Identifying the Potential of Participatory Modelling and Mobile Data Collection to Enhance Implementation of Integrated Water Resources Management

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Abstract

The global problem of increasing freshwater scarcity has led to the promotion and adoption of the concept of integrated water resources management (IWRM) as a way of achieving sustainable development and management of available freshwater resources. However, despite its popularity and the widespread support it has enjoyed among its proponents over the years, IWRM has registered dismal performance on the implementation front. Whereas participatory involvement in the management of water resources is a key requirement in IWRM, its realisation in practice remains a major challenge. This study investigated means through which participatory involvement in water resources management could be improved with the aim of enhancing implementation of IWRM. To that end a participatory modelling exercise was designed and implemented with a select group of participants and the process evaluated; a web-based mobile data collection system was developed, tested and evaluated; and an enabling framework for water resources management was assessed.

Key findings from the study suggest that participatory modelling can enhance implementation of IWRM by supporting participatory involvement in the management of water resources. However this is not possible with a web-based mobile data collection system, particularly in a developing country context. The findings also suggest that an enabling environment for water resources management is not sufficient to enhance implementation of IWRM but may need to be accompanied by additional supporting measures.

As the responsibilities of managing water resources are increasingly being decentralised with more emphasis being placed on stakeholder participation, participatory modelling offers methodological guidance on how to constructively involve stakeholders in water resources management.

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List of Abbreviations

2G	Second Generation
3G	Third Generation
4G	Fourth Generation
BN	Bayesian Networks
CBO	Community Based Organisation
CMC	Catchment Management Committee
CMO	Catchment Management Organisation
CPT	Conditional Probability Table
DEA	Directorate of Environmental Affairs
DLG	District Local Government
DPs	Development Partners
DWD	Directorate of Water Development
DWRM	Directorate of Water Resources Management
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GWP	Global Water Partnership
IWRM	Integrated Water Resources Management
JSR	Joint Sector Review
LVBC	Lake Victoria Basin Commission
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MDC	Mobile Data Collection
MFPED	Ministry of Finance, Planning and Economic Development
MLG	Ministry of Local Government
MLHUD	Ministry of Lands, Housing and Urban Development
MWE	Ministry of Water and Environment
NBI	Nile Basin Initiative
NEMA	National Environment Management Authority
NEMP	National Environment Management Policy
NFA	National Forestry Authority
NGO	Non-Governmental Organisation

NWP	National Water Policy
NWSC	National Water and Sewerage Corporation
ODK	Open Data Kit
PM	Participatory Modelling
SDGs	Sustainable Development Goals
SMS	Short Message Service
UGX	Ugandan Shilling
UN	United Nations
URL	Uniform Resource Locator
UWASNET	Uganda Water and Sanitation Network
WMZ	Water Management Zone
WPC	Water Policy Committee

Chapter 1

Introduction

A recent assessment of the global freshwater scarcity shows that around two-thirds of the world population experience severe water scarcity for at least one month in a year (Mekonnen and Hoekstra, 2016). This translates to about 5.0 billion people, given that the world population stood at about 7.3 billion people as of mid-2015, with an average annual growth rate of 1.18% (United Nations Department of Economic and Social Affairs Population Division, 2015). As the world population continues to grow, so does the demand for fresh water to meet various human and environmental requirements. In view of the fact that water is a finite resource, it is inevitable that the situation of freshwater scarcity could become worse if appropriate measures are not taken to address it.

This chapter gives the background to this study, followed by the aim and objectives of the study. It then provides the rationale and significance of the study and concludes by outlining the structure of this thesis report.

1.1 Background

Declining Freshwater Resources

Fresh water is a fundamental requirement for human life and for environmental sustainability. There is a pressing global problem of declining freshwater resources which has led to freshwater scarcity in many regions across the world (Gleick, 1998; Gleick and Ajami, 2014; Haddeland et al., 2014; Hanjra and Qureshi, 2010). The decline in freshwater resources is largely attributed to increasing demand from the ever growing population, deteriorating quality of available water resources and variable availability associated with the effects of climate change, among other factors (Gleick, 1998; Gleick and Ajami, 2014; Gