12     | 31.1109   | 1.4928   | 17.3  | ms    | 4.4       |
| 1443    | 2013 | 10    | 08  | 08   | 40     | 13     | 30.6786   | 1.4902   | 10.0  | ms    | 4.6       |
| 1444    | 2013 | 08    | 05  | 06   | 02     | 30     | 31.1148   | 1.5220   | 10.0  | ms    | 4.6       |
| 1445    | 2013 | 07    | 05  | 13   | 42     | 20     | 29.8701   | -0.3950  | 10.0  | ms    | 4.6       |
| 1446    | 2013 | 08    | 05  | 07   | 33     | 56     | 31.1504   | 1.4652   | 0.0   | ms    | 4.7       |
| 1447    | 2013 | 04    | 20  | 00   | 30     | 27     | 30.8165   | 1.4861   | 10.0  | ms    | 4.8       |
| 1448    | 2013 | 07    | 02  | 13   | 33     | 18     | 30.9588   | 1.5154   | 10.0  | ms    | 5.0       |
| 1449    | 2013 | 07    | 03  | 22   | 22     | 19     | 30.9103   | 1.5165   | 9.3   | ms    | 5.2       |
| 1450    | 2013 | 07    | 03  | 19   | 21     | 46     | 30.8894   | 1.5496   | 10.0  | ms    | 5.7       |
| 1451    | 2014 | 11    | 20  | 23   | 56     | 01     | 29.6152   | -0.3732  | 10.0  | ms    | 4.4       |
| 1452    | 2014 | 09    | 21  | 10   | 18     | 26     | 30.1294   | 0.6550   | 10.0  | ms    | 4.4       |
| 1453    | 2014 | 10    | 31  | 01   | 05     | 02     | 30.2374   | 0.4948   | 33.0  | ms    | 4.5       |
| 1454    | 2015 | 11    | 24  | 17   | 47     | 37     | 31.0764   | 1.4548   | 0.0   | ms    | 4.2       |
| 1455    | 2015 | 07    | 17  | 18   | 32     | 52     | 30.3164   | 1.1515   | 10.5  | ms    | 4.4       |
| 1456    | 2015 | 02    | 13  | 08   | 35     | 23     | 29.7330   | -0.2714  | 0.0   | ms    | 4.4       |
| 1457    | 2015 | 09    | 12  | 12   | 32     | 04     | 29.6640   | 0.3971   | 16.9  | ms    | 4.5       |
| 1458    | 2015 | 06    | 29  | 14   | 11     | 17     | 31.1498   | 2.6628   | 16.6  | ms    | 4.5       |
| 1459    | 2015 | 11    | 25  | 09   | 38     | 12     | 29.7271   | -0.1635  | 26.7  | ms    | 4.7       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1460    | 2016 | 06    | 11  | 01   | 05     | 16     | 29.4435   | -0.5957  | 10.0  | ms    | 4.0       |
| 1461    | 2016 | 09    | 10  | 12   | 27     | 33     | 31.6181   | -1.0355  | 10.0  | ms    | 5.9       |
| 1462    | 2017 | 02    | 18  | 03   | 37     | 14     | 30.7252   | 1.4576   | 10.0  | ms    | 4.2       |
| 1463    | 2017 | 04    | 29  | 22   | 28     | 30     | 31.5895   | -1.1588  | 0.0   | ms    | 4.3       |
| 1464    | 2017 | 02    | 25  | 17   | 19     | 35     | 31.1166   | 1.4127   | 10.0  | ms    | 4.7       |
| 1465    | 2017 | 07    | 30  | 07   | 02     | 29     | 29.7845   | -0.2437  | 0.0   | ms    | 5.3       |
| 1466    | 2018 | 09    | 13  | 23   | 52     | 47     | 29.9281   | 0.6273   | 20.2  | ms    | 4.5       |
| 1467    | 2019 | 08    | 05  | 09   | 37     | 13     | 29.4803   | -0.8796  | 10.0  | ms    | 4.4       |
| 1468    | 2019 | 04    | 03  | 19   | 40     | 51     | 31.1994   | 1.7615   | 12.0  | ms    | 4.5       |
| 1469    | 2019 | 09    | 06  | 06   | 15     | 35     | 30.3150   | 1.0546   | 0.0   | ms    | 4.6       |
| 1470    | 2019 | 08    | 06  | 16   | 58     | 31     | 30.1201   | 0.0359   | 0.0   | ms    | 4.6       |
| 1471    | 2019 | 01    | 05  | 18   | 13     | 46     | 31.4085   | 3.0863   | 5.0   | ms    | 4.8       |
| 1472    | 2020 | 10    | 04  | 06   | 47     | 32     | 29.7489   | 0.8556   | 29.0  | ms    | 4.2       |
| 1473    | 2020 | 06    | 21  | 21   | 54     | 58     | 29.9312   | 0.8089   | 15.7  | ms    | 4.3       |
| 1474    | 2020 | 03    | 19  | 22   | 35     | 49     | 29.7626   | -0.7920  | 6.5   | ms    | 4.3       |
| 1475    | 2020 | 08    | 06  | 02   | 17     | 46     | 29.9632   | 0.1063   | 21.3  | ms    | 4.4       |
| 1476    | 2020 | 06    | 08  | 22   | 34     | 15     | 30.8804   | 1.6150   | 40.0  | ms    | 4.5       |
| 1477    | 2020 | 01    | 28  | 22   | 32     | 06     | 29.7826   | -0.2296  | 14.2  | ms    | 4.7       |

### Appendix A-5: GEM Global Historical Archive

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1085    | 1903 | 06    | 04  | 14   | 56     | 00     | 31.0000   | 2.0000   | 10.0  | ms    | 6.4       |
| 1086    | 1909 | 11    | 12  | 19   | 50     | 00     | 27.0000   | -2.5000  |       | ms    | 5.8       |
| 1087    | 1912 | 07    | 09  | 08   | 18     | 00     | 31.0000   | 2.0000   |       | ms    | 6.2       |
| 1088    | 1912 | 03    | 08  | 14   | 45     | 00     | 29.0000   | -2.0000  |       | ms    | 6.1       |
| 1089    | 1917 | 12    | 05  | 12   | 49     | 00     | 36.0000   | -2.5000  |       | ms    | 5.7       |
| 1090    | 1924 | 07    | 01  | 06   | 20     | 00     | 36.0000   | 1.5000   |       | ms    | 5.6       |
| 1091    | 1928 | 01    | 06  | 19   | 32     | 00     | 36.2000   | 0.2000   | 35.0  | ms    | 6.9       |
| 1092    | 1928 | 01    | 10  | 02   | 25     | 00     | 36.2000   | 0.3000   |       | ms    | 6.0       |
| 1093    | 1945 | 05    | 21  | 04   | 19     | 00     | 31.9000   | 4.4000   |       | ms    | 6.3       |

### Appendix A-6: Compilations from Literature Review (Maasha, 1975)

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1094    | 1912 | 07    | 09  | 08   | 18     | 06     | 33.0000   | 3.0000   |       | mb    | 6.8       |
| 1095    | 1920 | 03    | 21  | 02   | 00     | 00     | 30.0000   | 0.5000   |       | mb    | 6.0       |
| 1096    | 1920 | 02    | 10  | 02   | 30     | 00     | 30.0000   | 0.5000   |       | mb    | 5.6       |
| 1097    | 1929 | 02    | 10  | 03   | 14     | 00     | 30.0000   | 0.4000   |       | mb    | 5.9       |
| 1098    | 1945 | 03    | 18  | 08   | 01     | 26     | 32.0000   | 0.0000   |       | mb    | 6.0       |
| 1099    | 1952 | 06    | 30  | 21   | 04     | 00     | 29.5000   | 0.5500   |       | mb    | 6.0       |
| 1100    | 1955 | 07    | 04  | 22   | 12     | 52     | 30.3500   | 1.7500   |       | mb    | 5.0       |
| 1101    | 1955 | 07    | 22  | 04   | 00     | 03     | 30.5200   | 1.4200   |       | mb    | 5.7       |
| 1102    | 1955 | 09    | 09  | 22   | 12     | 47     | 30.9000   | 1.6600   |       | mb    | 6.3       |
| 1103    | 1957 | 07    | 07  | 22   | 24     | 44     | 29.3200   | -0.1100  |       | mb    | 4.8       |
| 1104    | 1959 | 01    | 15  | 23   | 02     | 34     | 29.7600   | -0.1000  | 31.0  | mb    | 4.2       |
| 1105    | 1959 | 01    | 27  | 05   | 44     | 03     | 29.9700   | 0.4600   |       | mb    | 4.2       |
| 1106    | 1959 | 06    | 19  | 11   | 58     | 52     | 29.3800   | -0.1700  |       | mb    | 5.4       |
| 1107    | 1959 | 08    | 09  | 11   | 16     | 51     | 29.9100   | 0.7900   |       | mb    | 5.1       |
| 1108    | 1959 | 09    | 22  | 01   | 43     | 27     | 29.7600   | 0.9100   |       | mb    | 4.5       |
| 1109    | 1960 | 05    | 04  | 20   | 17     | 33     | 32.4600   | -1.2100  |       | mb    | 5.7       |
| 1110    | 1961 | 11    | 12  | 02   | 15     | 12     | 29.5000   | 0.5100   |       | mb    | 5.0       |
| 1111    | 1963 | 09    | 29  | 20   | 58     | 48     | 29.9000   | 0.8100   |       | mb    | 4.5       |
| 1112    | 1963 | 09    | 30  | 14   | 09     | 37     | 31.4000   | 1.4000   |       | mb    | 4.6       |
| 1113    | 1963 | 11    | 28  | 06   | 28     | 32     | 31.5100   | 0.7000   |       | mb    | 4.7       |
| 1114    | 1964 | 03    | 31  | 00   | 26     | 52     | 30.2200   | 0.6000   | 25.0  | mb    | 4.3       |
| 1115    | 1964 | 05    | 11  | 18   | 55     | 07     | 33.7500   | -1.3100  |       | mb    | 5.5       |
| 1116    | 1964 | 08    | 17  | 22   | 59     | 04     | 30.2500   | 0.9400   |       | mb    | 5.4       |
| 1117    | 1964 | 08    | 27  | 00   | 23     | 31     | 30.7500   | 1.1200   |       | mb    | 4.2       |
| 1118    | 1964 | 11    | 02  | 17   | 24     | 08     | 32.9800   | -0.5300  |       | mb    | 4.8       |
| 1119    | 1965 | 12    | 28  | 11   | 30     | 08     | 29.5000   | -1.4000  |       | mb    | 4.5       |
| 1120    | 1966 | 03    | 09  | 03   | 12     | 48     | 31.4200   | 2.2700   |       | mb    | 5.4       |
| 1121    | 1966 | 03    | 09  | 03   | 29     | 39     | 31.4000   | 2.2000   |       | mb    | 4.3       |
| 1122    | 1966 | 03    | 17  | 01   | 46     | 29     | 32.1000   | -1.0000  |       | mb    | 4.0       |
| 1123    | 1966 | 03    | 18  | 07   | 13     | 24     | 30.6000   | -0.1000  |       | mb    | 4.0       |
| 1124    | 1966 | 03    | 20  | 01   | 47     | 50     | 29.9000   | 0.8100   | 24.0  | mb    | 6.7       |
| 1125    | 1966 | 03    | 20  | 02   | 17     | 00     | 30.1000   | -0.3000  |       | mb    | 4.5       |
| 1126    | 1966 | 03    | 20  | 02   | 39     | 41     | 29.9200   | 1.0900   |       | mb    | 5.4       |
| 1127    | 1966 | 03    | 20  | 03   | 22     | 43     | 30.0500   | 0.8200   |       | mb    | 5.1       |
| 1128    | 1966 | 03    | 20  | 08   | 55     | 34     | 29.9200   | 0.7800   |       | mb    | 5.6       |
| 1129    | 1966 | 03    | 21  | 01   | 30     | 38     | 29.8100   | 0.8000   |       | mb    | 5.3       |
| 1130    | 1966 | 03    | 21  | 09   | 23     | 50     | 30.0000   | 0.8400   |       | mb    | 5.0       |
| 1131    | 1966 | 03    | 25  | 02   | 59     | 40     | 29.9000   | 0.8600   |       | mb    | 4.2       |
| 1132    | 1966 | 03    | 25  | 13   | 49     | 49     | 30.5000   | 0.8000   |       | mb    | 4.5       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1133    | 1966 | 03    | 25  | 21   | 57     | 39     | 30.4000   | 1.0000   | 33.0  | mb    | 4.2       |
| 1134    | 1966 | 03    | 29  | 17   | 24     | 10     | 30.4000   | 1.0200   | 33.0  | mb    | 4.7       |
| 1135    | 1966 | 04    | 01  | 07   | 59     | 41     | 29.5000   | 0.6000   | 6.0   | mb    | 4.5       |
| 1136    | 1966 | 04    | 06  | 01   | 17     | 53     | 29.9000   | 0.8000   | 17.0  | mb    | 4.3       |
| 1137    | 1966 | 07    | 07  | 00   | 09     | 11     | 29.9000   | 0.6000   | 41.0  | mb    | 4.3       |
| 1138    | 1966 | 04    | 12  | 07   | 35     | 15     | 30.0700   | 1.2000   | 24.0  | mb    | 4.7       |
| 1139    | 1966 | 04    | 13  | 02   | 14     | 19     | 30.7000   | 0.9900   | 17.0  | mb    | 5.5       |
| 1140    | 1966 | 04    | 13  | 09   | 43     | 05     | 30.2600   | 1.1600   | 43.0  | mb    | 4.5       |
| 1141    | 1966 | 04    | 13  | 11   | 58     | 27     | 30.3000   | 1.5000   |       | mb    | 4.0       |
| 1142    | 1966 | 04    | 14  | 13   | 16     | 19     | 30.0000   | 0.9000   | 33.0  | mb    | 4.7       |
| 1143    | 1966 | 04    | 15  | 03   | 08     | 15     | 29.9800   | 0.7700   | 26.0  | mb    | 4.9       |
| 1144    | 1966 | 04    | 16  | 14   | 43     | 18     | 29.8600   | 0.7600   | 11.0  | mb    | 5.1       |
| 1145    | 1966 | 04    | 17  | 18   | 08     | 17     | 31.0000   | -1.0000  |       | mb    | 4.0       |
| 1146    | 1966 | 04    | 30  | 20   | 38     | 47     | 29.8000   | 0.7000   | 33.0  | mb    | 4.8       |
| 1147    | 1966 | 05    | 10  | 21   | 53     | 28     | 31.1000   | 1.6000   |       | mb    | 4.1       |
| 1148    | 1966 | 05    | 16  | 05   | 44     | 20     | 30.1300   | 0.6100   | 33.0  | mb    | 5.4       |
| 1149    | 1966 | 05    | 17  | 07   | 03     | 33     | 29.9500   | 0.7600   | 35.0  | mb    | 6.3       |
| 1150    | 1966 | 05    | 18  | 01   | 46     | 34     | 29.8200   | 0.6700   | 34.0  | mb    | 4.0       |
| 1151    | 1966 | 05    | 29  | 02   | 26     | 11     | 30.0000   | 0.7000   | 33.0  | mb    | 4.7       |
| 1152    | 1966 | 06    | 03  | 07   | 17     | 42     | 29.9000   | 0.6000   | 33.0  | mb    | 5.0       |
| 1153    | 1966 | 06    | 04  | 19   | 02     | 03     | 29.9000   | 0.9000   | 33.0  | mb    | 4.7       |
| 1154    | 1966 | 06    | 14  | 15   | 37     | 47     | 30.2800   | 0.1900   | 24.0  | mb    | 4.8       |
| 1155    | 1966 | 06    | 14  | 23   | 50     | 41     | 30.0000   | 1.1000   | 33.0  | mb    | 4.7       |
| 1156    | 1966 | 06    | 17  | 18   | 31     | 52     | 29.9100   | 0.7500   | 33.0  | mb    | 5.3       |
| 1157    | 1966 | 06    | 19  | 00   | 54     | 53     | 29.8000   | 0.8000   | 33.0  | mb    | 5.0       |
| 1158    | 1966 | 07    | 02  | 11   | 21     | 28     | 30.0500   | 0.7600   | 12.0  | mb    | 4.6       |
| 1159    | 1966 | 07    | 06  | 02   | 58     | 37     | 30.5000   | 1.3000   | 33.0  | mb    | 5.1       |
| 1160    | 1966 | 07    | 12  | 17   | 45     | 39     | 29.6000   | 1.5000   |       | mb    | 4.6       |
| 1161    | 1966 | 07    | 14  | 04   | 34     | 46     | 29.9000   | 0.8000   |       | mb    | 5.2       |
| 1162    | 1966 | 07    | 22  | 02   | 51     | 24     | 29.7000   | 0.6000   | 33.0  | mb    | 4.5       |
| 1163    | 1966 | 07    | 22  | 05   | 46     | 05     | 30.9900   | -0.0100  |       | mb    | 4.0       |
| 1164    | 1966 | 07    | 31  | 15   | 17     | 15     | 30.0200   | 0.6700   |       | mb    | 5.0       |
| 1165    | 1966 | 08    | 01  | 17   | 16     | 43     | 30.0000   | 0.7000   | 6.0   | mb    | 4.2       |
| 1166    | 1966 | 08    | 01  | 18   | 06     | 32     | 30.0400   | 1.0100   |       | mb    | 4.0       |
| 1167    | 1966 | 09    | 02  | 00   | 09     | 16     | 30.1800   | 1.0300   |       | mb    | 4.2       |
| 1168    | 1966 | 09    | 02  | 07   | 51     | 00     | 31.6000   | 0.6000   | 20.0  | mb    | 4.0       |
| 1169    | 1966 | 09    | 26  | 23   | 24     | 06     | 30.2000   | 0.5000   |       | mb    | 4.0       |
| 1170    | 1966 | 10    | 05  | 08   | 34     | 37     | 29.8000   | 0.2000   |       | mb    | 5.2       |
| 1171    | 1966 | 10    | 10  | 01   | 44     | 54     | 32.4000   | 0.2000   | 8.0   | mb    | 4.1       |
| 1172    | 1966 | 10    | 26  | 08   | 04     | 07     | 30.8000   | 0.1000   |       | mb    | 4.0       |
| 1173    | 1966 | 10    | 29  | 05   | 10     | 06     | 29.7000   | -1.5000  |       | mb    | 4.0       |
| 1174    | 1966 | 11    | 17  | 20   | 26     | 01     | 30.2000   | 0.4000   | 33.0  | mb    | 4.3       |
| 1175    | 1966 | 11    | 23  | 04   | 17     | 38     | 31.3000   | 3.8000   | 33.0  | mb    | 4.3       |
| 1176    | 1966 | 11    | 25  | 21   | 29     | 00     | 30.0200   | 0.8000   |       | mb    | 4.6       |
| 1177    | 1967 | 01    | 12  | 22   | 22     | 10     | 31.2100   | 2.1000   | 33.0  | mb    | 4.5       |
| 1178    | 1967 | 02    | 07  | 06   | 20     | 26     | 30.6000   | -0.7000  | 18.0  | mb    | 4.6       |
| 1179    | 1967 | 02    | 14  | 02   | 06     | 36     | 30.4000   | 0.7000   |       | mb    | 4.0       |
| 1180    | 1967 | 03    | 10  | 12   | 41     | 13     | 30.1700   | 0.6800   |       | mb    | 5.5       |
| 1181    | 1967 | 04    | 06  | 06   | 46     | 13     | 30.0000   | 1.0000   | 33.0  | mb    | 4.0       |
| 1182    | 1967 | 05    | 28  | 12   | 19     | 33     | 31.3900   | 1.8600   |       | mb    | 5.1       |
| 1183    | 1967 | 06    | 08  | 18   | 39     | 45     | 30.8000   | -0.1000  | 40.0  | mb    | 4.0       |
| 1184    | 1967 | 06    | 19  | 16   | 43     | 06     | 30.1500   | 0.6400   |       | mb    | 4.7       |
| 1185    | 1967 | 09    | 09  | 22   | 35     | 59     | 32.7600   | 3.8000   | 34.0  | mb    | 4.8       |
| 1186    | 1967 | 10    | 30  | 19   | 55     | 45     | 31.8000   | 1.8000   | 33.0  | mb    | 5.2       |
| 1187    | 1967 | 10    | 30  | 21   | 22     | 31     | 31.6000   | 2.6000   | 33.0  | mb    | 4.2       |
| 1188    | 1967 | 10    | 31  | 13   | 51     | 04     | 31.2000   | 2.0000   | 33.0  | mb    | 5.2       |
| 1189    | 1967 | 11    | 02  | 15   | 20     | 42     | 30.4000   | 1.7000   | 33.0  | mb    | 4.3       |
| 1190    | 1967 | 11    | 11  | 02   | 28     | 44     | 31.4900   | 2.0200   |       | mb    | 5.3       |
| 1191    | 1967 | 11    | 13  | 20   | 29     | 05     | 31.6100   | 1.9000   | 33.0  | mb    | 5.1       |

| eventID | Year | Month | Day | Hour | Minute | Second | Longitude | Latitude | Depth | MType | Magnitude |
|---------|------|-------|-----|------|--------|--------|-----------|----------|-------|-------|-----------|
| 1192    | 1967 | 11    | 29  | 05   | 27     | 11     | 31.2000   | 2.0000   | 33.0  | mb    | 4.6       |
| 1193    | 1967 | 11    | 29  | 05   | 32     | 08     | 31.8000   | 1.9000   |       | mb    | 4.9       |
| 1194    | 1967 | 12    | 28  | 17   | 56     | 31     | 31.4000   | -1.0000  |       | mb    | 4.0       |
| 1195    | 1967 | 12    | 12  | 13   | 04     | 32     | 32.2000   | -0.2000  |       | mb    | 4.2       |
| 1196    | 1967 | 12    | 29  | 13   | 46     | 30     | 31.4000   | 3.0000   |       | mb    | 4.4       |
| 1197    | 1967 | 12    | 29  | 15   | 43     | 07     | 31.4000   | 3.0000   |       | mb    | 4.4       |
| 1198    | 1967 | 12    | 29  | 16   | 07     | 03     | 34.0000   | 1.3000   |       | mb    | 4.1       |
| 1199    | 1967 | 12    | 29  | 23   | 39     | 13     | 34.0000   | 1.3000   |       | mb    | 4.0       |
| 1200    | 1968 | 03    | 20  | 19   | 02     | 50     | 32.7600   | 0.6000   |       | mb    | 4.0       |
| 1201    | 1968 | 03    | 21  | 02   | 58     | 37     | 34.3800   | -0.5800  | 33.0  | mb    | 4.5       |
| 1202    | 1968 | 03    | 21  | 03   | 26     | 02     | 34.3800   | -0.5000  | 41.0  | mb    | 4.5       |
| 1203    | 1968 | 02    | 21  | 03   | 35     | 03     | 34.3000   | -0.5000  | 41.0  | mb    | 4.0       |
| 1204    | 1968 | 06    | 24  | 03   | 22     | 00     | 29.8300   | 0.3000   | 33.0  | mb    | 4.8       |
| 1205    | 1968 | 07    | 06  | 13   | 24     | 22     | 32.7600   | -0.2500  | 33.0  | mb    | 4.1       |
| 1206    | 1968 | 11    | 13  | 16   | 44     | 19     | 31.4900   | 1.7600   | 21.0  | mb    | 4.2       |
| 1207    | 1969 | 03    | 13  | 18   | 07     | 45     | 30.6000   | 0.6000   |       | mb    | 4.0       |
| 1208    | 1969 | 03    | 14  | 23   | 10     | 22     | 29.8700   | 0.7000   | 33.0  | mb    | 4.8       |
| 1209    | 1969 | 05    | 05  | 15   | 23     | 50     | 31.5400   | 4.4300   | 33.0  | mb    | 4.1       |
| 1210    | 1969 | 04    | 22  | 21   | 59     | 12     | 31.4900   | 1.9600   | 32.0  | mb    | 6.0       |
| 1211    | 1969 | 04    | 29  | 19   | 54     | 46     | 30.9100   | 0.7600   | 27.0  | mb    | 4.6       |
| 1212    | 1969 | 07    | 15  | 16   | 33     | 27     | 31.4400   | 3.6200   | 15.0  | mb    | 5.5       |
| 1213    | 1969 | 08    | 23  | 16   | 03     | 23     | 30.0000   | 1.1000   |       | mb    | 4.2       |
| 1214    | 1969 | 08    | 29  | 13   | 01     | 28     | 30.8000   | 0.4000   |       | mb    | 4.1       |
| 1215    | 1969 | 09    | 05  | 18   | 54     | 18     | 30.8000   | -0.3000  |       | mb    | 4.1       |
| 1216    | 1969 | 12    | 14  | 06   | 55     | 40     | 34.0200   | -1.2500  |       | mb    | 4.5       |
| 1217    | 1971 | 01    | 03  | 03   | 10     | 09     | 30.7500   | 1.9500   | 33.0  | mb    | 4.7       |
| 1218    | 1971 | 01    | 04  | 15   | 14     | 35     | 32.4500   | 3.6400   | 33.0  | mb    | 4.3       |
| 1219    | 1971 | 04    | 18  | 00   | 34     | 34     | 30.1400   | 0.2400   | 33.0  | mb    | 4.5       |
| 1220    | 1971 | 04    | 18  | 05   | 49     | 49     | 30.2000   | 0.1700   | 32.0  | mb    | 4.6       |
| 1221    | 1971 | 04    | 21  | 18   | 40     | 54     | 29.9000   | 0.2100   | 33.0  | mb    | 4.2       |
| 1222    | 1972 | 01    | 08  | 17   | 27     | 52     | 29.8400   | 0.7700   | 33.0  | mb    | 4.7       |
| 1223    | 1973 | 04    | 22  | 22   | 03     | 43     | 31.1700   | 3.9200   | 33.0  | mb    | 4.8       |
| 1224    | 1973 | 07    | 09  | 04   | 22     | 30     | 30.1500   | 0.5500   | 38.0  | mb    | 4.3       |
| 1225    | 1973 | 08    | 01  | 09   | 14     | 33     | 30.3100   | 0.3400   | 15.0  | mb    | 4.1       |
| 1226    | 1973 | 08    | 25  | 08   | 53     | 41     | 29.8900   | 0.6600   | 1.0   | mb    | 4.0       |
| 1227    | 1973 | 12    | 01  | 16   | 51     | 14     | 29.5200   | 0.6500   | 15.0  | mb    | 4.8       |

# APPENDIX B: LANDSLIDE CATALOGUE AND PIXEL DATA FOR UGANDA

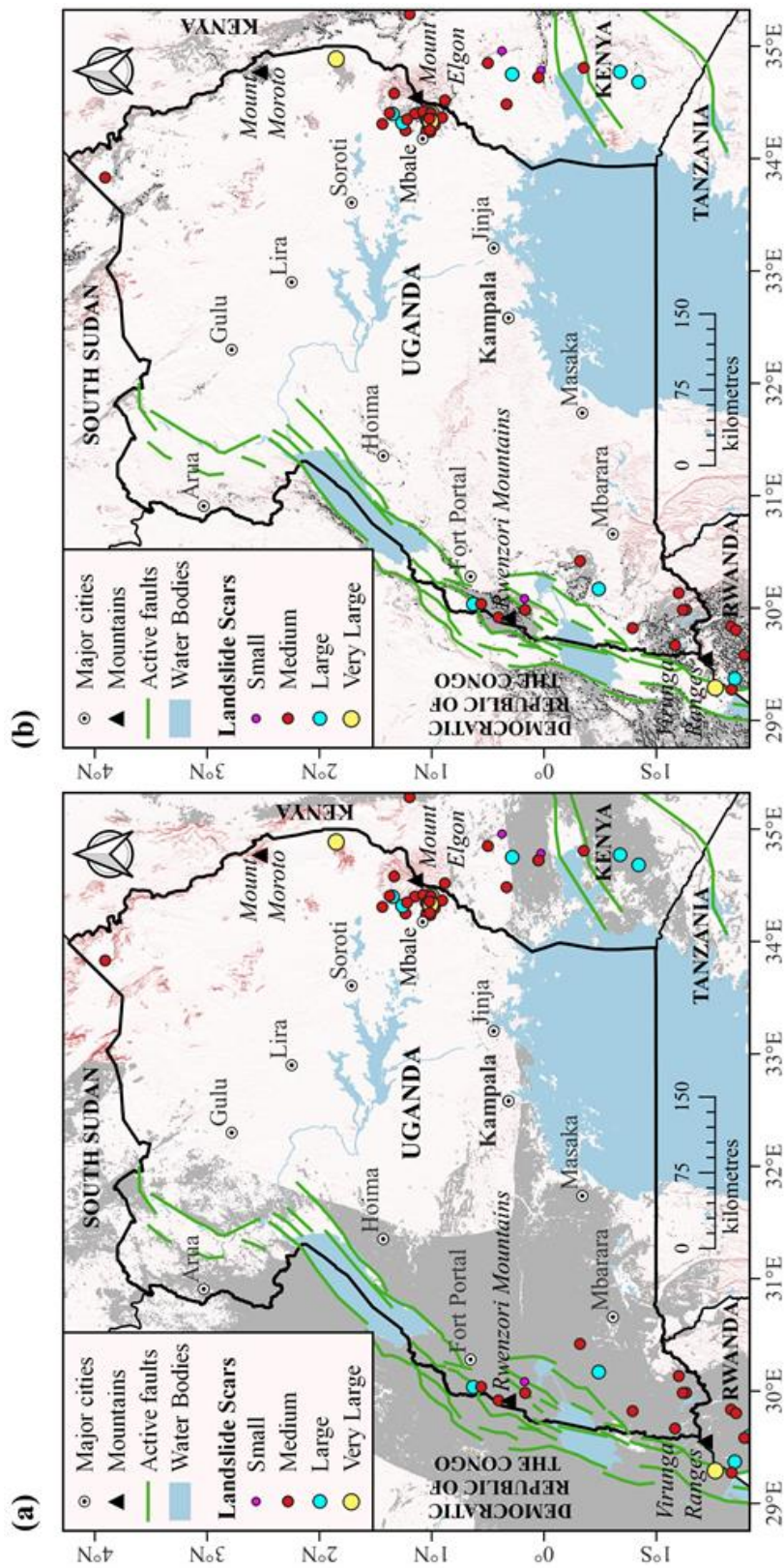


**Fig II:** Landslide pixels/areas (shown in grey) relative to regional cities, active and minor fault system, mountains and locations of known landslide scars that occurred in Uganda and around its neighbouring countries; shown for: **(a)** co-seismic landslides, and **(b)** rainfall-induced landslides

- Rainfall-induced and earthquake- triggered landslide inventory data was acquired from the National Aeronautics and Space Administration (NASA) satellite repository. <https://gpm.nasa.gov/applications/landslides>
- On the other hand, landslide pixel data was obtained from the database of the World Bank and Global Facility for Disaster Reduction and Recovery. <https://datacatalog.worldbank.org/search/dataset/0037584>

| eventID | Day | Month | Year | Latitude | Longitude | Main Trigger | Magnitude  | Deaths | Injuries |
|---------|-----|-------|------|----------|-----------|--------------|------------|--------|----------|
| 12833   | 20  | 3     | 1966 | 0.685    | 30.057    | Earthquake   | Small      | 0      | 0        |
| 12834   | 18  | 5     | 1966 | 0.395    | 30.164    | Earthquake   | Unknown    | 0      | 0        |
| 12733   | 12  | 12    | 1983 | -2.503   | 28.845    | Rain         | Small      | 0      | 0        |
| 12803   | 08  | 5     | 1988 | -1.552   | 29.608    | Rain         | Very large | 10     | 0        |
| 12835   | 05  | 2     | 1994 | 0.121    | 29.989    | Earthquake   | Medium     | 2      | 1        |
| 12734   | 11  | 8     | 1997 | -2.477   | 28.823    | Unknown      | Small      | 0      | 0        |
| 12836   | 03  | 9     | 2001 | 0.782    | 30.083    | Rain         | Medium     | 0      | 0        |
| 12837   | 02  | 11    | 2001 | 0.801    | 30.169    | Rain         | Medium     | 19     | 12       |
| 12735   | 26  | 12    | 2001 | -0.700   | 28.900    | Unknown      | Unknown    | 0      | 0        |
| 12737   | 06  | 2     | 2002 | -2.115   | 29.057    | Rain         | Medium     | 0      | 0        |
| 12838   | 07  | 5     | 2002 | -0.354   | 30.373    | Flooding     | Medium     | 9      | 0        |
| 12738   | 26  | 4     | 2003 | -2.100   | 28.900    | Rain         | Unknown    | 9      | 0        |
| 12739   | 26  | 4     | 2003 | -2.100   | 28.900    | Rain         | Unknown    | 1      | 0        |
| 12839   | 03  | 5     | 2003 | 0.243    | 29.951    | Rain         | Medium     | 0      | 0        |
| 12740   | 10  | 5     | 2005 | -1.710   | 29.020    | Unknown      | Unknown    | 8      | 101      |
| 12741   | 10  | 3     | 2006 | -2.097   | 28.906    | Unknown      | Medium     | 1      | 1        |
| 12804   | 28  | 11    | 2006 | -1.756   | 30.020    | Unknown      | Very large | 24     | 2000     |
| 12742   | 10  | 12    | 2006 | -2.530   | 28.850    | Unknown      | Unknown    | 5      | 0        |
| 12743   | 20  | 3     | 2007 | -2.492   | 28.831    | Unknown      | Medium     | 1      | 0        |
| 00175   | 11  | 8     | 2007 | 0.500    | 34.850    | Rain         | Medium     | 18     | 0        |
| 00176   | 11  | 8     | 2007 | 0.283    | 34.750    | Rain         | Large      | 0      | 0        |
| 00180   | 12  | 8     | 2007 | 1.044    | 34.258    | Rain         | Medium     | 0      | 0        |
| 00244   | 07  | 9     | 2007 | 1.483    | 35.467    | Rain         | Medium     | 0      | 0        |
| 00272   | 19  | 9     | 2007 | -1.783   | 29.583    | Rain         | Medium     | 0      | 9        |
| 00273   | 19  | 9     | 2007 | -1.670   | 29.274    | Rain         | Medium     | 6      | 0        |
| 12805   | 19  | 9     | 2007 | -1.783   | 29.583    | Downpour     | Medium     | 0      | 0        |
| 12806   | 19  | 9     | 2007 | -1.670   | 29.274    | Downpour     | Medium     | 6      | 0        |
| 12807   | 06  | 11    | 2007 | -1.472   | 29.658    | Rain         | Medium     | 3      | 0        |
| 12744   | 29  | 3     | 2008 | -2.530   | 28.850    | Unknown      | Unknown    | 5      | 0        |
| 00565   | 02  | 6     | 2008 | 0.441    | 35.777    | Rain         | Large      | 0      | 0        |
| 00882   | 07  | 11    | 2008 | 1.283    | 35.447    | Downpour     | Medium     | 11     | 0        |
| 00883   | 09  | 11    | 2008 | 1.300    | 35.617    | Downpour     | Medium     | 14     | 0        |
| 12745   | 04  | 2     | 2009 | -1.400   | 28.810    | Rain         | Medium     | 8      | 3        |
| 12808   | 11  | 5     | 2009 | -1.708   | 30.196    | Rain         | Medium     | 8      | 1        |
| 12841   | 17  | 5     | 2009 | 0.712    | 30.191    | Rain         | Medium     | 0      | 0        |
| 01120   | 23  | 8     | 2009 | -1.179   | 29.627    | Rain         | Medium     | 5      | 0        |
| 12842   | 23  | 8     | 2009 | -1.236   | 29.983    | Downpour     | Medium     | 5      | 0        |
| 01217   | 03  | 10    | 2009 | -1.251   | 29.982    | Downpour     | Medium     | 6      | 0        |
| 12843   | 03  | 10    | 2009 | -1.251   | 29.982    | Rain         | Medium     | 6      | 0        |
| 01262   | 15  | 10    | 2009 | 0.174    | 30.084    | Rain         | Small      | 0      | 0        |
| 12746   | 01  | 2     | 2010 | -1.180   | 29.450    | Unknown      | Unknown    | 0      | 0        |
| 01538   | 01  | 3     | 2010 | 1.005    | 34.401    | Downpour     | Very large | 388    | 0        |
| 12748   | 02  | 3     | 2010 | -2.490   | 28.848    | Earthquake   | Medium     | 0      | 0        |
| 01540   | 04  | 3     | 2010 | -1.265   | 29.985    | Downpour     | Medium     | 0      | 0        |
| 12845   | 04  | 3     | 2010 | -1.399   | 29.940    | Rain         | Medium     | 0      | 0        |
| 01542   | 05  | 3     | 2010 | 0.552    | 30.121    | Rain         | Medium     | 3      | 0        |
| 12846   | 05  | 3     | 2010 | -1.167   | 29.667    | Downpour     | Medium     | 3      | 0        |
| 01543   | 06  | 3     | 2010 | 0.384    | 30.130    | Unknown      | Unknown    | 0      | 0        |
| 12847   | 06  | 3     | 2010 | 0.587    | 30.256    | Rain         | Medium     | 0      | 0        |
| 12848   | 06  | 3     | 2010 | 0.406    | 29.917    | Downpour     | Medium     | 0      | 0        |
| 01593   | 26  | 3     | 2010 | -1.699   | 29.371    | Downpour     | Large      | 14     | 0        |
| 12809   | 26  | 3     | 2010 | -1.659   | 29.288    | Rain         | Very large | 14     | 0        |
| 12810   | 29  | 3     | 2010 | -2.392   | 29.023    | Rain         | Medium     | 2      | 0        |
| 01758   | 18  | 4     | 2010 | 1.050    | 34.233    | Downpour     | Medium     | 0      | 0        |
| 01759   | 18  | 4     | 2010 | 0.970    | 34.324    | Downpour     | Medium     | 0      | 0        |
| 01766   | 19  | 4     | 2010 | -0.354   | 34.808    | Downpour     | Medium     | 0      | 0        |
| 01778   | 24  | 4     | 2010 | 1.007    | 34.401    | Downpour     | Medium     | 0      | 0        |
| 01799   | 30  | 4     | 2010 | 1.250    | 35.584    | Downpour     | Large      | 16     | 0        |
| 01852   | 10  | 5     | 2010 | 0.883    | 34.519    | Downpour     | Medium     | 1      | 0        |

| eventID | Day | Month | Year | Latitude | Longitude | Main Trigger | Magnitude  | Deaths | Injuries |
|---------|-----|-------|------|----------|-----------|--------------|------------|--------|----------|
| 01853   | 10  | 5     | 2010 | 1.150    | 34.400    | Downpour     | Medium     | 4      | 0        |
| 12750   | 11  | 5     | 2010 | -1.708   | 29.025    | Unknown      | Medium     | 0      | 2        |
| 01861   | 15  | 5     | 2010 | -1.496   | 29.374    | Rain         | Large      | 47     | 1250     |
| 01862   | 15  | 5     | 2010 | -0.789   | 29.821    | Downpour     | Medium     | 0      | 0        |
| 12751   | 15  | 5     | 2010 | -0.792   | 29.835    | Rain         | Medium     | 0      | 0        |
| 12849   | 15  | 5     | 2010 | 0.975    | 34.294    | Downpour     | Medium     | 3      | 0        |
| 01866   | 16  | 5     | 2010 | -1.647   | 29.505    | Unknown      | Medium     | 7      | 0        |
| 01867   | 16  | 5     | 2010 | -1.525   | 29.291    | Downpour     | Very large | 54     | 0        |
| 01868   | 16  | 5     | 2010 | -1.200   | 30.133    | Downpour     | Medium     | 2      | 0        |
| 12811   | 16  | 5     | 2010 | 1.012    | 34.236    | Downpour     | Medium     | 0      | 0        |
| 12851   | 17  | 5     | 2010 | 0.083    | 29.860    | Rain         | Medium     | 0      | 0        |
| 12852   | 25  | 5     | 2010 | 0.222    | 30.092    | Unknown      | Unknown    | 0      | 0        |
| 12853   | 25  | 5     | 2010 | 0.169    | 29.879    | Unknown      | Unknown    | 0      | 0        |
| 12854   | 25  | 5     | 2010 | 0.588    | 30.152    | Unknown      | Unknown    | 0      | 0        |
| 12855   | 25  | 5     | 2010 | 0.508    | 30.176    | Unknown      | Unknown    | 0      | 0        |
| 12812   | 07  | 6     | 2010 | -1.754   | 29.801    | Rain         | Medium     | 6      | 4        |
| 02232   | 11  | 8     | 2010 | 1.006    | 34.401    | Downpour     | Medium     | 1      | 0        |
| 02239   | 13  | 8     | 2010 | 1.334    | 34.579    | Downpour     | Medium     | 0      | 0        |
| 02244   | 14  | 8     | 2010 | 1.020    | 34.355    | Downpour     | Medium     | 5      | 0        |
| 02653   | 27  | 10    | 2010 | -0.320   | 30.419    | Downpour     | Medium     | 0      | 0        |
| 12856   | 27  | 10    | 2010 | -0.255   | 30.350    | Rain         | Medium     | 1      | 0        |
| 12813   | 07  | 5     | 2011 | -1.621   | 29.611    | Flooding     | Large      | 14     | 0        |
| 03521   | 21  | 5     | 2011 | 0.907    | 34.365    | Downpour     | Medium     | 1      | 0        |
| 03853   | 28  | 7     | 2011 | 1.593    | 35.567    | Downpour     | Medium     | 0      | 0        |
| 03906   | 10  | 8     | 2011 | 3.908    | 33.831    | Downpour     | Medium     | 7      | 0        |
| 03910   | 11  | 8     | 2011 | 1.010    | 34.332    | Downpour     | Medium     | 0      | 0        |
| 03952   | 29  | 8     | 2011 | 1.220    | 34.348    | Downpour     | Medium     | 0      | 0        |
| 06568   | 29  | 8     | 2011 | 1.260    | 34.318    | Downpour     | Large      | 40     | 0        |
| 03959   | 01  | 9     | 2011 | 1.439    | 34.308    | Downpour     | Medium     | 0      | 0        |
| 03970   | 11  | 9     | 2011 | 1.348    | 34.399    | Downpour     | Large      | 1      | 0        |
| 12814   | 19  | 9     | 2011 | -1.443   | 29.857    | Rain         | Medium     | 6      | 0        |
| 12858   | 02  | 10    | 2011 | 0.117    | 30.017    | Unknown      | Unknown    | 0      | 0        |
| 12859   | 08  | 10    | 2011 | 0.138    | 29.999    | Unknown      | Unknown    | 5      | 0        |
| 12860   | 14  | 10    | 2011 | 0.125    | 29.990    | Unknown      | Unknown    | 0      | 0        |
| 12815   | 04  | 11    | 2011 | -2.130   | 29.415    | Rain         | Medium     | 0      | 0        |
| 12816   | 10  | 11    | 2011 | -2.007   | 29.662    | Rain         | Medium     | 3      | 0        |
| 04044   | 12  | 11    | 2011 | 1.851    | 34.886    | Downpour     | Very large | 3      | 0        |
| 04076   | 02  | 12    | 2011 | 0.334    | 34.483    | Downpour     | Medium     | 3      | 0        |
| 12817   | 04  | 12    | 2011 | -2.470   | 29.471    | Rain         | Medium     | 0      | 0        |
| 12754   | 03  | 1     | 2012 | 0.055    | 29.171    | Unknown      | Unknown    | 0      | 0        |
| 12755   | 04  | 1     | 2012 | 0.135    | 29.264    | Unknown      | Unknown    | 0      | 16       |
| 12756   | 04  | 1     | 2012 | 0.133    | 29.271    | Unknown      | Unknown    | 0      | 68       |
| 12861   | 01  | 5     | 2012 | 0.105    | 30.109    | Unknown      | Unknown    | 9      | 0        |
| 12818   | 06  | 5     | 2012 | -1.832   | 29.646    | Rain         | Medium     | 0      | 0        |
| 04363   | 17  | 5     | 2012 | 0.168    | 29.983    | Downpour     | Medium     | 4      | 0        |
| 12862   | 17  | 5     | 2012 | 0.222    | 30.092    | Unknown      | Unknown    | 1      | 0        |
| 12863   | 17  | 5     | 2012 | 0.168    | 29.983    | Rain         | Medium     | 4      | 0        |
| 12864   | 17  | 5     | 2012 | 0.095    | 30.134    | Unknown      | Unknown    | 1      | 0        |
| 12865   | 17  | 5     | 2012 | 0.128    | 29.961    | Unknown      | Unknown    | 1      | 0        |
| 12819   | 19  | 5     | 2012 | -1.611   | 29.499    | Unknown      | Unknown    | 0      | 0        |
| 04386   | 03  | 6     | 2012 | 1.234    | 34.250    | Downpour     | Medium     | 2      | 0        |
| 04437   | 25  | 6     | 2012 | 1.010    | 34.332    | Downpour     | Very large | 32     | 0        |
| 04466   | 18  | 7     | 2012 | 1.017    | 34.254    | Downpour     | Medium     | 0      | 0        |
| 04502   | 20  | 8     | 2012 | 0.434    | 35.788    | Downpour     | Large      | 2      | 0        |
| 12758   | 08  | 11    | 2012 | -2.044   | 28.900    | Rain         | Medium     | 7      | 2        |
| 12759   | 19  | 12    | 2012 | 0.481    | 29.449    | Rain         | Medium     | 20     | 86       |
| 12760   | 19  | 12    | 2012 | -2.501   | 28.835    | Unknown      | Medium     | 0      | 0        |
| 12761   | 23  | 12    | 2012 | -2.492   | 28.836    | Unknown      | Small      | 0      | 0        |
| 04689   | 29  | 12    | 2012 | 0.467    | 35.533    | Rain         | Large      | 4      | 0        |

| eventID | Day | Month | Year | Latitude | Longitude | Main Trigger | Magnitude | Deaths | Injuries |
|---------|-----|-------|------|----------|-----------|--------------|-----------|--------|----------|
| 04690   | 29  | 12    | 2012 | 0.771    | 35.566    | Rain         | Large     | 3      | 0        |
| 04691   | 29  | 12    | 2012 | 0.772    | 35.566    | Rain         | Large     | 3      | 0        |
| 04692   | 29  | 12    | 2012 | 0.770    | 35.566    | Rain         | Large     | 2      | 0        |
| 04693   | 29  | 12    | 2012 | 0.470    | 35.613    | Rain         | Large     | 2      | 0        |
| 04694   | 29  | 12    | 2012 | 1.084    | 35.471    | Rain         | Large     | 0      | 0        |
| 04695   | 29  | 12    | 2012 | 0.771    | 35.566    | Rain         | Large     | 2      | 0        |
| 04696   | 30  | 12    | 2012 | 0.317    | 32.581    | Rain         | Medium    | 0      | 0        |
| 12762   | 31  | 12    | 2012 | -2.218   | 29.007    | Unknown      | Small     | 0      | 0        |
| 12763   | 02  | 1     | 2013 | -2.505   | 28.880    | Rain         | Medium    | 6      | 1        |
| 12820   | 15  | 4     | 2013 | -1.954   | 30.089    | Rain         | Small     | 1      | 1        |
| 04808   | 17  | 4     | 2013 | -2.499   | 29.289    | Unknown      | Medium    | 0      | 0        |
| 12821   | 17  | 4     | 2013 | -2.250   | 29.415    | Rain         | Medium    | 5      | 0        |
| 12822   | 17  | 4     | 2013 | -1.083   | 35.867    | Rain         | Medium    | 2      | 0        |
| 12823   | 17  | 4     | 2013 | -1.878   | 29.420    | Rain         | Medium    | 3      | 0        |
| 12824   | 20  | 4     | 2013 | -2.183   | 29.918    | Rain         | Large     | 0      | 0        |
| 04818   | 22  | 4     | 2013 | -0.979   | 36.153    | Rain         | Large     | 1      | 0        |
| 04819   | 22  | 4     | 2013 | -0.677   | 34.772    | Rain         | Large     | 0      | 0        |
| 04820   | 22  | 4     | 2013 | -0.843   | 34.681    | Rain         | Large     | 0      | 0        |
| 12764   | 29  | 4     | 2013 | -1.788   | 29.004    | Rain         | Medium    | 14     | 10       |
| 12825   | 04  | 5     | 2013 | -1.665   | 29.835    | Rain         | Medium    | 0      | 0        |
| 04834   | 05  | 5     | 2013 | -1.665   | 29.835    | Rain         | Medium    | 0      | 0        |
| 12867   | 07  | 5     | 2013 | 0.364    | 30.067    | Unknown      | Unknown   | 0      | 0        |
| 04851   | 08  | 5     | 2013 | 0.873    | 36.089    | Rain         | Medium    | 0      | 0        |
| 12765   | 16  | 5     | 2013 | -1.544   | 28.869    | Flooding     | Medium    | 47     | 0        |
| 04967   | 19  | 6     | 2013 | 1.415    | 35.357    | Downpour     | Medium    | 0      | 0        |
| 05303   | 10  | 8     | 2013 | 1.077    | 34.416    | Downpour     | Medium    | 1      | 18       |
| 05304   | 10  | 8     | 2013 | 1.374    | 34.406    | Downpour     | Medium    | 0      | 0        |
| 05305   | 10  | 8     | 2013 | 1.027    | 34.379    | Downpour     | Medium    | 0      | 0        |
| 05306   | 10  | 8     | 2013 | 1.009    | 34.407    | Downpour     | Medium    | 0      | 0        |
| 05307   | 10  | 8     | 2013 | 1.059    | 34.396    | Downpour     | Medium    | 0      | 0        |
| 05308   | 10  | 8     | 2013 | 1.033    | 34.250    | Downpour     | Medium    | 0      | 0        |
| 05386   | 22  | 8     | 2013 | 1.197    | 35.284    | Downpour     | Medium    | 0      | 0        |
| 05557   | 26  | 9     | 2013 | 0.158    | 30.005    | Rain         | Medium    | 3      | 0        |
| 12868   | 26  | 9     | 2013 | 0.168    | 29.984    | Downpour     | Medium    | 3      | 0        |
| 05654   | 20  | 11    | 2013 | 0.242    | 35.661    | Mining       | Medium    | 1      | 0        |
| 12766   | 15  | 12    | 2013 | -2.519   | 28.845    | Unknown      | Medium    | 1      | 5        |
| 12826   | 17  | 12    | 2013 | -1.923   | 30.004    | Rain         | Medium    | 3      | 5        |
| 12767   | 17  | 1     | 2014 | -2.519   | 28.846    | Flooding     | Medium    | 5      | 0        |
| 12768   | 18  | 1     | 2014 | -2.498   | 28.873    | Rain         | Medium    | 6      | 0        |
| 12769   | 18  | 1     | 2014 | -2.519   | 28.862    | Rain         | Medium    | 5      | 0        |
| 12770   | 19  | 1     | 2014 | -2.496   | 28.879    | Rain         | Medium    | 6      | 0        |
| 12771   | 23  | 1     | 2014 | -2.529   | 28.857    | Rain         | Medium    | 3      | 0        |
| 12772   | 25  | 1     | 2014 | -2.508   | 28.848    | Rain         | Medium    | 4      | 2        |
| 12773   | 27  | 1     | 2014 | -2.498   | 28.873    | Unknown      | Medium    | 6      | 0        |
| 12870   | 04  | 2     | 2014 | 0.310    | 30.044    | Rain         | Medium    | 0      | 0        |
| 12775   | 18  | 2     | 2014 | -2.067   | 28.563    | Rain         | Medium    | 12     | 0        |
| 12827   | 23  | 2     | 2014 | -1.867   | 29.957    | Rain         | Medium    | 4      | 6        |
| 12871   | 12  | 8     | 2014 | -0.267   | 30.568    | Rain         | Medium    | 0      | 0        |
| 12777   | 04  | 10    | 2014 | 0.139    | 29.323    | Rain         | Medium    | 1      | 0        |
| 06272   | 17  | 10    | 2014 | 1.263    | 35.415    | Unknown      | Small     | 0      | 0        |
| 12872   | 24  | 10    | 2014 | -0.450   | 30.393    | Rain         | Medium    | 1      | 0        |
| 12778   | 25  | 10    | 2014 | -2.134   | 28.860    | Rain         | Large     | 5      | 0        |
| 12779   | 25  | 10    | 2014 | -2.044   | 28.900    | Rain         | Large     | 30     | 0        |
| 12780   | 26  | 12    | 2014 | -2.223   | 29.033    | Rain         | Medium    | 3      | 0        |
| 12828   | 03  | 4     | 2015 | -1.658   | 29.329    | Rain         | Large     | 2      | 6        |
| 12829   | 03  | 4     | 2015 | -2.392   | 29.175    | Rain         | Large     | 2      | 6        |
| 12781   | 14  | 4     | 2015 | -2.511   | 28.856    | Rain         | Large     | 16     | 0        |
| 07098   | 02  | 5     | 2015 | 0.052    | 34.723    | Downpour     | Medium    | 0      | 0        |
| 07105   | 03  | 5     | 2015 | 0.028    | 34.784    | Unknown      | Small     | 0      | 0        |

| eventID | Day | Month | Year | Latitude | Longitude | Main Trigger | Magnitude | Deaths | Injuries |
|---------|-----|-------|------|----------|-----------|--------------|-----------|--------|----------|
| 12782   | 12  | 5     | 2015 | -1.396   | 28.812    | Rain         | Large     | 10     | 0        |
| 12783   | 13  | 10    | 2015 | -2.231   | 29.073    | Rain         | Medium    | 0      | 0        |
| 12784   | 24  | 10    | 2015 | -2.019   | 28.907    | Unknown      | Medium    | 3      | 0        |
| 08951   | 17  | 11    | 2015 | -1.116   | 35.874    | Rain         | Medium    | 5      | 0        |
| 08994   | 03  | 12    | 2015 | -0.487   | 30.170    | Rain         | Large     | 4      | 0        |
| 12873   | 03  | 12    | 2015 | -0.487   | 30.170    | Unknown      | Large     | 4      | 0        |
| 12785   | 09  | 12    | 2015 | -1.911   | 28.954    | Rain         | Large     | 6      | 0        |
| 12786   | 11  | 12    | 2015 | -2.523   | 28.857    | Rain         | Large     | 13     | 0        |
| 09062   | 14  | 12    | 2015 | 0.048    | 34.722    | Rain         | Medium    | 0      | 0        |
| 12787   | 17  | 12    | 2015 | -1.759   | 28.982    | Unknown      | Medium    | 2      | 0        |
| 12788   | 17  | 12    | 2015 | -1.721   | 29.013    | Unknown      | Medium    | 5      | 0        |
| 12789   | 17  | 12    | 2015 | -1.708   | 29.025    | Unknown      | Medium    | 1      | 0        |
| 12790   | 19  | 12    | 2015 | -2.019   | 28.907    | Unknown      | Medium    | 0      | 0        |
| 12791   | 09  | 1     | 2016 | -2.496   | 28.890    | Unknown      | Small     | 0      | 0        |
| 12792   | 09  | 1     | 2016 | -2.495   | 28.890    | Unknown      | Small     | 0      | 0        |
| 12793   | 09  | 1     | 2016 | -2.492   | 28.892    | Unknown      | Small     | 0      | 0        |
| 12794   | 09  | 1     | 2016 | -2.497   | 28.890    | Unknown      | Small     | 0      | 0        |
| 12796   | 27  | 1     | 2016 | -2.501   | 28.581    | Unknown      | Small     | 0      | 0        |
| 12797   | 20  | 2     | 2016 | -2.277   | 28.872    | Unknown      | Small     | 0      | 0        |
| 12799   | 12  | 4     | 2016 | -1.716   | 29.023    | Rain         | Medium    | 5      | 2        |
| 12800   | 19  | 4     | 2016 | -1.716   | 29.023    | Unknown      | Medium    | 0      | 0        |
| 12801   | 21  | 4     | 2016 | -2.019   | 28.906    | Unknown      | Medium    | 3      | 0        |
| 12830   | 02  | 5     | 2016 | -2.172   | 29.369    | Rain         | Medium    | 1      | 0        |
| 07717   | 07  | 5     | 2016 | -1.815   | 29.740    | Rain         | Large     | 49     | 0        |
| 12831   | 07  | 5     | 2016 | -1.700   | 29.796    | Rain         | Medium    | 54     | 0        |
| 12832   | 07  | 5     | 2016 | -1.825   | 29.595    | Downpour     | Large     | 0      | 0        |
| 07716   | 08  | 5     | 2016 | -1.710   | 29.803    | Downpour     | Medium    | 54     | 0        |
| 09370   | 10  | 5     | 2016 | 0.835    | 30.158    | Rain         | Medium    | 11     | 50       |
| 12874   | 10  | 5     | 2016 | 0.835    | 30.158    | Rain         | Medium    | 15     | 50       |
| 12875   | 10  | 5     | 2016 | 0.630    | 30.036    | Downpour     | Large     | 15     | 50       |
| 09320   | 21  | 5     | 2016 | 0.375    | 34.958    | Downpour     | Small     | 5      | 0        |
| 08923   | 10  | 7     | 2016 | 0.560    | 30.037    | Downpour     | Medium    | 4      | 2        |
| 12876   | 10  | 7     | 2016 | 0.545    | 30.011    | Rain         | Medium    | 4      | 2        |
| 09551   | 05  | 10    | 2016 | 1.053    | 34.343    | Downpour     | Medium    | 0      | 0        |
| 09552   | 05  | 10    | 2016 | 1.047    | 34.341    | Downpour     | Medium    | 0      | 0        |
| 12802   | 04  | 11    | 2016 | -2.019   | 28.907    | Unknown      | Medium    | 2      | 0        |
| 10737   | 06  | 12    | 2016 | -1.853   | 30.114    | Mining       | Small     | 1      | 0        |
| 12945   | 28  | 8     | 2017 | 1.139    | 34.406    | Downpour     | Large     | 9      | 0        |
| 12679   | 07  | 9     | 2017 | -1.247   | 29.747    | Downpour     | Unknown   | 3      | 4        |
| 12678   | 26  | 9     | 2017 | -1.185   | 29.846    | Downpour     | Unknown   | 17     | 15       |
| 12651   | 23  | 4     | 2018 | -1.919   | 30.018    | Rain         | Medium    | 18     | 0        |
| 11430   | 27  | 4     | 2018 | 1.005    | 34.332    | Downpour     | Large     | 1      | 0        |
| 12681   | 27  | 4     | 2018 | 0.081    | 35.239    | Downpour     | Medium    | 0      | 0        |
| 11416   | 03  | 5     | 2018 | 1.218    | 35.383    | Downpour     | Large     | 1      | 8        |
| 11412   | 04  | 5     | 2018 | -0.935   | 35.440    | Downpour     | Medium    | 3      | 2        |
| 11325   | 06  | 5     | 2018 | -2.171   | 29.372    | Downpour     | Large     | 18     | 12       |
| 11324   | 09  | 5     | 2018 | 0.052    | 36.173    | Dam collapse | Large     | 44     | 0        |
| 11353   | 16  | 5     | 2018 | 0.991    | 34.332    | Rain         | Large     | 0      | 0        |
| 11366   | 19  | 5     | 2018 | -1.402   | 30.005    | Rain         | Medium    | 0      | 0        |
| 11435   | 22  | 5     | 2018 | 0.573    | 35.521    | Rain         | Medium    | 0      | 0        |
| 11464   | 24  | 5     | 2018 | 0.979    | 35.562    | Downpour     | Small     | 0      | 0        |
| 13806   | 11  | 10    | 2018 | 1.007    | 34.398    | Flooding     | Large     | 54     | 0        |
| 13848   | 11  | 10    | 2018 | 1.015    | 34.321    | Rain         | Medium    | 40     | 0        |
| 13813   | 23  | 12    | 2018 | -2.509   | 28.840    | Rain         | Unknown   | 5      | 4        |
| 13754   | 04  | 6     | 2019 | 1.020    | 34.398    | Rain         | Unknown   | 1      | 0        |
| 13755   | 04  | 6     | 2019 | 1.006    | 34.396    | Rain         | Unknown   | 2      | 0        |

## APPENDIX C: BUILDING EXPOSURE MODEL FOR UGANDA

### Appendix C-1: Building taxonomies

#### Typologies for non-ductile unreinforced masonry (MUR) buildings

| GEM Taxonomy                | Material technology          | No. of Storeys |
|-----------------------------|------------------------------|----------------|
| MUR+ADO/LWAL+CDN/H:2        | Adobe blocks                 | 2              |
| MUR+ADO/LWAL+CDN/HBET:3-6   | Adobe blocks                 | 3 to 6         |
| MUR+CB/LWAL+CDN/H:1         | Concrete blocks              | 1              |
| MUR+CB/LWAL+CDN/H:2         | Concrete blocks              | 2              |
| MUR+CB/LWAL+CDN/HBET:3-6    | Concrete blocks              | 3 to 6         |
| MUR+CL/LWAL+CDN/H:1         | Fired clay bricks            | 1              |
| MUR+CL/LWAL+CDN/H:2         | Fired clay bricks            | 2              |
| MUR+CL/LWAL+CDN/HBET:3-6    | Fired clay bricks            | 3 to 6         |
| MUR+STDRE/LWAL+CDN/H:1      | Dressed stone masonry        | 1              |
| MUR+STDRE/LWAL+CDN/H:2      | Dressed stone masonry        | 2              |
| MUR+STDRE/LWAL+CDN/HBET:3-6 | Dressed stone masonry        | 3 to 6         |
| MUR+STRUB/LWAL+CDN/H:1      | Rubble or semi-dressed stone | 1              |
| MUR+STRUB/LWAL+CDN/H:2      | Rubble or semi-dressed stone | 2              |
| MUR+STRUB/LWAL+CDN/HBET:3-6 | Rubble or semi-dressed stone | 3 to 6         |

#### Reinforced concrete (RC) building taxonomy

| GEM Taxonomy          | Lateral load resisting system | No. of Storeys | Ductility |
|-----------------------|-------------------------------|----------------|-----------|
| CR/LFINF+CDL/H:1      | Infilled frame                | 1              | Low       |
| CR/LFINF+CDL/H:2      | Infilled frame                | 2              | Low       |
| CR/LFINF+CDL/H:3      | Infilled frame                | 3              | Low       |
| CR/LFINF+CDL/HBET:4-7 | Infilled frame                | 4 to 7         | Low       |
| CR/LFINF+CDL/HBET:8+  | Infilled frame                | ≥ 8            | Low       |
| CR/LFINF+CDM/H:1      | Infilled frame                | 1              | Medium    |
| CR/LFINF+CDM/H:2      | Infilled frame                | 2              | Medium    |
| CR/LFINF+CDM/H:3      | Infilled frame                | 3              | Medium    |
| CR/LFINF+CDM/HBET:4-7 | Infilled frame                | 4 to 7         | Medium    |
| CR/LFINF+CDM/HBET:8+  | Infilled frame                | ≥ 8            | Medium    |
| CR/LWAL+CDL/H:1       | Wall                          | 1              | Low       |
| CR/LWAL+CDL/H:2       | Wall                          | 2              | Low       |
| CR/LWAL+CDL/H:3       | Wall                          | 3              | Low       |
| CR/LWAL+CDL/HBET:4-7  | Wall                          | 4 to 7         | Low       |
| CR/LWAL+CDL/HBET:8+   | Wall                          | ≥ 8            | Low       |
| CR/LWAL+CDM/H:1       | Wall                          | 1              | Medium    |
| CR/LWAL+CDM/H:2       | Wall                          | 2              | Medium    |
| CR/LWAL+CDM/H:3       | Wall                          | 3              | Medium    |
| CR/LWAL+CDM/HBET:4-7  | Wall                          | 4 to 7         | Medium    |
| CR/LWAL+CDM/HBET:8+   | Wall                          | ≥ 8            | Medium    |

**Description of confined masonry (MCF) building taxonomy**

| GEM Taxonomy          | Lateral load resisting system | No. of Storeys | Ductility |
|-----------------------|-------------------------------|----------------|-----------|
| MCF/LWAL+CDL/H:1      | Wall                          | 1              | Low       |
| MCF/LWAL+CDL/H:2      | Wall                          | 2              | Low       |
| MCF/LWAL+CDL/HBET:3-6 | Wall                          | 3 to 6         | Low       |
| MCF/LWAL+CDM/H:1      | Wall                          | 1              | Medium    |
| MCF/LWAL+CDM/H:2      | Wall                          | 2              | Medium    |
| MCF/LWAL+CDM/HBET:3-6 | Wall                          | 3 to 6         | Medium    |

**Structural steel (S) typologies; all with moment frame lateral load resisting system**

| GEM Taxonomy     | Material technology                     | No. of Storeys | Ductility |
|------------------|-----------------------------------------|----------------|-----------|
| S/LFM+CDL/H:1    | Steel (hot-rolled sections)             | 1              | Low       |
| S/LFM+CDL/H:2    | Steel (hot-rolled sections)             | 2              | Low       |
| S/LFM+CDM/H:1    | Steel (hot-rolled sections)             | 1              | Medium    |
| S/LFM+CDM/H:2    | Steel (hot-rolled sections)             | 2              | Medium    |
| S+S/LFM+CDL/H:1  | Steel (hot-rolled sections)             | 1              | Low       |
| S+S/LFM+CDM/H:1  | Steel (hot-rolled sections)             | 1              | Medium    |
| S+S/LFM+CDM/H:2  | Steel (hot-rolled sections)             | 2              | Medium    |
| S+SL/LFM+CDM/H:1 | Light weight cold-foamed steel sections | 1              | Medium    |
| S+SL/LFM+CDM/H:2 | Light weight cold-foamed steel sections | 2              | Medium    |
| S+SL/LFM+CDL/H:1 | Light weight cold-foamed steel sections | 1              | Low       |
| S+SL/LFM+CDL/H:2 | Light weight cold-foamed steel sections | 2              | Low       |

**Wooden (W), metal (ME) and vegetative exterior wall (EWV) building taxonomies**

| GEM Taxonomy        | Material technology                 | No. of Storeys | Ductility   |
|---------------------|-------------------------------------|----------------|-------------|
| W/LWAL+CDL/H:1      | Wood                                | 1              | Low         |
| W/LWAL+CDL/H:2      | Wood                                | 2              | Low         |
| W/LWAL+CDL/H:3      | Wood                                | 3              | Low         |
| W/LWAL+CDM/H:1      | Wood                                | 1              | Moderate    |
| W/LWAL+CDM/H:2      | Wood                                | 2              | Moderate    |
| W/LWAL+CDM/H:3      | Wood                                | 3              | Moderate    |
| W+WWD/LWAL+CDN/H:1  | Wood, together with wattle and daub | 1              | Non-ductile |
| W+WWD/LWAL+CDN/H:2  | Wood, together with wattle and daub | 2              | Non-ductile |
| ME+MEO/LWAL+CDN/H:1 | Metal, other (except steel)         | 1              | Non-ductile |
| EWV/LN+CDN/H:1      | Vegetative exterior walls           | 1              | Non-ductile |

**Appendix C-2: Regional exposure for rural settlements in residential buildings**

| Region   | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Occupants | Cost (US\$) |
|----------|-----------------------------|--------|------------------------|-----------|-------------|
| Northern | EWV/LN+CDN/H:1              | 6660   | 399630                 | 31060     | 31607230    |
| Northern | ME+MEO/LWAL+CDN/H:1         | 16651  | 999075                 | 77651     | 79018076    |
| Northern | MUR+ADO/LWAL+CDN/H:1        | 349737 | 20984204               | 1630951   | 3983200649  |
| Northern | MUR+ADO/LWAL+CDN/H:2        | 340993 | 34361634               | 1630951   | 6559738963  |
| Northern | MUR+ADO/LWAL+CDN/HBET:3-6   | 4602   | 3129224                | 171679    | 867249242   |
| Northern | MUR+CB/LWAL+CDN/H:1         | 9491   | 569473                 | 44261     | 120107476   |
| Northern | MUR+CB/LWAL+CDN/H:2         | 9254   | 932511                 | 44261     | 197799146   |
| Northern | MUR+CB/LWAL+CDN/HBET:3-6    | 124    | 84921                  | 4659      | 26150608    |
| Northern | MUR+CL/LWAL+CDN/H:1         | 87434  | 5246051                | 407738    | 1106444625  |
| Northern | MUR+CL/LWAL+CDN/H:2         | 85248  | 8590408                | 407738    | 1822149712  |
| Northern | MUR+CL/LWAL+CDN/HBET:3-6    | 1150   | 782306                 | 42920     | 240902567   |
| Northern | MUR+STRUB/LWAL+CDN/H:1      | 9491   | 569473                 | 44261     | 96085981    |
| Northern | MUR+STRUB/LWAL+CDN/H:2      | 9254   | 932511                 | 44261     | 158239317   |
| Northern | MUR+STRUB/LWAL+CDN/HBET:3-6 | 124    | 84921                  | 4659      | 20920486    |
| Northern | W+WWD/LWAL+CDN/H:1          | 368749 | 22124966               | 1719614   | 3499782426  |
| Northern | W+WWD/LWAL+CDN/H:2          | 154085 | 15526985               | 736977    | 2470123311  |
| Northern | W/LWAL+CDL/H:1              | 1066   | 63941                  | 4970      | 16182902    |
| Northern | W/LWAL+CDL/H:2              | 1039   | 104703                 | 4969      | 26650832    |
| Northern | W/LWAL+CDL/H:3              | 416    | 61121                  | 2484      | 16371296    |
| Northern | W/LWAL+CDM/H:1              | 266    | 15985                  | 1242      | 4045725     |
| Northern | W/LWAL+CDM/H:2              | 260    | 26176                  | 1242      | 6662708     |
| Northern | W/LWAL+CDM/H:3              | 104    | 15280                  | 621       | 4092824     |
| Eastern  | EWV/LN+CDN/H:1              | 8445   | 506711                 | 39383     | 40076388    |
| Eastern  | ME+MEO/LWAL+CDN/H:1         | 21113  | 1266777                | 98457     | 100190970   |
| Eastern  | MUR+ADO/LWAL+CDN/H:1        | 443449 | 26606922               | 2067964   | 5050499282  |
| Eastern  | MUR+ADO/LWAL+CDN/H:2        | 432362 | 43568834               | 2067964   | 8317421049  |
| Eastern  | MUR+ADO/LWAL+CDN/HBET:3-6   | 5834   | 3967699                | 217680    | 1099628679  |
| Eastern  | MUR+CB/LWAL+CDN/H:1         | 12034  | 722063                 | 56121     | 152290274   |
| Eastern  | MUR+CB/LWAL+CDN/H:2         | 11734  | 1182378                | 56121     | 250799429   |
| Eastern  | MUR+CB/LWAL+CDN/HBET:3-6    | 158    | 107676                 | 5908      | 33157663    |
| Eastern  | MUR+CL/LWAL+CDN/H:1         | 110862 | 6651730                | 516991    | 1402916467  |
| Eastern  | MUR+CL/LWAL+CDN/H:2         | 108091 | 10892209               | 516991    | 2310394735  |
| Eastern  | MUR+CL/LWAL+CDN/HBET:3-6    | 1458   | 991925                 | 54420     | 305452411   |
| Eastern  | MUR+STRUB/LWAL+CDN/H:1      | 12034  | 722063                 | 56121     | 121832220   |
| Eastern  | MUR+STRUB/LWAL+CDN/H:2      | 11734  | 1182378                | 56121     | 200639543   |
| Eastern  | MUR+STRUB/LWAL+CDN/HBET:3-6 | 158    | 107676                 | 5908      | 26526130    |
| Eastern  | W+WWD/LWAL+CDN/H:1          | 467556 | 28053351               | 2180384   | 4437549144  |
| Eastern  | W+WWD/LWAL+CDN/H:2          | 195372 | 19687440               | 934451    | 3131992864  |
| Eastern  | W/LWAL+CDL/H:1              | 1351   | 81074                  | 6301      | 20519111    |
| Eastern  | W/LWAL+CDL/H:2              | 1318   | 132758                 | 6301      | 33791923    |
| Eastern  | W/LWAL+CDL/H:3              | 526    | 77499                  | 3150      | 20757986    |
| Eastern  | W/LWAL+CDM/H:1              | 338    | 20268                  | 1575      | 5129778     |
| Eastern  | W/LWAL+CDM/H:2              | 329    | 33190                  | 1576      | 8447981     |
| Eastern  | W/LWAL+CDM/H:3              | 131    | 19375                  | 788       | 5189495     |
| Central  | EWV/LN+CDN/H:1              | 8987   | 539197                 | 41908     | 42645781    |
| Central  | ME+MEO/LWAL+CDN/H:1         | 22467  | 1347993                | 104770    | 106614451   |
| Central  | MUR+ADO/LWAL+CDN/H:1        | 471879 | 28312755               | 2200546   | 5374298804  |
| Central  | MUR+ADO/LWAL+CDN/H:2        | 460082 | 46362136               | 2200546   | 8850670695  |
| Central  | MUR+ADO/LWAL+CDN/HBET:3-6   | 6208   | 4222077                | 231636    | 1170128490  |
| Central  | MUR+CB/LWAL+CDN/H:1         | 12806  | 768356                 | 59719     | 162053966   |
| Central  | MUR+CB/LWAL+CDN/H:2         | 12486  | 1258183                | 59719     | 266878776   |
| Central  | MUR+CB/LWAL+CDN/HBET:3-6    | 168    | 114580                 | 6287      | 35283479    |
| Central  | MUR+CL/LWAL+CDN/H:1         | 117970 | 7078189                | 550136    | 1492860779  |
| Central  | MUR+CL/LWAL+CDN/H:2         | 115020 | 11590534               | 550137    | 2458519638  |
| Central  | MUR+CL/LWAL+CDN/HBET:3-6    | 1552   | 1055519                | 57909     | 325035692   |

| Region  | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Occupants | Cost (US\$) |
|---------|-----------------------------|--------|------------------------|-----------|-------------|
| Central | MUR+STRUB/LWAL+CDN/H:1      | 12806  | 768356                 | 59719     | 129643173   |
| Central | MUR+STRUB/LWAL+CDN/H:2      | 12486  | 1258183                | 59719     | 213503021   |
| Central | MUR+STRUB/LWAL+CDN/HBET:3-6 | 168    | 114580                 | 6287      | 28226784    |
| Central | W+WWD/LWAL+CDN/H:1          | 497532 | 29851918               | 2320174   | 4722050974  |
| Central | W+WWD/LWAL+CDN/H:2          | 207898 | 20949649               | 994360    | 3332792375  |
| Central | W/LWAL+CDL/H:1              | 1438   | 86272                  | 6705      | 21834640    |
| Central | W/LWAL+CDL/H:2              | 1402   | 141270                 | 6705      | 35958404    |
| Central | W/LWAL+CDL/H:3              | 560    | 82467                  | 3353      | 22088828    |
| Central | W/LWAL+CDM/H:1              | 359    | 21568                  | 1676      | 5458660     |
| Central | W/LWAL+CDM/H:2              | 350    | 35317                  | 1677      | 8989601     |
| Central | W/LWAL+CDM/H:3              | 140    | 20617                  | 839       | 5522208     |
| Western | EWV/LN+CDN/H:1              | 8231   | 493858                 | 38384     | 39059830    |
| Western | ME+MEO/LWAL+CDN/H:1         | 20577  | 1234644                | 95960     | 97649574    |
| Western | MUR+ADO/LWAL+CDN/H:1        | 432200 | 25932023               | 2015509   | 4922390741  |
| Western | MUR+ADO/LWAL+CDN/H:2        | 421395 | 42463688               | 2015508   | 8106445338  |
| Western | MUR+ADO/LWAL+CDN/HBET:3-6   | 5686   | 3867056                | 212159    | 1071736026  |
| Western | MUR+CB/LWAL+CDN/H:1         | 11729  | 703747                 | 54697     | 148427352   |
| Western | MUR+CB/LWAL+CDN/H:2         | 11436  | 1152387                | 54697     | 244437771   |
| Western | MUR+CB/LWAL+CDN/HBET:3-6    | 154    | 104945                 | 5757      | 32316602    |
| Western | MUR+CL/LWAL+CDN/H:1         | 108050 | 6483006                | 503877    | 1367330761  |
| Western | MUR+CL/LWAL+CDN/H:2         | 105349 | 10615922               | 503877    | 2251790372  |
| Western | MUR+CL/LWAL+CDN/HBET:3-6    | 1422   | 966764                 | 53040     | 297704452   |
| Western | MUR+STRUB/LWAL+CDN/H:1      | 11729  | 703747                 | 54697     | 118741882   |
| Western | MUR+STRUB/LWAL+CDN/H:2      | 11436  | 1152387                | 54697     | 195550217   |
| Western | MUR+STRUB/LWAL+CDN/HBET:3-6 | 154    | 104945                 | 5757      | 25853281    |
| Western | W+WWD/LWAL+CDN/H:1          | 455696 | 27341763               | 2125078   | 4324988402  |
| Western | W+WWD/LWAL+CDN/H:2          | 190415 | 19188058               | 910747    | 3052548236  |
| Western | W/LWAL+CDL/H:1              | 1317   | 79017                  | 6141      | 19998633    |
| Western | W/LWAL+CDL/H:2              | 1284   | 129391                 | 6141      | 32934773    |
| Western | W/LWAL+CDL/H:3              | 513    | 75533                  | 3071      | 20231449    |
| Western | W/LWAL+CDM/H:1              | 329    | 19754                  | 1535      | 4999658     |
| Western | W/LWAL+CDM/H:2              | 321    | 32348                  | 1536      | 8233693     |
| Western | W/LWAL+CDM/H:3              | 128    | 18882                  | 768       | 5057862     |

**Appendix C-3: Regional exposure for urban settlements in residential buildings**

| Region   | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Occupants | Cost (US\$) |
|----------|-----------------------------|--------|------------------------|-----------|-------------|
| Northern | CR/LFINF+CDL/H:1            | 6211   | 372663                 | 25413     | 110962278   |
| Northern | CR/LFINF+CDL/H:2            | 21195  | 2135823                | 88945     | 639584282   |
| Northern | CR/LFINF+CDL/H:3            | 16938  | 2493605                | 88946     | 785778364   |
| Northern | CR/LFINF+CDL/HBET:4-7       | 776    | 745325                 | 38120     | 350597426   |
| Northern | CR/LFINF+CDL/HBET:8+        | 194    | 232914                 | 12707     | 109561696   |
| Northern | CR/LFINF+CDM/H:1            | 1553   | 93166                  | 6353      | 27740570    |
| Northern | CR/LFINF+CDM/H:2            | 5299   | 533956                 | 22237     | 159896071   |
| Northern | CR/LFINF+CDM/H:3            | 4234   | 623401                 | 22236     | 196444591   |
| Northern | CR/LFINF+CDM/HBET:4-7       | 194    | 186331                 | 9530      | 87649357    |
| Northern | CR/LFINF+CDM/HBET:8+        | 49     | 58229                  | 3177      | 27390424    |
| Northern | CR/LWAL+CDL/H:1             | 198    | 11870                  | 809       | 3534354     |
| Northern | CR/LWAL+CDL/H:2             | 675    | 68030                  | 2833      | 20371944    |
| Northern | CR/LWAL+CDL/H:3             | 540    | 79426                  | 2833      | 25028496    |
| Northern | CR/LWAL+CDL/HBET:4-7        | 25     | 23740                  | 1214      | 11167177    |
| Northern | CR/LWAL+CDL/HBET:8+         | 6      | 7419                   | 405       | 3489743     |
| Northern | CR/LWAL+CDM/H:1             | 49     | 2967                   | 202       | 883589      |
| Northern | CR/LWAL+CDM/H:2             | 168    | 17008                  | 708       | 5092986     |
| Northern | CR/LWAL+CDM/H:3             | 135    | 19856                  | 709       | 6257123     |
| Northern | CR/LWAL+CDM/HBET:4-7        | 6      | 5935                   | 304       | 2791794     |
| Northern | CR/LWAL+CDM/HBET:8+         | 2      | 1855                   | 101       | 872436      |
| Northern | MCF/LWAL+CDL/H:1            | 25279  | 1516737                | 103431    | 479842502   |
| Northern | MCF/LWAL+CDL/H:2            | 24647  | 2483657                | 103431    | 790229223   |
| Northern | MCF/LWAL+CDL/HBET:3-6       | 702    | 477492                 | 22984     | 220557357   |
| Northern | MCF/LWAL+CDM/H:1            | 6320   | 379184                 | 25858     | 119960625   |
| Northern | MCF/LWAL+CDM/H:2            | 6162   | 620914                 | 25858     | 197557306   |
| Northern | MCF/LWAL+CDM/HBET:3-6       | 176    | 119373                 | 5747      | 55139339    |
| Northern | ME+MEO/LWAL+CDN/H:1         | 9892   | 593500                 | 40473     | 46940640    |
| Northern | MUR+ADO/LWAL+CDN/H:1        | 77826  | 4669584                | 318433    | 886375732   |
| Northern | MUR+ADO/LWAL+CDN/H:2        | 75881  | 7646444                | 318434    | 1459728982  |
| Northern | MUR+ADO/LWAL+CDN/HBET:3-6   | 1024   | 696341                 | 33519     | 192987688   |
| Northern | MUR+CB/LWAL+CDN/H:1         | 7048   | 422869                 | 28837     | 89187215    |
| Northern | MUR+CB/LWAL+CDN/H:2         | 6871   | 692447                 | 28837     | 146878077   |
| Northern | MUR+CB/LWAL+CDN/HBET:3-6    | 92     | 63059                  | 3036      | 19418440    |
| Northern | MUR+CL/LWAL+CDN/H:1         | 77826  | 4669584                | 318433    | 984861925   |
| Northern | MUR+CL/LWAL+CDN/H:2         | 75881  | 7646444                | 318434    | 1621921090  |
| Northern | MUR+CL/LWAL+CDN/HBET:3-6    | 1024   | 696341                 | 33519     | 214430763   |
| Northern | MUR+STDRE/LWAL+CDN/H:1      | 5873   | 352390                 | 24031     | 74322679    |
| Northern | MUR+STDRE/LWAL+CDN/H:2      | 5727   | 577040                 | 24031     | 122398398   |
| Northern | MUR+STDRE/LWAL+CDN/HBET:3-6 | 78     | 52550                  | 2529      | 16182034    |
| Northern | W+WWD/LWAL+CDN/H:1          | 40257  | 2415406                | 164714    | 382074974   |
| Northern | W+WWD/LWAL+CDN/H:2          | 16821  | 1695098                | 70592     | 269665992   |
| Northern | W/LWAL+CDL/H:1              | 791    | 47480                  | 3238      | 12016804    |
| Northern | W/LWAL+CDL/H:2              | 772    | 77749                  | 3238      | 19789888    |
| Northern | W/LWAL+CDL/H:3              | 308    | 45386                  | 1619      | 12156699    |
| Northern | W/LWAL+CDM/H:1              | 198    | 11870                  | 809       | 3004201     |
| Northern | W/LWAL+CDM/H:2              | 193    | 19437                  | 809       | 4947472     |
| Northern | W/LWAL+CDM/H:3              | 77     | 11347                  | 404       | 3039175     |
| Eastern  | CR/LFINF+CDL/H:1            | 7875   | 472518                 | 32222     | 140694621   |
| Eastern  | CR/LFINF+CDL/H:2            | 26874  | 2708116                | 112779    | 810960894   |
| Eastern  | CR/LFINF+CDL/H:3            | 21477  | 3161766                | 112779    | 996327680   |
| Eastern  | CR/LFINF+CDL/HBET:4-7       | 984    | 945035                 | 48334     | 444540008   |
| Eastern  | CR/LFINF+CDL/HBET:8+        | 246    | 295324                 | 16111     | 138918753   |
| Eastern  | CR/LFINF+CDM/H:1            | 1969   | 118129                 | 8056      | 35173655    |
| Eastern  | CR/LFINF+CDM/H:2            | 6718   | 677029                 | 28195     | 202740223   |
| Eastern  | CR/LFINF+CDM/H:3            | 5369   | 790441                 | 28194     | 249081920   |

| Region  | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Occupants | Cost (US\$) |
|---------|-----------------------------|--------|------------------------|-----------|-------------|
| Eastern | CR/LFINF+CDM/HBET:4-7       | 246    | 236259                 | 12083     | 111135002   |
| Eastern | CR/LFINF+CDM/HBET:8+        | 62     | 73831                  | 4028      | 34729688    |
| Eastern | CR/LWAL+CDL/H:1             | 251    | 15051                  | 1026      | 4481384     |
| Eastern | CR/LWAL+CDL/H:2             | 856    | 86258                  | 3593      | 25830607    |
| Eastern | CR/LWAL+CDL/H:3             | 685    | 100708                 | 3592      | 31734882    |
| Eastern | CR/LWAL+CDL/HBET:4-7        | 31     | 30101                  | 1540      | 14159422    |
| Eastern | CR/LWAL+CDL/HBET:8+         | 8      | 9407                   | 513       | 4424820     |
| Eastern | CR/LWAL+CDM/H:1             | 63     | 3763                   | 257       | 1120346     |
| Eastern | CR/LWAL+CDM/H:2             | 214    | 21564                  | 898       | 6457651     |
| Eastern | CR/LWAL+CDM/H:3             | 172    | 25176                  | 899       | 7933720     |
| Eastern | CR/LWAL+CDM/HBET:4-7        | 8      | 7525                   | 385       | 3539856     |
| Eastern | CR/LWAL+CDM/HBET:8+         | 2      | 2352                   | 128       | 1106205     |
| Eastern | MCF/LWAL+CDL/H:1            | 32052  | 1923147                | 131145    | 608416302   |
| Eastern | MCF/LWAL+CDL/H:2            | 31251  | 3149152                | 131145    | 1001971147  |
| Eastern | MCF/LWAL+CDL/HBET:3-6       | 890    | 605435                 | 29144     | 279655702   |
| Eastern | MCF/LWAL+CDM/H:1            | 8013   | 480787                 | 32786     | 152104076   |
| Eastern | MCF/LWAL+CDM/H:2            | 7812   | 787289                 | 32786     | 250492787   |
| Eastern | MCF/LWAL+CDM/HBET:3-6       | 222    | 151358                 | 7285      | 69913925    |
| Eastern | ME+MEO/LWAL+CDN/H:1         | 12542  | 752528                 | 51317     | 59518384    |
| Eastern | MUR+ADO/LWAL+CDN/H:1        | 98680  | 5920799                | 403757    | 1123880114  |
| Eastern | MUR+ADO/LWAL+CDN/H:2        | 96213  | 9695308                | 403758    | 1850863369  |
| Eastern | MUR+ADO/LWAL+CDN/HBET:3-6   | 1298   | 882926                 | 42501     | 244698739   |
| Eastern | MUR+CB/LWAL+CDN/H:1         | 8936   | 536176                 | 36564     | 113084930   |
| Eastern | MUR+CB/LWAL+CDN/H:2         | 8712   | 877989                 | 36563     | 186234058   |
| Eastern | MUR+CB/LWAL+CDN/HBET:3-6    | 118    | 79957                  | 3849      | 24621612    |
| Eastern | MUR+CL/LWAL+CDN/H:1         | 98680  | 5920799                | 403757    | 1248755682  |
| Eastern | MUR+CL/LWAL+CDN/H:2         | 96213  | 9695308                | 403758    | 2056514855  |
| Eastern | MUR+CL/LWAL+CDN/HBET:3-6    | 1298   | 882926                 | 42501     | 271887488   |
| Eastern | MUR+STDRE/LWAL+CDN/H:1      | 7447   | 446814                 | 30470     | 94237442    |
| Eastern | MUR+STDRE/LWAL+CDN/H:2      | 7261   | 731657                 | 30469     | 155195049   |
| Eastern | MUR+STDRE/LWAL+CDN/HBET:3-6 | 98     | 66630                  | 3207      | 20518010    |
| Eastern | W+WWD/LWAL+CDN/H:1          | 51044  | 3062614                | 208849    | 484451965   |
| Eastern | W+WWD/LWAL+CDN/H:2          | 21329  | 2149298                | 89506     | 341922996   |
| Eastern | W/LWAL+CDL/H:1              | 1003   | 60202                  | 4105      | 15236706    |
| Eastern | W/LWAL+CDL/H:2              | 978    | 98581                  | 4105      | 25092589    |
| Eastern | W/LWAL+CDL/H:3              | 390    | 57547                  | 2053      | 15414085    |
| Eastern | W/LWAL+CDM/H:1              | 251    | 15051                  | 1026      | 3809177     |
| Eastern | W/LWAL+CDM/H:2              | 244    | 24645                  | 1026      | 6273147     |
| Eastern | W/LWAL+CDM/H:3              | 98     | 14387                  | 513       | 3853522     |
| Central | CR/LFINF+CDL/H:1            | 8380   | 502812                 | 34288     | 149714888   |
| Central | CR/LFINF+CDL/H:2            | 28597  | 2881741                | 120009    | 862953526   |
| Central | CR/LFINF+CDL/H:3            | 22853  | 3364475                | 120009    | 1060204618  |
| Central | CR/LFINF+CDL/HBET:4-7       | 1048   | 1005624                | 51432     | 473040525   |
| Central | CR/LFINF+CDL/HBET:8+        | 262    | 314257                 | 17144     | 147825164   |
| Central | CR/LFINF+CDM/H:1            | 2095   | 125703                 | 8572      | 37428722    |
| Central | CR/LFINF+CDM/H:2            | 7149   | 720435                 | 30002     | 215738381   |
| Central | CR/LFINF+CDM/H:3            | 5714   | 841119                 | 30002     | 265051155   |
| Central | CR/LFINF+CDM/HBET:4-7       | 262    | 251406                 | 12858     | 118260131   |
| Central | CR/LFINF+CDM/HBET:8+        | 65     | 78564                  | 4286      | 36956291    |
| Central | CR/LWAL+CDL/H:1             | 267    | 16015                  | 1092      | 4768696     |
| Central | CR/LWAL+CDL/H:2             | 911    | 91788                  | 3822      | 27486668    |
| Central | CR/LWAL+CDL/H:3             | 728    | 107165                 | 3823      | 33769481    |
| Central | CR/LWAL+CDL/HBET:4-7        | 33     | 32031                  | 1638      | 15067217    |
| Central | CR/LWAL+CDL/HBET:8+         | 8      | 10010                  | 546       | 4708505     |
| Central | CR/LWAL+CDM/H:1             | 67     | 4004                   | 273       | 1192174     |
| Central | CR/LWAL+CDM/H:2             | 228    | 22947                  | 956       | 6871667     |
| Central | CR/LWAL+CDM/H:3             | 182    | 26791                  | 956       | 8442370     |
| Central | CR/LWAL+CDM/HBET:4-7        | 8      | 8008                   | 410       | 3766804     |
| Central | CR/LWAL+CDM/HBET:8+         | 2      | 2502                   | 137       | 1177126     |

| Region  | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Occupants | Cost (US\$) |
|---------|-----------------------------|--------|------------------------|-----------|-------------|
| Central | MCF/LWAL+CDL/H:2            | 33255  | 3351052                | 139554    | 1066209901  |
| Central | MCF/LWAL+CDL/HBET:3-6       | 948    | 644251                 | 31012     | 297585093   |
| Central | MCF/LWAL+CDM/H:1            | 8527   | 511611                 | 34888     | 161855830   |
| Central | MCF/LWAL+CDM/H:2            | 8314   | 837763                 | 34888     | 266552475   |
| Central | MCF/LWAL+CDM/HBET:3-6       | 236    | 161062                 | 7753      | 74396274    |
| Central | ME+MEO/LWAL+CDN/H:1         | 13346  | 800774                 | 54607     | 63334249    |
| Central | MUR+ADO/LWAL+CDN/H:1        | 105007 | 6300395                | 429643    | 1195934741  |
| Central | MUR+ADO/LWAL+CDN/H:2        | 102381 | 10316897               | 429643    | 1969526622  |
| Central | MUR+ADO/LWAL+CDN/HBET:3-6   | 1382   | 939533                 | 45225     | 260386957   |
| Central | MUR+CB/LWAL+CDN/H:1         | 9509   | 570552                 | 38908     | 120335074   |
| Central | MUR+CB/LWAL+CDN/H:2         | 9272   | 934279                 | 38907     | 198173967   |
| Central | MUR+CB/LWAL+CDN/HBET:3-6    | 126    | 85082                  | 4096      | 26200162    |
| Central | MUR+CL/LWAL+CDN/H:1         | 105007 | 6300395                | 429643    | 1328816379  |
| Central | MUR+CL/LWAL+CDN/H:2         | 102381 | 10316897               | 429643    | 2188362913  |
| Central | MUR+CL/LWAL+CDN/HBET:3-6    | 1382   | 939533                 | 45225     | 289318841   |
| Central | MUR+STDRE/LWAL+CDN/H:1      | 7924   | 475460                 | 32423     | 100279228   |
| Central | MUR+STDRE/LWAL+CDN/H:2      | 7726   | 778565                 | 32423     | 165144973   |
| Central | MUR+STDRE/LWAL+CDN/HBET:3-6 | 104    | 70902                  | 3413      | 21833468    |
| Central | W+WWD/LWAL+CDN/H:1          | 54316  | 3258966                | 222239    | 515511333   |
| Central | W+WWD/LWAL+CDN/H:2          | 22696  | 2287096                | 95245     | 363844493   |
| Central | W/LWAL+CDL/H:1              | 1068   | 64062                  | 4369      | 16213568    |
| Central | W/LWAL+CDL/H:2              | 1041   | 104901                 | 4368      | 26701334    |
| Central | W/LWAL+CDL/H:3              | 417    | 61236                  | 2184      | 16402319    |
| Central | W/LWAL+CDM/H:1              | 267    | 16015                  | 1092      | 4053392     |
| Central | W/LWAL+CDM/H:2              | 261    | 26226                  | 1093      | 6675334     |
| Central | W/LWAL+CDM/H:3              | 104    | 15309                  | 546       | 4100580     |
| Western | CR/LFINF+CDL/H:1            | 7676   | 460532                 | 31405     | 137125829   |
| Western | CR/LFINF+CDL/H:2            | 26193  | 2639424                | 109918    | 790390449   |
| Western | CR/LFINF+CDL/H:3            | 20932  | 3081566                | 109918    | 971055310   |
| Western | CR/LFINF+CDL/HBET:4-7       | 959    | 921064                 | 47108     | 433264020   |
| Western | CR/LFINF+CDL/HBET:8+        | 240    | 287832                 | 15703     | 135395006   |
| Western | CR/LFINF+CDM/H:1            | 1919   | 115133                 | 7851      | 34281457    |
| Western | CR/LFINF+CDM/H:2            | 6548   | 659856                 | 27479     | 197597612   |
| Western | CR/LFINF+CDM/H:3            | 5233   | 770391                 | 27480     | 242763827   |
| Western | CR/LFINF+CDM/HBET:4-7       | 240    | 230266                 | 11777     | 108316005   |
| Western | CR/LFINF+CDM/HBET:8+        | 60     | 71958                  | 3926      | 33848752    |
| Western | CR/LWAL+CDL/H:1             | 244    | 14669                  | 1000      | 4367712     |
| Western | CR/LWAL+CDL/H:2             | 834    | 84071                  | 3501      | 25175400    |
| Western | CR/LWAL+CDL/H:3             | 667    | 98154                  | 3501      | 30929910    |
| Western | CR/LWAL+CDL/HBET:4-7        | 31     | 29338                  | 1500      | 13800261    |
| Western | CR/LWAL+CDL/HBET:8+         | 8      | 9168                   | 500       | 4312582     |
| Western | CR/LWAL+CDM/H:1             | 61     | 3667                   | 250       | 1091928     |
| Western | CR/LWAL+CDM/H:2             | 208    | 21017                  | 876       | 6293849     |
| Western | CR/LWAL+CDM/H:3             | 167    | 24539                  | 876       | 7732478     |
| Western | CR/LWAL+CDM/HBET:4-7        | 8      | 7334                   | 375       | 3450065     |
| Western | CR/LWAL+CDM/HBET:8+         | 2      | 2292                   | 125       | 1078145     |
| Western | MCF/LWAL+CDL/H:1            | 31239  | 1874365                | 127819    | 592983506   |
| Western | MCF/LWAL+CDL/H:2            | 30458  | 3069273                | 127819    | 976555628   |
| Western | MCF/LWAL+CDL/HBET:3-6       | 868    | 590078                 | 28404     | 272562090   |
| Western | MCF/LWAL+CDM/H:1            | 7810   | 468591                 | 31955     | 148245877   |
| Western | MCF/LWAL+CDM/H:2            | 7614   | 767318                 | 31955     | 244138907   |
| Western | MCF/LWAL+CDM/HBET:3-6       | 216    | 147519                 | 7101      | 68140522    |
| Western | ME+MEO/LWAL+CDN/H:1         | 12224  | 733440                 | 50016     | 58008670    |
| Western | MUR+ADO/LWAL+CDN/H:1        | 96177  | 5770615                | 393516    | 1095372310  |
| Western | MUR+ADO/LWAL+CDN/H:2        | 93772  | 9449382                | 393516    | 1803915258  |
| Western | MUR+ADO/LWAL+CDN/HBET:3-6   | 1266   | 860530                 | 41423     | 238491828   |
| Western | MUR+CB/LWAL+CDN/H:1         | 8710   | 522576                 | 35636     | 110216472   |
| Western | MUR+CB/LWAL+CDN/H:2         | 8492   | 855718                 | 35636     | 181510135   |
| Western | MUR+CB/LWAL+CDN/HBET:3-6    | 114    | 77928                  | 3751      | 23997072    |

| Region  | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Occupants | Cost (US\$) |
|---------|-----------------------------|--------|------------------------|-----------|-------------|
| Western | MUR+CL/LWAL+CDN/H:1         | 96177  | 5770615                | 393516    | 1217080345  |
| Western | MUR+CL/LWAL+CDN/H:2         | 93772  | 9449382                | 393516    | 2004350285  |
| Western | MUR+CL/LWAL+CDN/HBET:3-6    | 1266   | 860530                 | 41423     | 264990920   |
| Western | MUR+STDRE/LWAL+CDN/H:1      | 7258   | 435480                 | 29697     | 91847060    |
| Western | MUR+STDRE/LWAL+CDN/H:2      | 7076   | 713098                 | 29697     | 151258446   |
| Western | MUR+STDRE/LWAL+CDN/HBET:3-6 | 96     | 64940                  | 3125      | 19997560    |
| Western | W+WWD/LWAL+CDN/H:1          | 49749  | 2984929                | 203551    | 472163589   |
| Western | W+WWD/LWAL+CDN/H:2          | 20788  | 2094781                | 87237     | 333249941   |
| Western | W/LWAL+CDL/H:1              | 978    | 58675                  | 4001      | 14850219    |
| Western | W/LWAL+CDL/H:2              | 953    | 96080                  | 4001      | 24456102    |
| Western | W/LWAL+CDL/H:3              | 381    | 56087                  | 2000      | 15023099    |
| Western | W/LWAL+CDM/H:1              | 244    | 14669                  | 1000      | 3712555     |
| Western | W/LWAL+CDM/H:2              | 238    | 24021                  | 1000      | 6114026     |
| Western | W/LWAL+CDM/H:3              | 96     | 14022                  | 500       | 3755775     |

**Appendix C-4: Commercial buildings located in rural and urban settlements**

| Region   | Settlement | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|----------|------------|-----------------------------|--------|------------------------|-------------|
| Northern | Rural      | MUR+ADO/LWAL+CDN/H:1        | 15672  | 2037223                | 543436612   |
| Northern | Rural      | MUR+ADO/LWAL+CDN/H:2        | 7835   | 2037223                | 557976239   |
| Northern | Rural      | MUR+ADO/LWAL+CDN/HBET:3-6   | 329    | 296923                 | 86143234    |
| Northern | Rural      | MUR+CB/LWAL+CDN/H:1         | 655    | 85056                  | 28361285    |
| Northern | Rural      | MUR+CB/LWAL+CDN/H:2         | 327    | 85055                  | 29120091    |
| Northern | Rural      | MUR+CB/LWAL+CDN/HBET:3-6    | 14     | 12397                  | 4495708     |
| Northern | Rural      | MUR+CL/LWAL+CDN/H:1         | 3917   | 509305                 | 169823941   |
| Northern | Rural      | MUR+CL/LWAL+CDN/H:2         | 1960   | 509305                 | 174367575   |
| Northern | Rural      | MUR+CL/LWAL+CDN/HBET:3-6    | 82     | 74231                  | 26919761    |
| Northern | Rural      | MUR+STRUB/LWAL+CDN/H:1      | 655    | 85056                  | 22689029    |
| Northern | Rural      | MUR+STRUB/LWAL+CDN/H:2      | 327    | 85055                  | 23296073    |
| Northern | Rural      | MUR+STRUB/LWAL+CDN/HBET:3-6 | 14     | 12397                  | 3596567     |
| Northern | Rural      | W/LWAL+CDL/H:1              | 73     | 9551                   | 3429381     |
| Northern | Rural      | W/LWAL+CDL/H:2              | 37     | 9550                   | 3521134     |
| Northern | Rural      | W/LWAL+CDL/H:3              | 12     | 5510                   | 2137641     |
| Northern | Rural      | W/LWAL+CDM/H:1              | 19     | 2387                   | 857346      |
| Northern | Rural      | W/LWAL+CDM/H:2              | 10     | 2388                   | 880283      |
| Northern | Rural      | W/LWAL+CDM/H:3              | 2      | 1102                   | 437451      |
| Northern | Urban      | CR/LFINF+CDL/H:1            | 181    | 23545                  | 11215900    |
| Northern | Urban      | CR/LFINF+CDL/H:2            | 317    | 82410                  | 40305931    |
| Northern | Urban      | CR/LFINF+CDL/H:3            | 211    | 95089                  | 48938575    |
| Northern | Urban      | CR/LFINF+CDL/HBET:4-7       | 54     | 65203                  | 30757733    |
| Northern | Urban      | CR/LFINF+CDL/HBET:8+        | 9      | 28979                  | 19033318    |
| Northern | Urban      | CR/LFINF+CDM/H:1            | 45     | 5887                   | 2803975     |
| Northern | Urban      | CR/LFINF+CDM/H:2            | 80     | 20603                  | 10076484    |
| Northern | Urban      | CR/LFINF+CDM/H:3            | 52     | 23772                  | 12234644    |
| Northern | Urban      | CR/LFINF+CDM/HBET:4-7       | 13     | 16301                  | 7689433     |
| Northern | Urban      | CR/LFINF+CDM/HBET:8+        | 2      | 6520                   | 4413987     |
| Northern | Urban      | CR/LWAL+CDL/H:1             | 7      | 870                    | 414381      |
| Northern | Urban      | CR/LWAL+CDL/H:2             | 12     | 3205                   | 1567331     |
| Northern | Urban      | CR/LWAL+CDL/H:3             | 9      | 3698                   | 1903020     |
| Northern | Urban      | CR/LWAL+CDL/HBET:4-7        | 2      | 2282                   | 1075531     |
| Northern | Urban      | CR/LWAL+CDM/H:1             | 1      | 160                    | 73460       |
| Northern | Urban      | CR/LWAL+CDM/H:2             | 3      | 800                    | 391832      |
| Northern | Urban      | CR/LWAL+CDM/H:3             | 2      | 740                    | 389438      |
| Northern | Urban      | MCF/LWAL+CDL/H:1            | 720    | 93596                  | 41611413    |
| Northern | Urban      | MCF/LWAL+CDL/H:2            | 360    | 93595                  | 42724725    |
| Northern | Urban      | MCF/LWAL+CDL/HBET:3-6       | 32     | 28799                  | 13925020    |
| Northern | Urban      | MCF/LWAL+CDM/H:1            | 180    | 23399                  | 10402852    |
| Northern | Urban      | MCF/LWAL+CDM/H:2            | 90     | 23400                  | 10681182    |
| Northern | Urban      | MCF/LWAL+CDM/HBET:3-6       | 8      | 6840                   | 3327217     |
| Northern | Urban      | MUR+ADO/LWAL+CDN/H:1        | 2217   | 288152                 | 76865527    |
| Northern | Urban      | MUR+ADO/LWAL+CDN/H:2        | 1108   | 288152                 | 78922061    |
| Northern | Urban      | MUR+ADO/LWAL+CDN/HBET:3-6   | 47     | 41998                  | 12184392    |
| Northern | Urban      | MUR+CB/LWAL+CDN/H:1         | 252    | 32619                  | 10876243    |
| Northern | Urban      | MUR+CB/LWAL+CDN/H:2         | 125    | 32618                  | 11167236    |
| Northern | Urban      | MUR+CB/LWAL+CDN/HBET:3-6    | 5      | 4516                   | 1647769     |
| Northern | Urban      | MUR+CL/LWAL+CDN/H:1         | 2217   | 288152                 | 96081908    |
| Northern | Urban      | MUR+CL/LWAL+CDN/H:2         | 1108   | 288152                 | 98652576    |
| Northern | Urban      | MUR+CL/LWAL+CDN/HBET:3-6    | 47     | 41998                  | 15230492    |
| Northern | Urban      | MUR+STDRE/LWAL+CDN/H:1      | 208    | 27181                  | 9063535     |
| Northern | Urban      | MUR+STDRE/LWAL+CDN/H:2      | 105    | 27182                  | 9306030     |
| Northern | Urban      | MUR+STDRE/LWAL+CDN/HBET:3-6 | 4      | 3367                   | 1241333     |
| Northern | Urban      | W/LWAL+CDL/H:1              | 28     | 3663                   | 1315129     |
| Northern | Urban      | W/LWAL+CDL/H:2              | 15     | 3662                   | 1350316     |

| Region   | Settlement | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|----------|------------|-----------------------------|--------|------------------------|-------------|
| Northern | Urban      | W/LWAL+CDL/H:3              | 4      | 1690                   | 671031      |
| Northern | Urban      | W/LWAL+CDM/H:1              | 7      | 870                    | 312380      |
| Northern | Urban      | W/LWAL+CDM/H:2              | 3      | 915                    | 337579      |
| Northern | Urban      | W/LWAL+CDM/H:3              | 1      | 423                    | 167758      |
| Eastern  | Rural      | MUR+ADO/LWAL+CDN/H:1        | 19869  | 2583097                | 689050454   |
| Eastern  | Rural      | MUR+ADO/LWAL+CDN/H:2        | 9935   | 2583098                | 707485975   |
| Eastern  | Rural      | MUR+ADO/LWAL+CDN/HBET:3-6   | 419    | 376483                 | 109225313   |
| Eastern  | Rural      | MUR+CB/LWAL+CDN/H:1         | 829    | 107847                 | 35960692    |
| Eastern  | Rural      | MUR+CB/LWAL+CDN/H:2         | 415    | 107847                 | 36922820    |
| Eastern  | Rural      | MUR+CB/LWAL+CDN/HBET:3-6    | 18     | 15719                  | 5700334     |
| Eastern  | Rural      | MUR+CL/LWAL+CDN/H:1         | 4967   | 645775                 | 215328266   |
| Eastern  | Rural      | MUR+CL/LWAL+CDN/H:2         | 2483   | 645775                 | 221089368   |
| Eastern  | Rural      | MUR+CL/LWAL+CDN/HBET:3-6    | 104    | 94121                  | 34132911    |
| Eastern  | Rural      | MUR+STRUB/LWAL+CDN/H:1      | 829    | 107847                 | 28768553    |
| Eastern  | Rural      | MUR+STRUB/LWAL+CDN/H:2      | 415    | 107847                 | 29538255    |
| Eastern  | Rural      | MUR+STRUB/LWAL+CDN/HBET:3-6 | 18     | 15719                  | 4560268     |
| Eastern  | Rural      | W/LWAL+CDL/H:1              | 93     | 12108                  | 4348283     |
| Eastern  | Rural      | W/LWAL+CDL/H:2              | 47     | 12110                  | 4464622     |
| Eastern  | Rural      | W/LWAL+CDL/H:3              | 16     | 6987                   | 2710423     |
| Eastern  | Rural      | W/LWAL+CDM/H:1              | 23     | 3027                   | 1087071     |
| Eastern  | Rural      | W/LWAL+CDM/H:2              | 12     | 3027                   | 1116155     |
| Eastern  | Rural      | W/LWAL+CDM/H:3              | 3      | 1397                   | 554666      |
| Eastern  | Urban      | CR/LFINF+CDL/H:1            | 229    | 29855                  | 14221200    |
| Eastern  | Urban      | CR/LFINF+CDL/H:2            | 402    | 104492                 | 51105905    |
| Eastern  | Urban      | CR/LFINF+CDL/H:3            | 268    | 120568                 | 62051666    |
| Eastern  | Urban      | CR/LFINF+CDL/HBET:4-7       | 69     | 82674                  | 38999268    |
| Eastern  | Urban      | CR/LFINF+CDL/HBET:8+        | 11     | 36744                  | 24133297    |
| Eastern  | Urban      | CR/LFINF+CDM/H:1            | 57     | 7464                   | 3555301     |
| Eastern  | Urban      | CR/LFINF+CDM/H:2            | 100    | 26123                  | 12776476    |
| Eastern  | Urban      | CR/LFINF+CDM/H:3            | 68     | 30141                  | 15512916    |
| Eastern  | Urban      | CR/LFINF+CDM/HBET:4-7       | 18     | 20669                  | 9749817     |
| Eastern  | Urban      | CR/LFINF+CDM/HBET:8+        | 3      | 8267                   | 5596715     |
| Eastern  | Urban      | CR/LWAL+CDL/H:1             | 8      | 1103                   | 525415      |
| Eastern  | Urban      | CR/LWAL+CDL/H:2             | 15     | 4063                   | 1987297     |
| Eastern  | Urban      | CR/LWAL+CDL/H:3             | 10     | 4689                   | 2412932     |
| Eastern  | Urban      | CR/LWAL+CDL/HBET:4-7        | 2      | 2893                   | 1363719     |
| Eastern  | Urban      | CR/LWAL+CDM/H:1             | 3      | 276                    | 131354      |
| Eastern  | Urban      | CR/LWAL+CDM/H:2             | 5      | 1015                   | 496825      |
| Eastern  | Urban      | CR/LWAL+CDM/H:3             | 2      | 938                    | 493788      |
| Eastern  | Urban      | CR/LWAL+CDM/HBET:4-7        | 1      | 723                    | 340930      |
| Eastern  | Urban      | MCF/LWAL+CDL/H:1            | 913    | 118675                 | 52761192    |
| Eastern  | Urban      | MCF/LWAL+CDL/H:2            | 457    | 118675                 | 54172815    |
| Eastern  | Urban      | MCF/LWAL+CDL/HBET:3-6       | 40     | 36516                  | 17656230    |
| Eastern  | Urban      | MCF/LWAL+CDM/H:1            | 228    | 29668                  | 13190297    |
| Eastern  | Urban      | MCF/LWAL+CDM/H:2            | 115    | 29668                  | 13543204    |
| Eastern  | Urban      | MCF/LWAL+CDM/HBET:3-6       | 11     | 9128                   | 4414057     |
| Eastern  | Urban      | MUR+ADO/LWAL+CDN/H:1        | 2811   | 365362                 | 97461645    |
| Eastern  | Urban      | MUR+ADO/LWAL+CDN/H:2        | 1405   | 365362                 | 100069229   |
| Eastern  | Urban      | MUR+ADO/LWAL+CDN/HBET:3-6   | 59     | 53251                  | 15449201    |
| Eastern  | Urban      | MUR+CB/LWAL+CDN/H:1         | 319    | 41359                  | 13790532    |
| Eastern  | Urban      | MUR+CB/LWAL+CDN/H:2         | 160    | 41358                  | 14159498    |
| Eastern  | Urban      | MUR+CB/LWAL+CDN/HBET:3-6    | 7      | 5727                   | 2089290     |
| Eastern  | Urban      | MUR+CL/LWAL+CDN/H:1         | 2811   | 365362                 | 121827056   |
| Eastern  | Urban      | MUR+CL/LWAL+CDN/H:2         | 1405   | 365362                 | 125086535   |
| Eastern  | Urban      | MUR+CL/LWAL+CDN/HBET:3-6    | 59     | 53251                  | 19311500    |
| Eastern  | Urban      | MUR+STDRE/LWAL+CDN/H:1      | 265    | 34465                  | 11492110    |
| Eastern  | Urban      | MUR+STDRE/LWAL+CDN/H:2      | 133    | 34465                  | 11799581    |
| Eastern  | Urban      | MUR+STDRE/LWAL+CDN/HBET:3-6 | 6      | 4772                   | 1741075     |
| Eastern  | Urban      | W/LWAL+CDL/H:1              | 36     | 4644                   | 1667519     |

| Region  | Settlement | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|---------|------------|-----------------------------|--------|------------------------|-------------|
| Eastern | Urban      | W/LWAL+CDL/H:2              | 18     | 4643                   | 1712133     |
| Eastern | Urban      | W/LWAL+CDL/H:3              | 7      | 2679                   | 1039418     |
| Eastern | Urban      | W/LWAL+CDM/H:1              | 8      | 1103                   | 396082      |
| Eastern | Urban      | W/LWAL+CDM/H:2              | 5      | 1160                   | 428033      |
| Eastern | Urban      | W/LWAL+CDM/H:3              | 1      | 536                    | 212709      |
| Central | Rural      | MUR+ADO/LWAL+CDN/H:1        | 21144  | 2748706                | 733227117   |
| Central | Rural      | MUR+ADO/LWAL+CDN/H:2        | 10572  | 2748705                | 752844584   |
| Central | Rural      | MUR+ADO/LWAL+CDN/HBET:3-6   | 445    | 400621                 | 116228008   |
| Central | Rural      | MUR+CB/LWAL+CDN/H:1         | 883    | 114761                 | 38266217    |
| Central | Rural      | MUR+CB/LWAL+CDN/H:2         | 442    | 114762                 | 39290030    |
| Central | Rural      | MUR+CB/LWAL+CDN/HBET:3-6    | 19     | 16726                  | 6065796     |
| Central | Rural      | MUR+CL/LWAL+CDN/H:1         | 5285   | 687177                 | 229133474   |
| Central | Rural      | MUR+CL/LWAL+CDN/H:2         | 2643   | 687177                 | 235263932   |
| Central | Rural      | MUR+CL/LWAL+CDN/HBET:3-6    | 112    | 100156                 | 36321253    |
| Central | Rural      | MUR+STRUB/LWAL+CDN/H:1      | 883    | 114761                 | 30612974    |
| Central | Rural      | MUR+STRUB/LWAL+CDN/H:2      | 442    | 114762                 | 31432023    |
| Central | Rural      | MUR+STRUB/LWAL+CDN/HBET:3-6 | 19     | 16726                  | 4852636     |
| Central | Rural      | W/LWAL+CDL/H:1              | 99     | 12885                  | 4627062     |
| Central | Rural      | W/LWAL+CDL/H:2              | 50     | 12885                  | 4750860     |
| Central | Rural      | W/LWAL+CDL/H:3              | 17     | 7433                   | 2884195     |
| Central | Rural      | W/LWAL+CDM/H:1              | 24     | 3221                   | 1156766     |
| Central | Rural      | W/LWAL+CDM/H:2              | 12     | 3222                   | 1187714     |
| Central | Rural      | W/LWAL+CDM/H:3              | 3      | 1487                   | 590227      |
| Central | Urban      | CR/LFINF+CDL/H:1            | 244    | 31768                  | 15132954    |
| Central | Urban      | CR/LFINF+CDL/H:2            | 428    | 111190                 | 54382428    |
| Central | Urban      | CR/LFINF+CDL/H:3            | 286    | 128298                 | 66029946    |
| Central | Urban      | CR/LFINF+CDL/HBET:4-7       | 73     | 87976                  | 41499603    |
| Central | Urban      | CR/LFINF+CDL/HBET:8+        | 12     | 39100                  | 25680539    |
| Central | Urban      | CR/LFINF+CDM/H:1            | 61     | 7943                   | 3783238     |
| Central | Urban      | CR/LFINF+CDM/H:2            | 107    | 27798                  | 13595607    |
| Central | Urban      | CR/LFINF+CDM/H:3            | 71     | 32073                  | 16507487    |
| Central | Urban      | CR/LFINF+CDM/HBET:4-7       | 18     | 21993                  | 10374901    |
| Central | Urban      | CR/LFINF+CDM/HBET:8+        | 3      | 8798                   | 5955533     |
| Central | Urban      | CR/LWAL+CDL/H:1             | 9      | 1174                   | 559100      |
| Central | Urban      | CR/LWAL+CDL/H:2             | 17     | 4325                   | 2114708     |
| Central | Urban      | CR/LWAL+CDL/H:3             | 11     | 4989                   | 2567632     |
| Central | Urban      | CR/LWAL+CDL/HBET:4-7        | 3      | 3079                   | 1451150     |
| Central | Urban      | CR/LWAL+CDM/H:1             | 3      | 293                    | 139775      |
| Central | Urban      | CR/LWAL+CDM/H:2             | 5      | 1080                   | 528677      |
| Central | Urban      | CR/LWAL+CDM/H:3             | 2      | 998                    | 525445      |
| Central | Urban      | CR/LWAL+CDM/HBET:4-7        | 1      | 770                    | 362788      |
| Central | Urban      | MCF/LWAL+CDL/H:1            | 972    | 126283                 | 56143837    |
| Central | Urban      | MCF/LWAL+CDL/H:2            | 485    | 126282                 | 57645963    |
| Central | Urban      | MCF/LWAL+CDL/HBET:3-6       | 43     | 38857                  | 18788212    |
| Central | Urban      | MCF/LWAL+CDM/H:1            | 243    | 31571                  | 14035959    |
| Central | Urban      | MCF/LWAL+CDM/H:2            | 122    | 31570                  | 14411491    |
| Central | Urban      | MCF/LWAL+CDM/HBET:3-6       | 11     | 9714                   | 4697053     |
| Central | Urban      | MUR+ADO/LWAL+CDN/H:1        | 2991   | 388786                 | 103710143   |
| Central | Urban      | MUR+ADO/LWAL+CDN/H:2        | 1495   | 388787                 | 106484904   |
| Central | Urban      | MUR+ADO/LWAL+CDN/HBET:3-6   | 63     | 56665                  | 16439686    |
| Central | Urban      | MUR+CB/LWAL+CDN/H:1         | 339    | 44009                  | 14674675    |
| Central | Urban      | MUR+CB/LWAL+CDN/H:2         | 170    | 44010                  | 15067296    |
| Central | Urban      | MUR+CB/LWAL+CDN/HBET:3-6    | 7      | 6093                   | 2223239     |
| Central | Urban      | MUR+CL/LWAL+CDN/H:1         | 2991   | 388786                 | 129637679   |
| Central | Urban      | MUR+CL/LWAL+CDN/H:2         | 1495   | 388787                 | 133106130   |
| Central | Urban      | MUR+CL/LWAL+CDN/HBET:3-6    | 63     | 56665                  | 20549607    |
| Central | Urban      | MUR+STDRE/LWAL+CDN/H:1      | 282    | 36675                  | 12228897    |
| Central | Urban      | MUR+STDRE/LWAL+CDN/H:2      | 140    | 36675                  | 12556080    |
| Central | Urban      | MUR+STDRE/LWAL+CDN/HBET:3-6 | 6      | 5079                   | 1852698     |

| Region  | Settlement | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|---------|------------|-----------------------------|--------|------------------------|-------------|
| Central | Urban      | W/LWAL+CDL/H:1              | 39     | 4941                   | 1774428     |
| Central | Urban      | W/LWAL+CDL/H:2              | 20     | 4942                   | 1821902     |
| Central | Urban      | W/LWAL+CDL/H:3              | 7      | 2851                   | 1106057     |
| Central | Urban      | W/LWAL+CDM/H:1              | 9      | 1174                   | 421476      |
| Central | Urban      | W/LWAL+CDM/H:2              | 5      | 1235                   | 455476      |
| Central | Urban      | W/LWAL+CDM/H:3              | 1      | 570                    | 226346      |
| Western | Rural      | MUR+ADO/LWAL+CDN/H:1        | 19365  | 2517576                | 671572331   |
| Western | Rural      | MUR+ADO/LWAL+CDN/H:2        | 9683   | 2517575                | 689540226   |
| Western | Rural      | MUR+ADO/LWAL+CDN/HBET:3-6   | 408    | 366934                 | 106454756   |
| Western | Rural      | MUR+CB/LWAL+CDN/H:1         | 808    | 105112                 | 35048531    |
| Western | Rural      | MUR+CB/LWAL+CDN/H:2         | 405    | 105112                 | 35986252    |
| Western | Rural      | MUR+CB/LWAL+CDN/HBET:3-6    | 17     | 15320                  | 5555742     |
| Western | Rural      | MUR+CL/LWAL+CDN/H:1         | 4841   | 629394                 | 209866354   |
| Western | Rural      | MUR+CL/LWAL+CDN/H:2         | 2420   | 629395                 | 215481321   |
| Western | Rural      | MUR+CL/LWAL+CDN/HBET:3-6    | 102    | 91734                  | 33267112    |
| Western | Rural      | MUR+STRUB/LWAL+CDN/H:1      | 808    | 105112                 | 28038824    |
| Western | Rural      | MUR+STRUB/LWAL+CDN/H:2      | 405    | 105112                 | 28789003    |
| Western | Rural      | MUR+STRUB/LWAL+CDN/HBET:3-6 | 17     | 15320                  | 4444594     |
| Western | Rural      | W/LWAL+CDL/H:1              | 92     | 11801                  | 4237988     |
| Western | Rural      | W/LWAL+CDL/H:2              | 45     | 11802                  | 4351374     |
| Western | Rural      | W/LWAL+CDL/H:3              | 16     | 6809                   | 2641672     |
| Western | Rural      | W/LWAL+CDM/H:1              | 23     | 2951                   | 1059496     |
| Western | Rural      | W/LWAL+CDM/H:2              | 12     | 2950                   | 1087844     |
| Western | Rural      | W/LWAL+CDM/H:3              | 3      | 1362                   | 540597      |
| Western | Urban      | CR/LFINF+CDL/H:1            | 224    | 29097                  | 13860472    |
| Western | Urban      | CR/LFINF+CDL/H:2            | 392    | 101842                 | 49809578    |
| Western | Urban      | CR/LFINF+CDL/H:3            | 261    | 117509                 | 60477694    |
| Western | Urban      | CR/LFINF+CDL/HBET:4-7       | 67     | 80578                  | 38010031    |
| Western | Urban      | CR/LFINF+CDL/HBET:8+        | 11     | 35812                  | 23521142    |
| Western | Urban      | CR/LFINF+CDM/H:1            | 56     | 7275                   | 3465117     |
| Western | Urban      | CR/LFINF+CDM/H:2            | 98     | 25460                  | 12452395    |
| Western | Urban      | CR/LFINF+CDM/H:3            | 66     | 29378                  | 15119423    |
| Western | Urban      | CR/LFINF+CDM/HBET:4-7       | 17     | 20144                  | 9502508     |
| Western | Urban      | CR/LFINF+CDM/HBET:8+        | 3      | 8058                   | 5454751     |
| Western | Urban      | CR/LWAL+CDL/H:1             | 8      | 1075                   | 512087      |
| Western | Urban      | CR/LWAL+CDL/H:2             | 15     | 3960                   | 1936889     |
| Western | Urban      | CR/LWAL+CDL/H:3             | 10     | 4570                   | 2351728     |
| Western | Urban      | CR/LWAL+CDL/HBET:4-7        | 2      | 2820                   | 1329128     |
| Western | Urban      | CR/LWAL+CDM/H:1             | 3      | 269                    | 128022      |
| Western | Urban      | CR/LWAL+CDM/H:2             | 5      | 990                    | 484223      |
| Western | Urban      | CR/LWAL+CDM/H:3             | 2      | 914                    | 481262      |
| Western | Urban      | CR/LWAL+CDM/HBET:4-7        | 1      | 705                    | 332282      |
| Western | Urban      | MCF/LWAL+CDL/H:1            | 889    | 115664                 | 51422877    |
| Western | Urban      | MCF/LWAL+CDL/H:2            | 445    | 115665                 | 52798694    |
| Western | Urban      | MCF/LWAL+CDL/HBET:3-6       | 40     | 35589                  | 17208370    |
| Western | Urban      | MCF/LWAL+CDM/H:1            | 223    | 28916                  | 12855719    |
| Western | Urban      | MCF/LWAL+CDM/H:2            | 110    | 28915                  | 13199673    |
| Western | Urban      | MCF/LWAL+CDM/HBET:3-6       | 9      | 8453                   | 4111734     |
| Western | Urban      | MUR+ADO/LWAL+CDN/H:1        | 2739   | 356095                 | 94989479    |
| Western | Urban      | MUR+ADO/LWAL+CDN/H:2        | 1370   | 356095                 | 97530920    |
| Western | Urban      | MUR+ADO/LWAL+CDN/HBET:3-6   | 58     | 51900                  | 15057324    |
| Western | Urban      | MUR+CB/LWAL+CDN/H:1         | 311    | 40308                  | 13440728    |
| Western | Urban      | MUR+CB/LWAL+CDN/H:2         | 155    | 40310                  | 13800334    |
| Western | Urban      | MUR+CB/LWAL+CDN/HBET:3-6    | 7      | 5582                   | 2036294     |
| Western | Urban      | MUR+CL/LWAL+CDN/H:1         | 2739   | 356095                 | 118736850   |
| Western | Urban      | MUR+CL/LWAL+CDN/H:2         | 1370   | 356095                 | 121913650   |
| Western | Urban      | MUR+CL/LWAL+CDN/HBET:3-6    | 58     | 51900                  | 18821655    |
| Western | Urban      | MUR+STDRE/LWAL+CDN/H:1      | 259    | 33592                  | 11200606    |
| Western | Urban      | MUR+STDRE/LWAL+CDN/H:2      | 130    | 33590                  | 11500278    |

| Region  | Settlement | Taxonomy                    | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|---------|------------|-----------------------------|--------|------------------------|-------------|
| Western | Urban      | MUR+STDRE/LWAL+CDN/HBET:3-6 | 6      | 4651                   | 1696911     |
| Western | Urban      | W/LWAL+CDL/H:1              | 35     | 4525                   | 1625222     |
| Western | Urban      | W/LWAL+CDL/H:2              | 17     | 4525                   | 1668704     |
| Western | Urban      | W/LWAL+CDL/H:3              | 7      | 2611                   | 1013052     |
| Western | Urban      | W/LWAL+CDM/H:1              | 8      | 1075                   | 386035      |
| Western | Urban      | W/LWAL+CDM/H:2              | 5      | 1132                   | 417176      |
| Western | Urban      | W/LWAL+CDM/H:3              | 1      | 522                    | 207313      |

**Appendix C-5: Industrial buildings located in rural and urban settlements**

| Region   | Settlement | Taxonomy               | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|----------|------------|------------------------|--------|------------------------|-------------|
| Northern | Rural      | MUR+CB/LWAL+CDN/H:1    | 194    | 42570                  | 10531356    |
| Northern | Rural      | MUR+CB/LWAL+CDN/H:2    | 64     | 30960                  | 7659169     |
| Northern | Rural      | MUR+CL/LWAL+CDN/H:1    | 5348   | 1176473                | 291048398   |
| Northern | Rural      | MUR+CL/LWAL+CDN/H:2    | 1782   | 855618                 | 211671563   |
| Northern | Rural      | MUR+STRUB/LWAL+CDN/H:1 | 194    | 42570                  | 8425085     |
| Northern | Rural      | MUR+STRUB/LWAL+CDN/H:2 | 64     | 30960                  | 6127334     |
| Northern | Rural      | S+SL/LFM+CDL/H:1       | 1224   | 269145                 | 103574649   |
| Northern | Rural      | S+SL/LFM+CDL/H:2       | 409    | 195742                 | 75327018    |
| Northern | Rural      | S+SL/LFM+CDM/H:1       | 306    | 67285                  | 25893663    |
| Northern | Rural      | S+SL/LFM+CDM/H:2       | 103    | 48936                  | 18831755    |
| Northern | Rural      | S/LFM+CDL/H:1          | 306    | 67285                  | 25893663    |
| Northern | Rural      | S/LFM+CDL/H:2          | 103    | 48936                  | 18831755    |
| Northern | Rural      | S/LFM+CDM/H:1          | 76     | 16821                  | 6473415     |
| Northern | Rural      | S/LFM+CDM/H:2          | 25     | 12233                  | 4707939     |
| Northern | Urban      | CR/LFINF+CDL/H:1       | 348    | 76649                  | 32178157    |
| Northern | Urban      | CR/LFINF+CDL/H:2       | 115    | 55745                  | 23402296    |
| Northern | Urban      | CR/LFINF+CDM/H:1       | 88     | 19163                  | 8044539     |
| Northern | Urban      | CR/LFINF+CDM/H:2       | 30     | 13936                  | 5850574     |
| Northern | Urban      | CR/LWAL+CDL/H:1        | 9      | 2143                   | 899739      |
| Northern | Urban      | CR/LWAL+CDL/H:2        | 3      | 1558                   | 654356      |
| Northern | Urban      | CR/LWAL+CDM/H:1        | 3      | 536                    | 224935      |
| Northern | Urban      | MCF/LWAL+CDL/H:1       | 319    | 70218                  | 24943717    |
| Northern | Urban      | MCF/LWAL+CDL/H:2       | 106    | 51069                  | 18140885    |
| Northern | Urban      | MCF/LWAL+CDM/H:1       | 79     | 17555                  | 6235929     |
| Northern | Urban      | MCF/LWAL+CDM/H:2       | 27     | 12767                  | 4535221     |
| Northern | Urban      | MUR+CB/LWAL+CDN/H:1    | 73     | 16073                  | 3976526     |
| Northern | Urban      | MUR+CB/LWAL+CDN/H:2    | 24     | 11691                  | 2892019     |
| Northern | Urban      | MUR+CL/LWAL+CDN/H:1    | 931    | 204806                 | 50666926    |
| Northern | Urban      | MUR+CL/LWAL+CDN/H:2    | 310    | 148949                 | 36848673    |
| Northern | Urban      | MUR+STDRE/LWAL+CDN/H:1 | 61     | 13394                  | 3313771     |
| Northern | Urban      | MUR+STDRE/LWAL+CDN/H:2 | 21     | 9742                   | 2410016     |
| Northern | Urban      | S+SL/LFM+CDL/H:1       | 103    | 22428                  | 8631221     |
| Northern | Urban      | S+SL/LFM+CDL/H:2       | 34     | 16312                  | 6277251     |
| Northern | Urban      | S+SL/LFM+CDM/H:1       | 25     | 5606                   | 2157805     |
| Northern | Urban      | S+SL/LFM+CDM/H:2       | 9      | 4078                   | 1569313     |
| Northern | Urban      | S/LFM+CDL/H:1          | 409    | 89715                  | 34524882    |
| Northern | Urban      | S/LFM+CDL/H:2          | 136    | 65248                  | 25109006    |
| Northern | Urban      | S/LFM+CDM/H:1          | 103    | 22428                  | 8631221     |
| Northern | Urban      | S/LFM+CDM/H:2          | 34     | 16312                  | 6277251     |
| Eastern  | Rural      | MUR+CB/LWAL+CDN/H:1    | 245    | 53976                  | 13353234    |
| Eastern  | Rural      | MUR+CB/LWAL+CDN/H:2    | 82     | 39255                  | 9711443     |
| Eastern  | Rural      | MUR+CL/LWAL+CDN/H:1    | 6781   | 1491709                | 369034817   |
| Eastern  | Rural      | MUR+CL/LWAL+CDN/H:2    | 2260   | 1084879                | 268388958   |
| Eastern  | Rural      | MUR+STRUB/LWAL+CDN/H:1 | 245    | 53976                  | 10682587    |
| Eastern  | Rural      | MUR+STRUB/LWAL+CDN/H:2 | 82     | 39255                  | 7769154     |
| Eastern  | Rural      | S+SL/LFM+CDL/H:1       | 1551   | 341261                 | 131327478   |
| Eastern  | Rural      | S+SL/LFM+CDL/H:2       | 518    | 248191                 | 95510893    |
| Eastern  | Rural      | S+SL/LFM+CDM/H:1       | 388    | 85315                  | 32831870    |
| Eastern  | Rural      | S+SL/LFM+CDM/H:2       | 130    | 62048                  | 23877723    |
| Eastern  | Rural      | S/LFM+CDL/H:1          | 388    | 85315                  | 32831870    |
| Eastern  | Rural      | S/LFM+CDL/H:2          | 130    | 62048                  | 23877723    |
| Eastern  | Rural      | S/LFM+CDM/H:1          | 97     | 21330                  | 8207967     |
| Eastern  | Rural      | S/LFM+CDM/H:2          | 33     | 15512                  | 5969431     |
| Eastern  | Urban      | CR/LFINF+CDL/H:1       | 442    | 97187                  | 40800294    |
| Eastern  | Urban      | CR/LFINF+CDL/H:2       | 148    | 70682                  | 29672941    |

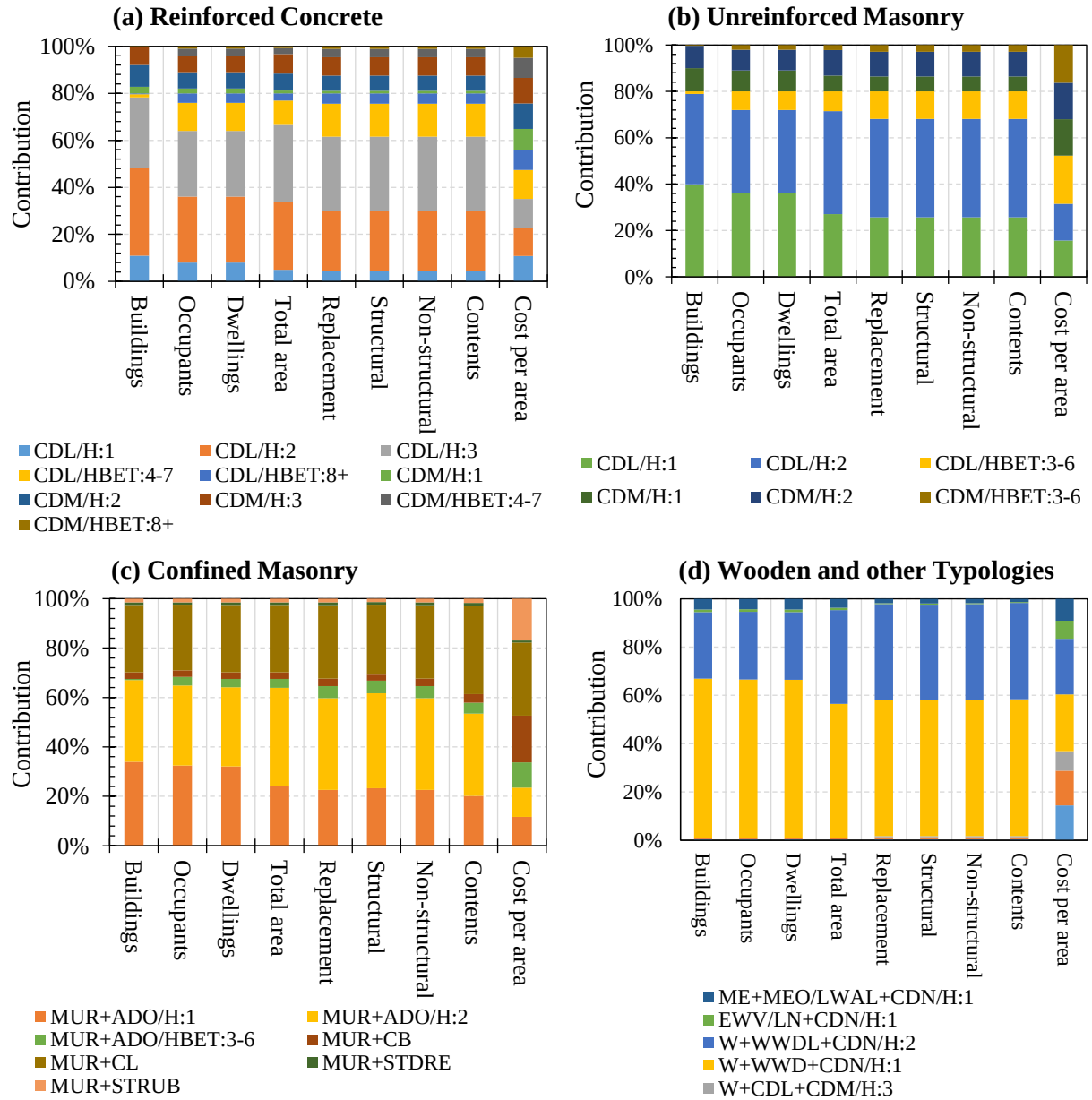
| Region  | Settlement | Taxonomy               | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|---------|------------|------------------------|--------|------------------------|-------------|
| Eastern | Urban      | CR/LFINF+CDM/H:1       | 110    | 24297                  | 10200073    |
| Eastern | Urban      | CR/LFINF+CDM/H:2       | 37     | 17670                  | 7418235     |
| Eastern | Urban      | CR/LWAL+CDL/H:1        | 12     | 2718                   | 1140825     |
| Eastern | Urban      | CR/LWAL+CDL/H:2        | 3      | 1976                   | 829691      |
| Eastern | Urban      | CR/LWAL+CDM/H:1        | 3      | 679                    | 285206      |
| Eastern | Urban      | MCF/LWAL+CDL/H:1       | 406    | 89034                  | 31627387    |
| Eastern | Urban      | MCF/LWAL+CDL/H:2       | 136    | 64752                  | 23001735    |
| Eastern | Urban      | MCF/LWAL+CDM/H:1       | 100    | 22258                  | 7906847     |
| Eastern | Urban      | MCF/LWAL+CDM/H:2       | 33     | 16188                  | 5750434     |
| Eastern | Urban      | MUR+CB/LWAL+CDN/H:1    | 93     | 20381                  | 5042036     |
| Eastern | Urban      | MUR+CB/LWAL+CDN/H:2    | 30     | 14822                  | 3666937     |
| Eastern | Urban      | MUR+CL/LWAL+CDN/H:1    | 1181   | 259682                 | 64243130    |
| Eastern | Urban      | MUR+CL/LWAL+CDN/H:2    | 394    | 188861                 | 46722275    |
| Eastern | Urban      | MUR+STDRE/LWAL+CDN/H:1 | 76     | 16985                  | 4201698     |
| Eastern | Urban      | MUR+STDRE/LWAL+CDN/H:2 | 25     | 12352                  | 3055779     |
| Eastern | Urban      | S+SL/LFM+CDL/H:1       | 130    | 28439                  | 10943956    |
| Eastern | Urban      | S+SL/LFM+CDL/H:2       | 43     | 20682                  | 7959241     |
| Eastern | Urban      | S+SL/LFM+CDM/H:1       | 33     | 7109                   | 2735989     |
| Eastern | Urban      | S+SL/LFM+CDM/H:2       | 12     | 5170                   | 1989810     |
| Eastern | Urban      | S/LFM+CDL/H:1          | 518    | 113754                 | 43775826    |
| Eastern | Urban      | S/LFM+CDL/H:2          | 173    | 82730                  | 31836964    |
| Eastern | Urban      | S/LFM+CDM/H:1          | 130    | 28439                  | 10943956    |
| Eastern | Urban      | S/LFM+CDM/H:2          | 43     | 20682                  | 7959241     |
| Central | Rural      | MUR+CB/LWAL+CDN/H:1    | 261    | 57437                  | 14209341    |
| Central | Rural      | MUR+CB/LWAL+CDN/H:2    | 88     | 41773                  | 10334066    |
| Central | Rural      | MUR+CL/LWAL+CDN/H:1    | 7215   | 1587346                | 392694517   |
| Central | Rural      | MUR+CL/LWAL+CDN/H:2    | 2406   | 1154433                | 285596013   |
| Central | Rural      | MUR+STRUB/LWAL+CDN/H:1 | 261    | 57437                  | 11367473    |
| Central | Rural      | MUR+STRUB/LWAL+CDN/H:2 | 88     | 41773                  | 8267253     |
| Central | Rural      | S+SL/LFM+CDL/H:1       | 1651   | 363140                 | 139747195   |
| Central | Rural      | S+SL/LFM+CDL/H:2       | 551    | 264103                 | 101634323   |
| Central | Rural      | S+SL/LFM+CDM/H:1       | 412    | 90785                  | 34936799    |
| Central | Rural      | S+SL/LFM+CDM/H:2       | 137    | 66025                  | 25408581    |
| Central | Rural      | S/LFM+CDL/H:1          | 412    | 90785                  | 34936799    |
| Central | Rural      | S/LFM+CDL/H:2          | 137    | 66025                  | 25408581    |
| Central | Rural      | S/LFM+CDM/H:1          | 103    | 22697                  | 8734200     |
| Central | Rural      | S/LFM+CDM/H:2          | 34     | 16506                  | 6352145     |
| Central | Urban      | CR/LFINF+CDL/H:1       | 470    | 103418                 | 43416098    |
| Central | Urban      | CR/LFINF+CDL/H:2       | 157    | 75212                  | 31575344    |
| Central | Urban      | CR/LFINF+CDM/H:1       | 118    | 25854                  | 10854024    |
| Central | Urban      | CR/LFINF+CDM/H:2       | 39     | 18803                  | 7893836     |
| Central | Urban      | CR/LWAL+CDL/H:1        | 12     | 2891                   | 1213966     |
| Central | Urban      | CR/LWAL+CDL/H:2        | 3      | 2103                   | 882884      |
| Central | Urban      | CR/LWAL+CDM/H:1        | 3      | 724                    | 303491      |
| Central | Urban      | MCF/LWAL+CDL/H:1       | 430    | 94742                  | 33655094    |
| Central | Urban      | MCF/LWAL+CDL/H:2       | 143    | 68903                  | 24476431    |
| Central | Urban      | MCF/LWAL+CDM/H:1       | 109    | 23685                  | 8413774     |
| Central | Urban      | MCF/LWAL+CDM/H:2       | 36     | 17227                  | 6119108     |
| Central | Urban      | MUR+CB/LWAL+CDN/H:1    | 100    | 21688                  | 5365294     |
| Central | Urban      | MUR+CB/LWAL+CDN/H:2    | 33     | 15773                  | 3902032     |
| Central | Urban      | MUR+CL/LWAL+CDN/H:1    | 1255   | 276333                 | 68361909    |
| Central | Urban      | MUR+CL/LWAL+CDN/H:2    | 418    | 200969                 | 49717752    |
| Central | Urban      | MUR+STDRE/LWAL+CDN/H:1 | 82     | 18073                  | 4471078     |
| Central | Urban      | MUR+STDRE/LWAL+CDN/H:2 | 27     | 13145                  | 3251693     |
| Central | Urban      | S+SL/LFM+CDL/H:1       | 137    | 30261                  | 11645599    |
| Central | Urban      | S+SL/LFM+CDL/H:2       | 46     | 22009                  | 8469527     |
| Central | Urban      | S+SL/LFM+CDM/H:1       | 34     | 7566                   | 2911401     |
| Central | Urban      | S+SL/LFM+CDM/H:2       | 12     | 5503                   | 2117382     |
| Central | Urban      | S/LFM+CDL/H:1          | 551    | 121046                 | 46582398    |

| Region  | Settlement | Taxonomy               | Number | Area (m <sup>2</sup> ) | Cost (US\$) |
|---------|------------|------------------------|--------|------------------------|-------------|
| Central | Urban      | S/LFM+CDL/H:2          | 184    | 88034                  | 33878108    |
| Central | Urban      | S/LFM+CDM/H:1          | 137    | 30261                  | 11645599    |
| Central | Urban      | S/LFM+CDM/H:2          | 46     | 22009                  | 8469527     |
| Western | Rural      | MUR+CB/LWAL+CDN/H:1    | 239    | 52606                  | 13014522    |
| Western | Rural      | MUR+CB/LWAL+CDN/H:2    | 79     | 38260                  | 9465107     |
| Western | Rural      | MUR+CL/LWAL+CDN/H:1    | 6609   | 1453872                | 359674057   |
| Western | Rural      | MUR+CL/LWAL+CDN/H:2    | 2203   | 1057361                | 261581132   |
| Western | Rural      | MUR+STRUB/LWAL+CDN/H:1 | 239    | 52606                  | 10411618    |
| Western | Rural      | MUR+STRUB/LWAL+CDN/H:2 | 79     | 38260                  | 7572086     |
| Western | Rural      | S+SL/LFM+CDL/H:1       | 1512   | 332606                 | 127996288   |
| Western | Rural      | S+SL/LFM+CDL/H:2       | 503    | 241894                 | 93088210    |
| Western | Rural      | S+SL/LFM+CDM/H:1       | 379    | 83151                  | 31999072    |
| Western | Rural      | S+SL/LFM+CDM/H:2       | 127    | 60473                  | 23272053    |
| Western | Rural      | S/LFM+CDL/H:1          | 379    | 83151                  | 31999072    |
| Western | Rural      | S/LFM+CDL/H:2          | 127    | 60473                  | 23272053    |
| Western | Rural      | S/LFM+CDM/H:1          | 94     | 20788                  | 7999769     |
| Western | Rural      | S/LFM+CDM/H:2          | 31     | 15118                  | 5818012     |
| Western | Urban      | CR/LFINF+CDL/H:1       | 430    | 94721                  | 39765374    |
| Western | Urban      | CR/LFINF+CDL/H:2       | 143    | 68888                  | 28920271    |
| Western | Urban      | CR/LFINF+CDM/H:1       | 109    | 23681                  | 9941343     |
| Western | Urban      | CR/LFINF+CDM/H:2       | 36     | 17222                  | 7230068     |
| Western | Urban      | CR/LWAL+CDL/H:1        | 12     | 2648                   | 1111887     |
| Western | Urban      | CR/LWAL+CDL/H:2        | 3      | 1927                   | 808644      |
| Western | Urban      | CR/LWAL+CDM/H:1        | 3      | 663                    | 277971      |
| Western | Urban      | MCF/LWAL+CDL/H:1       | 394    | 86776                  | 30825141    |
| Western | Urban      | MCF/LWAL+CDL/H:2       | 131    | 63109                  | 22418285    |
| Western | Urban      | MCF/LWAL+CDM/H:1       | 100    | 21694                  | 7706286     |
| Western | Urban      | MCF/LWAL+CDM/H:2       | 33     | 15778                  | 5604571     |
| Western | Urban      | MUR+CB/LWAL+CDN/H:1    | 91     | 19864                  | 4914143     |
| Western | Urban      | MUR+CB/LWAL+CDN/H:2    | 30     | 14446                  | 3573922     |
| Western | Urban      | MUR+CL/LWAL+CDN/H:1    | 1151   | 253097                 | 62613568    |
| Western | Urban      | MUR+CL/LWAL+CDN/H:2    | 384    | 184070                 | 45537141    |
| Western | Urban      | MUR+STDRE/LWAL+CDN/H:1 | 76     | 16554                  | 4095119     |
| Western | Urban      | MUR+STDRE/LWAL+CDN/H:2 | 25     | 12039                  | 2978269     |
| Western | Urban      | S+SL/LFM+CDL/H:1       | 127    | 27718                  | 10666357    |
| Western | Urban      | S+SL/LFM+CDL/H:2       | 42     | 20158                  | 7757351     |
| Western | Urban      | S+SL/LFM+CDM/H:1       | 31     | 6930                   | 2666590     |
| Western | Urban      | S+SL/LFM+CDM/H:2       | 10     | 5039                   | 1939337     |
| Western | Urban      | S/LFM+CDL/H:1          | 503    | 110869                 | 42665429    |
| Western | Urban      | S/LFM+CDL/H:2          | 167    | 80631                  | 31029403    |
| Western | Urban      | S/LFM+CDM/H:1          | 127    | 27718                  | 10666357    |
| Western | Urban      | S/LFM+CDM/H:2          | 42     | 20158                  | 7757351     |

Appendix C-5: Overall exposure summarised for the whole country

| Occupancy    | Buildings        | Dwellings         | Occupants per asset | Area (m <sup>2</sup> ) | Average area (m <sup>2</sup> ) | Estimated economic value (asset costs in US\$) |                       |                       | Cost per per area (US\$) |
|--------------|------------------|-------------------|---------------------|------------------------|--------------------------------|------------------------------------------------|-----------------------|-----------------------|--------------------------|
|              |                  |                   |                     |                        |                                | Contents                                       | Non-structural        | Structural            | Total replacement        |
| Commercial   | 203,025          | 286,072           | 0                   | 38,270,893             | 189                            | 2,994,654,388                                  | 3,122,126,563         | 5,643,847,217         | 11,760,628,179           |
| Industrial   | 65,977           | 65,977            | 0                   | 18,798,768             | 285                            | 1,895,913,619                                  | 1,419,028,647         | 2,185,390,259         | 5,500,332,509            |
| Residential  | 9,620,501        | 10,137,126        | 45,677,340          | 786,273,549            | 82                             | 27,424,905,365                                 | 44,665,660,226        | 85,020,924,997        | 157,111,490,586          |
| <b>Total</b> | <b>9,889,503</b> | <b>10,489,175</b> | <b>45,677,340</b>   | <b>843,343,210</b>     | <b>556</b>                     | <b>32,315,473,372</b>                          | <b>49,206,815,436</b> | <b>92,850,162,473</b> | <b>174,372,451,274</b>   |

## Appendix C-7: Microzonation across various residential building taxonomies



Most RC buildings comprise low ductility 2-3 storey infilled frames in which CR/LFINF+CDL/H:2 and CR/LFINF+CDL/H:3 constitute approximately 65.24%, with over 55% of occupants and 50% contribution to the economic value of RC buildings. On the other hand, indicates that MUR+ADO/LWAL+CDN/H:2 makes up 51.2% of Uganda's residential MUR buildings with at least 49 % inhabitants and the highest economic value of MUR buildings is associated with MUR+ADO/LWAL+CDN/H:2 and MUR+CL/LWAL+CDN/H:1-2. For the MCF buildings, MCF/LWAL+CDL/H:1-2, which constitute the largest proportion of building economic value and with over 68% of inhabitants, comprise more than 78%. The rest of the country's buildings predominantly comprise single storey non-ductile wooden wattle and daub and 1-storey non-ductile buildings made of metals except steel. Moreover, more than 76% of people reside in ME+MEO/LWAL+CDN/H:1 and W+WWD/LWAL+CDN/H:1 building classes.

## APPENDIX D: POPULATION STATISTICS

The population projections for the baseline year 2020, presented in the subsequent tables, are estimated based on the most recent national housing and population census data from 2014; conducted by the Uganda Bureau of Statistics, under the Uganda Ministry of Finance, Planning and Economic Development.

### Appendix D-1: Regional population data

| District     | Region  | Area (km <sup>2</sup> ) | Population (persons) | Density (persons per km <sup>2</sup> ) |
|--------------|---------|-------------------------|----------------------|----------------------------------------|
| Central      | Kampala | 40 579                  | 11 562 900           | 284,95                                 |
| Eastern      | Jinja   | 31 809                  | 10 836 500           | 340,67                                 |
| Northern     | Gulu    | 85 361                  | 8 606 300            | 100,82                                 |
| Western      | Mbarara | 51 345                  | 10 577 900           | 206,02                                 |
| <b>Total</b> |         | <b>209 094</b>          | <b>41 583 600</b>    | <b>198.88</b>                          |

### Appendix D-2: District population data

| District     | Region   | Area (km <sup>2</sup> ) | Population (persons) | Density (persons per km <sup>2</sup> ) |
|--------------|----------|-------------------------|----------------------|----------------------------------------|
| Abim         | Northern | 2 353                   | 153 500              | 65.24                                  |
| Adjumani     | Northern | 3 087                   | 235 900              | 76.42                                  |
| Agago        | Northern | 3 497                   | 251 200              | 71.83                                  |
| Alebtong     | Northern | 1 528                   | 266 100              | 174.15                                 |
| Amolatar     | Northern | 1 758                   | 170 100              | 96.76                                  |
| Amudat       | Northern | 1 615                   | 134 900              | 83.53                                  |
| Amuria       | Eastern  | 1 371                   | 225 000              | 164.11                                 |
| Amuru        | Northern | 3 626                   | 216 800              | 59.79                                  |
| Apac         | Northern | 1 815                   | 226 600              | 124.85                                 |
| Arua         | Northern | 1 217                   | 751 000              | 617.09                                 |
| Budaka       | Eastern  | 410                     | 253 100              | 617.32                                 |
| Bududa       | Eastern  | 251                     | 271 100              | 1 080.08                               |
| Bugiri       | Eastern  | 1 048                   | 480 400              | 458.4                                  |
| Bugweri      | Eastern  | 379                     | 191 600              | 505.54                                 |
| Buhweju      | Western  | 802                     | 144 100              | 179.68                                 |
| Buikwe       | Central  | 1 241                   | 474 100              | 382.03                                 |
| Bukedea      | Eastern  | 1 052                   | 259 300              | 246.48                                 |
| Bukomansimbi | Central  | 600                     | 156 600              | 261                                    |
| Bukwo        | Eastern  | 525                     | 119 100              | 226.86                                 |
| Bulambuli    | Eastern  | 652                     | 230 600              | 353.68                                 |
| Buliisa      | Western  | 2 483                   | 149 300              | 60.13                                  |
| Bundibugyo   | Western  | 848                     | 263 800              | 311.08                                 |
| Bunyangabu   | Western  | 498                     | 195 100              | 391.77                                 |
| Bushenyi     | Western  | 942                     | 248 300              | 263.59                                 |
| Busia        | Eastern  | 736                     | 384 000              | 521.74                                 |

| District    | Region   | Area (km <sup>2</sup> ) | Population (persons) | Density (persons per km <sup>2</sup> ) |
|-------------|----------|-------------------------|----------------------|----------------------------------------|
| Butaleja    | Eastern  | 653                     | 300 500              | 460.18                                 |
| Butambala   | Central  | 406                     | 107 800              | 265.52                                 |
| Butebo      | Eastern  | 236                     | 121 200              | 513.56                                 |
| Buvuma      | Central  | 299                     | 128 900              | 431.1                                  |
| Buyende     | Eastern  | 1 881                   | 414 600              | 220.41                                 |
| Dokolo      | Northern | 1 073                   | 215 500              | 200.84                                 |
| Gomba       | Central  | 1 679                   | 173 800              | 103.51                                 |
| Gulu        | Northern | 1 870                   | 325 600              | 174.12                                 |
| Hoima       | Western  | 1 518                   | 374 500              | 246.71                                 |
| Ibanda      | Western  | 965                     | 277 300              | 287.36                                 |
| Iganga      | Eastern  | 640                     | 402 600              | 629.06                                 |
| Isingiro    | Western  | 2 656                   | 596 400              | 224.55                                 |
| Jinja       | Eastern  | 697                     | 515 100              | 739.02                                 |
| Kaabong     | Northern | 4 104                   | 125 400              | 30.56                                  |
| Kabale      | Western  | 582                     | 248 700              | 427.32                                 |
| Kabarole    | Western  | 1 315                   | 337 800              | 256.88                                 |
| Kaberamaido | Eastern  | 888                     | 132 700              | 149.44                                 |
| Kagadi      | Western  | 1 405                   | 430 200              | 306.19                                 |
| Kakumiro    | Western  | 1 669                   | 473 400              | 283.64                                 |
| Kalaki      | Eastern  | 737                     | 138 700              | 188.2                                  |
| Kalangala   | Central  | 452                     | 67 200               | 148.67                                 |
| Kaliro      | Eastern  | 869                     | 288 500              | 331.99                                 |
| Kalungu     | Central  | 797                     | 194 100              | 243.54                                 |
| Kampala     | Central  | 181                     | 1 680 600            | 9 285.08                               |
| Kamuli      | Eastern  | 1 557                   | 558 500              | 358.7                                  |
| Kamwenge    | Western  | 1 692                   | 335 200              | 198.11                                 |
| Kanungu     | Western  | 1 270                   | 277 300              | 218.35                                 |
| Kapchorwa   | Eastern  | 355                     | 123 800              | 348.73                                 |
| Kapelebyong | Eastern  | 1 217                   | 103 800              | 85.29                                  |
| Karenga     | Northern | 3 193                   | 68 500               | 21.45                                  |
| Kasese      | Western  | 3 195                   | 793 200              | 248.26                                 |
| Kassanda    | Central  | 1 909                   | 312 700              | 163.8                                  |
| Katakwi     | Eastern  | 2 429                   | 194 600              | 80.12                                  |
| Kayunga     | Central  | 1 704                   | 407 700              | 239.26                                 |
| Kazo        | Western  | 1 556                   | 217 600              | 139.85                                 |
| Kibaale     | Western  | 1 161                   | 198 200              | 170.71                                 |
| Kiboga      | Central  | 1 587                   | 171 200              | 107.88                                 |
| Kibuku      | Eastern  | 490                     | 250 600              | 511.43                                 |
| Kikuube     | Western  | 2 116                   | 358 700              | 169.52                                 |
| Kiruhura    | Western  | 3 049                   | 185 700              | 60.91                                  |
| Kiryandongo | Western  | 3 624                   | 313 800              | 86.59                                  |
| Kisoro      | Western  | 728                     | 315 400              | 433.24                                 |
| Kitagwenda  | Western  | 716                     | 178 300              | 249.02                                 |
| Kitgum      | Northern | 3 960                   | 223 600              | 56.46                                  |
| Koboko      | Northern | 760                     | 258 000              | 339.47                                 |
| Kole        | Northern | 1 074                   | 284 300              | 264.71                                 |
| Kotido      | Northern | 3 702                   | 206 500              | 55.78                                  |
| Kumi        | Eastern  | 1 075                   | 284 800              | 264.93                                 |

| District      | Region   | Area (km <sup>2</sup> ) | Population (persons) | Density (persons per km <sup>2</sup> ) |
|---------------|----------|-------------------------|----------------------|----------------------------------------|
| Kwania        | Northern | 1 440                   | 216 600              | 150.42                                 |
| Kween         | Eastern  | 851                     | 109 500              | 128.67                                 |
| Kyankwanzi    | Central  | 2 455                   | 282 800              | 115.19                                 |
| Kyegege       | Western  | 1 747                   | 441 000              | 252.43                                 |
| Kyenjojo      | Western  | 2 350                   | 525 400              | 223.57                                 |
| Kyotera       | Central  | 1 746                   | 261 000              | 149.48                                 |
| Lamwo         | Northern | 5 596                   | 143 800              | 25.7                                   |
| Lira          | Northern | 1 329                   | 478 500              | 360.05                                 |
| Luuka         | Eastern  | 650                     | 267 100              | 410.92                                 |
| Luwero        | Central  | 2 218                   | 523 600              | 236.07                                 |
| Lwengo        | Central  | 915                     | 290 500              | 317.49                                 |
| Lyantonde     | Central  | 888                     | 110 500              | 124.44                                 |
| Madi Okollo   | Northern | 2 019                   | 164 200              | 81.33                                  |
| Manafwa       | Eastern  | 235                     | 175 200              | 745.53                                 |
| Maracha       | Northern | 1 572                   | 208 300              | 132.51                                 |
| Masaka        | Central  | 1 298                   | 335 700              | 258.63                                 |
| Masindi       | Western  | 2 585                   | 340 500              | 131.72                                 |
| Mayuge        | Eastern  | 1 090                   | 565 100              | 518.44                                 |
| Mbale         | Eastern  | 519                     | 586 300              | 1 129.67                               |
| Mbarara       | Western  | 1 203                   | 390 700              | 324.77                                 |
| Mitooma       | Western  | 543                     | 194 300              | 357.83                                 |
| Mityana       | Central  | 1 579                   | 362 500              | 229.58                                 |
| Moroto        | Northern | 3 538                   | 118 500              | 33.49                                  |
| Moyo          | Northern | 1 010                   | 109 500              | 108.42                                 |
| Mpigi         | Central  | 1 216                   | 286 600              | 235.69                                 |
| Mubende       | Central  | 2 711                   | 554 800              | 204.65                                 |
| Mukono        | Central  | 1 860                   | 701 400              | 377.1                                  |
| Nabilatuk     | Northern | 1 704                   | 89 700               | 52.64                                  |
| Nakapiripirit | Northern | 2 498                   | 113 300              | 45.36                                  |
| Nakaseke      | Central  | 3 477                   | 234 600              | 67.47                                  |
| Nakasongola   | Central  | 3 512                   | 215 200              | 61.28                                  |
| Namayingo     | Eastern  | 535                     | 237 000              | 442.99                                 |
| Namisindwa    | Eastern  | 367                     | 231 500              | 630.79                                 |
| Namutumba     | Eastern  | 814                     | 306 500              | 376.54                                 |
| Napak         | Northern | 4 978                   | 158 300              | 31.8                                   |
| Nebbi         | Northern | 991                     | 282 600              | 285.17                                 |
| Ngora         | Eastern  | 721                     | 165 800              | 229.96                                 |
| Ntoroko       | Western  | 1 236                   | 76 000               | 61.49                                  |
| Ntungamo      | Western  | 2 048                   | 540 800              | 264.06                                 |
| Nwoya         | Northern | 4 742                   | 236 000              | 49.77                                  |
| Obongi        | Northern | 847                     | 49 100               | 57.97                                  |
| Omoro         | Northern | 1 582                   | 196 400              | 124.15                                 |
| Otuke         | Northern | 1 550                   | 133 500              | 86.13                                  |
| Oyam          | Northern | 2 191                   | 453 700              | 207.07                                 |
| Pader         | Northern | 3 362                   | 197 300              | 58.69                                  |
| Pakwach       | Northern | 961                     | 196 800              | 204.79                                 |
| Pallisa       | Eastern  | 860                     | 353 400              | 410.93                                 |
| Rakai         | Central  | 1 598                   | 317 700              | 198.81                                 |

| District  | Region   | Area (km <sup>2</sup> ) | Population (persons) | Density (persons per km <sup>2</sup> ) |
|-----------|----------|-------------------------|----------------------|----------------------------------------|
| Rubanda   | Western  | 721                     | 208 500              | 289.18                                 |
| Rubirizi  | Western  | 985                     | 144 100              | 146.29                                 |
| Rukiga    | Western  | 426                     | 105 400              | 247.42                                 |
| Rukungiri | Western  | 1 437                   | 333 800              | 232.29                                 |
| Rwampara  | Western  | 575                     | 144 600              | 251.48                                 |
| Sembabule | Central  | 2 318                   | 296 100              | 127.74                                 |
| Serere    | Eastern  | 1 965                   | 359 500              | 182.95                                 |
| Sheema    | Western  | 699                     | 220 500              | 315.45                                 |
| Sironko   | Eastern  | 446                     | 274 300              | 615.02                                 |
| Soroti    | Eastern  | 1 412                   | 363 600              | 257.51                                 |
| Tororo    | Eastern  | 1 196                   | 597 500              | 499.58                                 |
| Wakiso    | Central  | 1 933                   | 2 915 200            | 1 508.12                               |
| Yumbe     | Northern | 2 321                   | 663 600              | 285.91                                 |
| Zombo     | Northern | 898                     | 283 100              | 315.26                                 |

Appendix D-3: Population distribution per each soil type

The population distribution of Uganda per soil type presented in Fig III is developed by crossing the slope-based shear wave velocity in the upper 30-metre of soil ( $V_{s,30}$ ) map with the recent population distribution dataset. The result shows that regions with less stiff soils are highly populated compared with areas where stiffer soils exist.

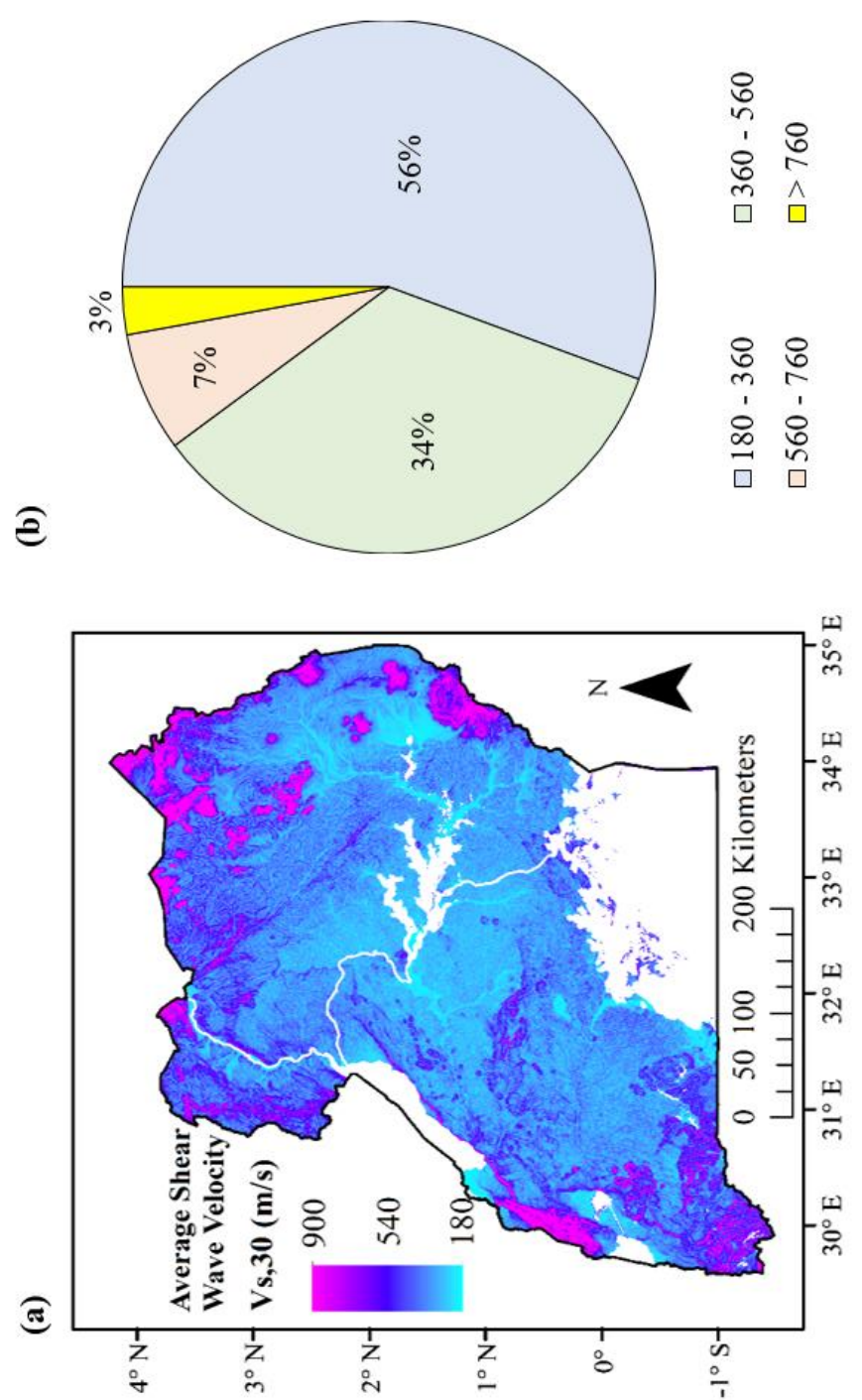


Fig III (a) Slope-based average seismic shear wave velocity in the upper 30 m of soil reference map of Uganda obtained from the repository of the US. Geological Survey (Allen and Wald, 2007); and (b) Corresponding distribution of the country's population per each soil type categorised across Uganda

## APPENDIX E: ANALYTICAL VULNERABILITY CURVES

### Appendix E-1: Vulnerability curves for predicting mean economic losses

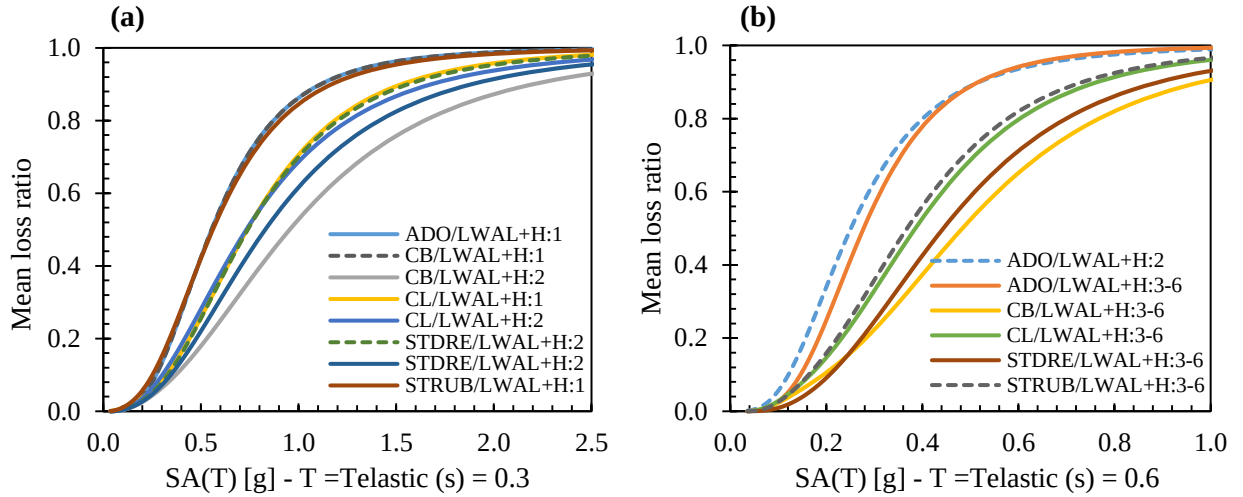


**Fig IV** Non-ductile unreinforced masonry buildings, presented in terms of: **(a)** SA ( $T = 0.3$  second) [g], and **(b)** SA ( $T = 0.6$  second) [g]. Building class taxonomies are defined in Appendix C

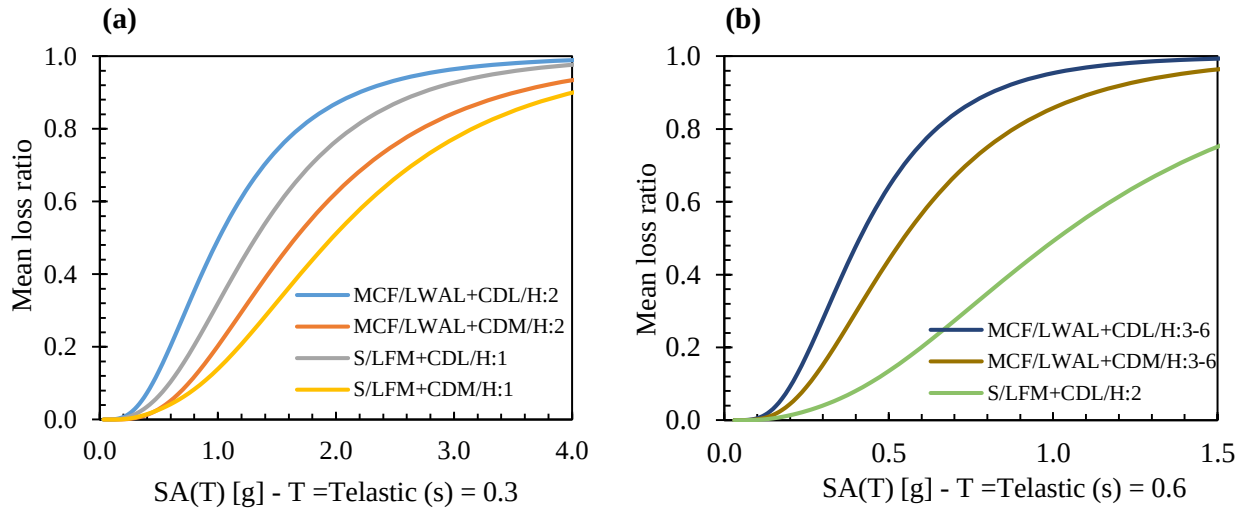


**Fig V** Confined masonry and steel buildings of low-medium ductility, presented in terms of: **(a)** SA( $T = 0.3$  second) [g], and **(b)** SA( $T = 0.6$  second) [g]. Building taxonomies defined in Appendix C

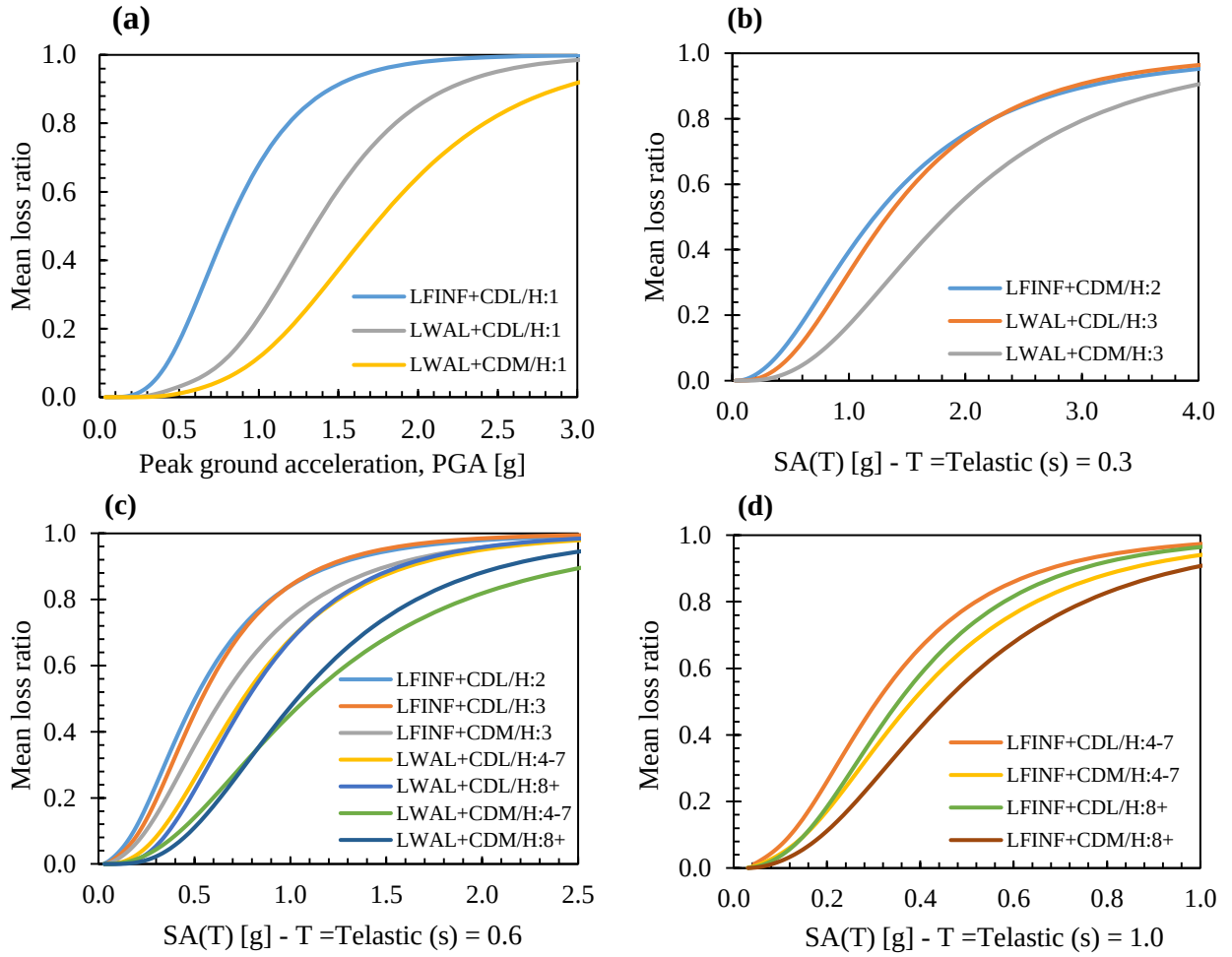


Fig VI Reinforced concrete buildings of low-medium ductility, presented in terms of mean loss ratios and: **(a)** peak ground acceleration, **(b)** spectral acceleration, SA(T) [g] - T = 0.3 second, **(c)** SA(T) [g] - T = 0.6 second, and **(d)** SA(T) [g] - T = 1.0 second.

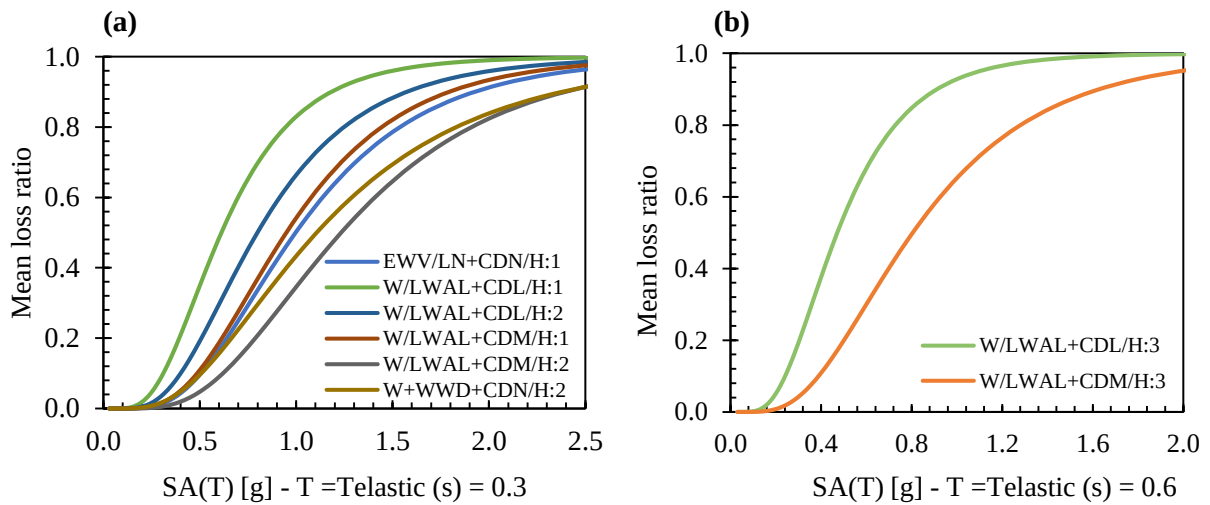


Fig VII Wooden and vegetative exterior walled buildings of various ductility levels, described in terms of: **(a)** SA (T = 0.3 second) [g], and **(b)** SA (T = 0.6 second) [g].

### Appendix E-2: Vulnerability curves for predicting average fatalities

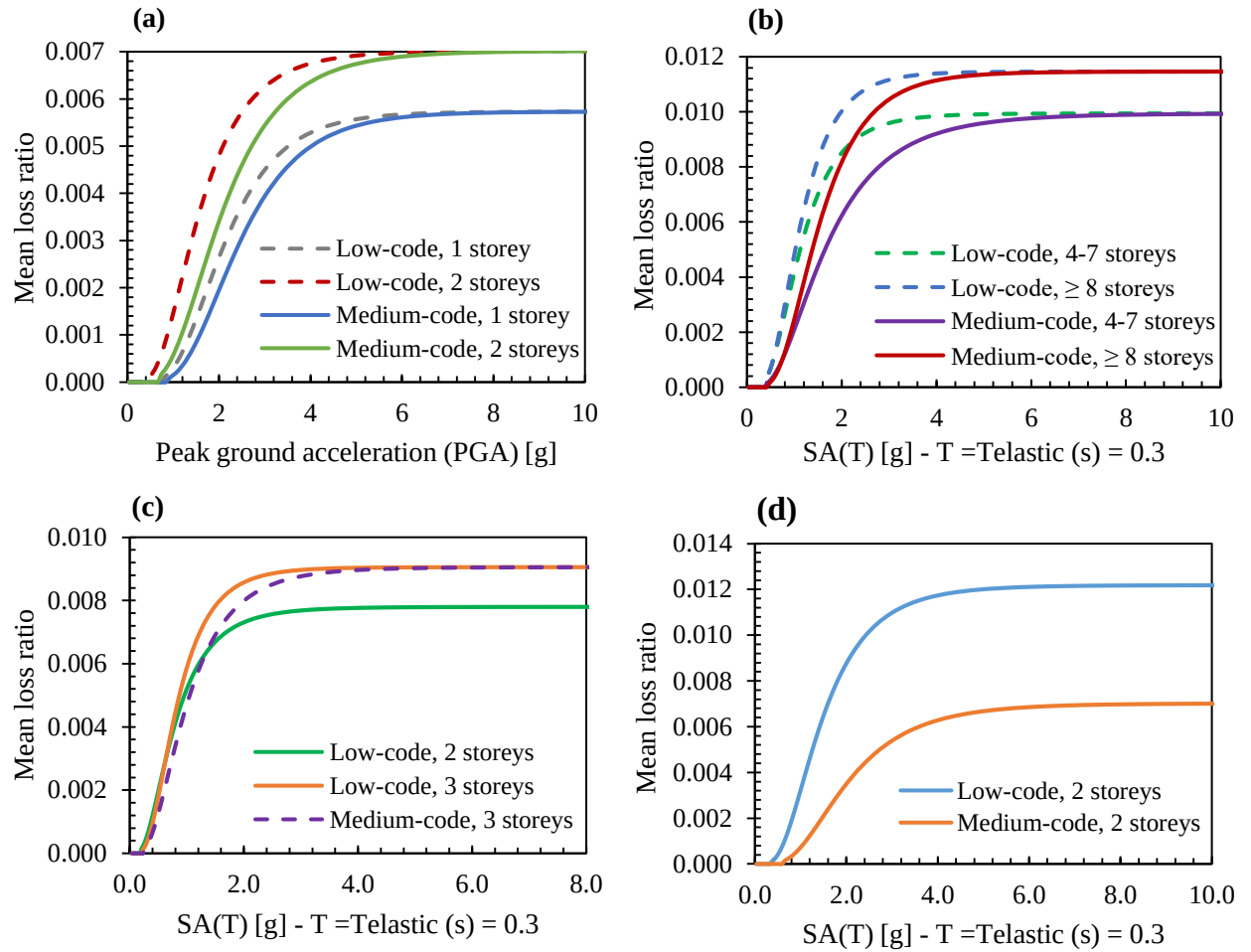


Fig VIII Residential buildings of low-moderate ductility, shown for: **(a-b)** reinforced concrete buildings with shear-wall **(c)** infilled walled reinforced concrete buildings, and **(d)** confined masonry buildings

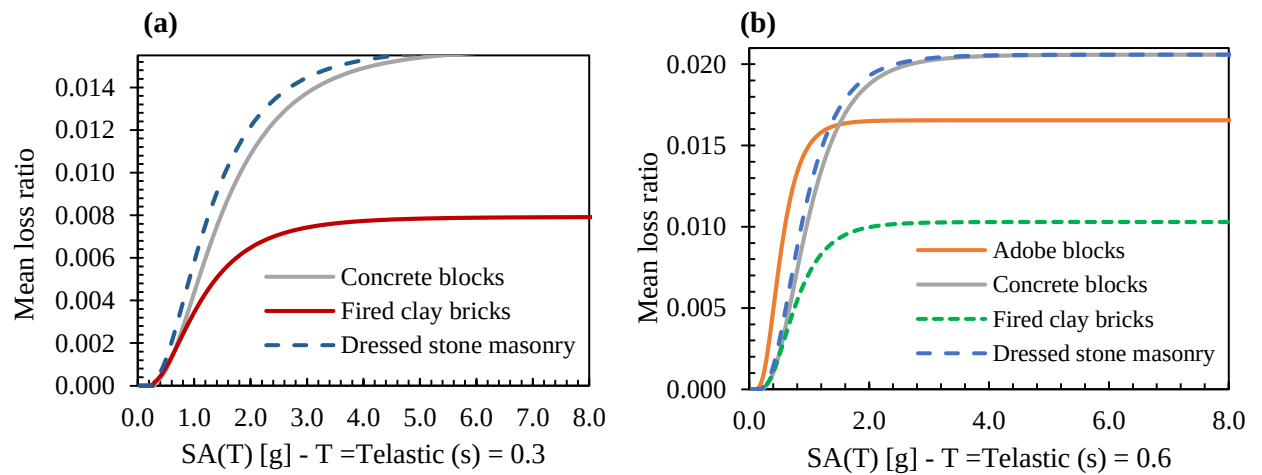


Fig IX Non-ductile unreinforced masonry residential buildings comprising of various wall construction materials, presented for: **(a)** two-storey masonry buildings, and **(b)** three-six storey masonry buildings

## APPENDIX F: RISK REDUCTION AND MANAGEMENT (NPDPM, 2010)

The increasing frequency of natural hazards such as landslides and earthquakes can wreak havoc and retard the efforts towards achieving sustainable growth and development in the fragile mountainous ecosystems across Uganda. The NPDPM (2010) largely points toward the urgent need for disaster policy reforms, resettlement plans, land use planning, early warning systems and budgetary allocations; towards achieving a well-balanced short and long term recovery plan. In this regard, NPDPM (2010) recommends key structural and non-structural ideas for identifying and designing robust DRR/DRM action plans towards mitigating the adverse impacts of natural hazards across the country. Accordingly, the national risk and vulnerability atlas of Uganda emphasises structural and non-structural actions, their purposes and tools. Structural actions include retrofitting, physical protection, relocation, and legal and institutional frameworks. On the other hand, non-structural actions include development regulation and land use management, natural resources protection, public information and awareness drive, incentive mechanisms, property acquisition programs, financial instruments, critical public and private facility policies, and private-public sector initiatives.

### Appendix F-1: Structural actions for identifying and designing DRR/DRM measures

| Category                           | Purpose                                                                                                                                                                                                                                           | Tools                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Structural retrofitting            | <ul style="list-style-type: none"><li>○ Increase design standards of hazard resistance</li><li>○ Retain original structural plans and purposes</li><li>○ Design regulations that reduce loss and damage</li><li>○ Compliance and safety</li></ul> | <ul style="list-style-type: none"><li>○ Building codes like the Uganda seismic code of practice for structural designs US319:2003 (UNBS, 2003)</li><li>○ Wind hazard resistance standards</li><li>○ Flood hazard resistance for new homes</li><li>○ Retrofitting guide for existing buildings</li><li>○ Standards and codes for special utilities</li><li>○ Original architectural and structural plans</li><li>○ Indigenous knowledge and skills</li><li>○ Structural data bank</li></ul> |
| Physical protection                | <ul style="list-style-type: none"><li>○ Mitigate hazard impacts</li><li>○ Shock absorbers</li><li>○ Clear hazard alarms</li><li>○ Enhanced foundations</li><li>○ Good structural detailing</li></ul>                                              | <ul style="list-style-type: none"><li>○ Retention walls, Levees, isolators, etc.</li><li>○ Suitable lateral load resisting systems such as shear walls</li></ul>                                                                                                                                                                                                                                                                                                                           |
| Relocation                         | <ul style="list-style-type: none"><li>○ Reduce the exposure of the population to natural hazards</li></ul>                                                                                                                                        | <ul style="list-style-type: none"><li>○ Suitable requirements for locating public and private facilities and infrastructure.</li><li>○ New location site plans and legitimately approved detailed building plans</li></ul>                                                                                                                                                                                                                                                                 |
| Legal and institutional frameworks | <ul style="list-style-type: none"><li>○ Legal requirements</li><li>○ Expiry of property leases</li></ul>                                                                                                                                          | <ul style="list-style-type: none"><li>○ Municipality regulations on development</li><li>○ Civil and professional standards</li></ul>                                                                                                                                                                                                                                                                                                                                                       |

**Appendix F-2: Non-structural actions towards DRR/DRM measures**

| Category                                       | Purpose                                                                                                                                                                                                                                   | Tools                                                                                                                                                                                                                                                                                                                               |
|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Development regulation and land use management | <ul style="list-style-type: none"> <li>○ Restrict occupancy in hazard-prone areas</li> <li>○ Regulate density</li> <li>○ Discourage development in environmentally sensitive or hazard-prone areas</li> </ul>                             | <ul style="list-style-type: none"> <li>○ Residential subdivision ordinances</li> <li>○ Planned unit development</li> <li>○ Special overlay districts</li> <li>○ agricultural or open space zoning</li> <li>○ Performance-based zoning</li> <li>○ Hazard setback ordinances</li> <li>○ Storm water retention requirements</li> </ul> |
| Natural Resources Protection                   | <ul style="list-style-type: none"> <li>○ Preserve ecologically sensitive areas</li> <li>○ Integrate equity</li> <li>○ Natural resources are finite</li> </ul>                                                                             | <ul style="list-style-type: none"> <li>○ Protect and reduce wetland pollution</li> <li>○ Protect habitat, wildlife, endangered species and restore vegetation</li> <li>○ Legal and regulatory framework</li> <li>○ Controlled exploitation, value addition and recycling.</li> </ul>                                                |
| Public information and awareness               | <ul style="list-style-type: none"> <li>○ Disseminate information and advice the community on hazards, prone areas, and mitigation and goals</li> <li>○ Preparedness for effective response</li> </ul>                                     | <ul style="list-style-type: none"> <li>○ Public education for DRR</li> <li>○ Citizen involvement in DRR plans</li> <li>○ Seminars or workshops on DRR practices for developers and builders</li> <li>○ Hazard disclosure and zone signs</li> <li>○ Suitable technology and resources</li> </ul>                                     |
| Incentive mechanisms                           | <ul style="list-style-type: none"> <li>○ Encourage land owners and developers to avoid environmentally sensitive and hazard-prone areas</li> <li>○ Disperse and reduce risks</li> <li>○ Support investment response mechanisms</li> </ul> | <ul style="list-style-type: none"> <li>○ Transfer development rights and risk</li> <li>○ Density bonus</li> <li>○ Clustered development for densely populated zones</li> <li>○ Participation in insurance programs</li> <li>○ Participation in the national Community Rating System (CRS)</li> </ul>                                |
| Property acquisition programs                  | <ul style="list-style-type: none"> <li>○ Acquire and hold property for public benefit and use</li> <li>○ Remove property at risk from the private market</li> </ul>                                                                       | <ul style="list-style-type: none"> <li>○ Levy fees for simple purchases of undeveloped lands</li> <li>○ Acquisition of developments</li> <li>○ Relocation of existing structures out of hazard-prone areas</li> </ul>                                                                                                               |
| Financial instruments                          | <ul style="list-style-type: none"> <li>○ A fairer distribution of the public costs of private development</li> </ul>                                                                                                                      | <ul style="list-style-type: none"> <li>○ Low tax rates</li> <li>○ Special tax assessments</li> <li>○ Impact fees or special assessments</li> </ul>                                                                                                                                                                                  |
| Critical public and private facility policies  | <ul style="list-style-type: none"> <li>○ Direct infrastructure areas away from hazard-prone regions</li> </ul>                                                                                                                            | <ul style="list-style-type: none"> <li>○ Requirements for locating public and private facilities and infrastructure</li> <li>○ Using municipal service areas to limit development</li> </ul>                                                                                                                                        |
| Private-Public sector initiatives              | <ul style="list-style-type: none"> <li>○ Work with other private entities to mitigate the impacts of natural hazards</li> </ul>                                                                                                           | <ul style="list-style-type: none"> <li>○ Land Trusts</li> <li>○ Public-Private Partnerships</li> </ul>                                                                                                                                                                                                                              |

## Appendix F-3: Hazard specific DRR measures

| Hazard        | Local planning and regulation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Structural retrofitting and infrastructure protection                                                                                                                                                 | Natural systems protection                                                                                                                                  | Education and awareness raising                                                                                                                                                                                                                                                                                                                                               |
|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Earthquakes   | <ul style="list-style-type: none"> <li>Map and assess community vulnerability to earthquakes</li> <li>Adopt and enforce building codes</li> <li>Incorporate earthquake mitigation into local planning</li> <li>Conduct inspections of building safety</li> </ul>                                                                                                                                                                                                                                                                                            | <ul style="list-style-type: none"> <li>Protect critical facilities and infrastructure</li> <li>Implement structural mitigation techniques</li> <li>Design structures for the right purpose</li> </ul> | <ul style="list-style-type: none"> <li>Map active fault and geo-tectonic zones</li> <li>Use indigenous knowledge and skills</li> </ul>                      | <ul style="list-style-type: none"> <li>Increase risk awareness</li> <li>Conduct outreach to builders, architects, engineers and inspectors</li> <li>Provide information on structural and non-structural retrofitting</li> <li>Regular bulletins</li> </ul>                                                                                                                   |
| Landslide     | <ul style="list-style-type: none"> <li>Map and assess community vulnerability to landslides</li> <li>Manage development in prone areas</li> <li>Good environmental practices</li> <li>Restore vegetation and afforestation</li> <li>For settlements in safe areas</li> <li>Prone areas can be used seasonally for specific activities</li> <li>Resettlement plans</li> </ul>                                                                                                                                                                                | <ul style="list-style-type: none"> <li>Prevent impacts to roadways</li> <li>Remove existing buildings and infrastructure from landslide-prone areas</li> </ul>                                        | <ul style="list-style-type: none"> <li>Set up early warning systems for adaptation</li> <li>Gazette landslide-prone areas for non-settlement</li> </ul>     | <ul style="list-style-type: none"> <li>Use indigenous knowledge to create awareness</li> </ul>                                                                                                                                                                                                                                                                                |
| Multi-hazards | <ul style="list-style-type: none"> <li>Multi-sectoral methods for planning, mainstreaming and response</li> <li>Assess and map community risk</li> <li>Restrict development in prone areas</li> <li>Adopt development regulations</li> <li>Limit human populace in prone areas</li> <li>Integrate mitigation into local planning</li> <li>Strengthen land use regulation</li> <li>Adopt and enforce building codes</li> <li>Create local funding mechanisms</li> <li>Incentive hazard mitigation</li> <li>Monitor mitigation plan implementation</li> </ul> | <ul style="list-style-type: none"> <li>Multi-sectoral response to protecting buildings and infrastructure</li> <li>Protect infrastructure and critical facilities</li> </ul>                          | <ul style="list-style-type: none"> <li>Use indigenous knowledge and skills</li> <li>Use service and technology to the benefit of the communities</li> </ul> | <ul style="list-style-type: none"> <li>Increase hazard education and risk awareness</li> <li>Improve household disaster preparedness</li> <li>Promote private mitigation efforts</li> <li>Investment in education</li> <li>Multi-sectoral approach</li> <li>Invest in risk transfer systems</li> <li>Research on innovative learning</li> <li>Indecisive knowledge</li> </ul> |

Effective implementation of DRR/DRM measures by the concerned stakeholders and government agencies is likely to offer several benefits such as reducing or avoiding economic, social, and environment-related costs. In addition to increasing community awareness levels on hazard and their appropriate reduction strategies, DRR/DRM measures aid in enhancing cooperation and collaboration amongst implementing agencies as well as promote environmental conservation and management. However, the major challenge remains in the appropriate implementation of the DRR/DRM measures.

On the other hand, gazetting, prohibition of settlement and resettlement of people living in landslide-prone areas are the least implemented policies in addition to lack of awareness household level and deficiencies in enforcement of relevant laws and regulations. The study further points out the high institutional vulnerability to disasters which is largely characterised by inadequate human and financial capabilities, political interference, misuse of resources and corruption, poor social capital (cooperation amongst local community inhabitants) and absence of particular sectoral laws on enforcement. The loopholes in the implementation of DRR/DRM policies in Uganda point to the need for detailed assessments into the efficacy of the [NPDPM \(2010\)](#). There is an urgent need to re-visit and update the policies and address challenges within their appropriate implementation.

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**STOCHASTIC MODELLING OF  
SEISMIC HAZARD AND RISK  
ASSESSMENT FRAMEWORK  
FOR UGANDA**

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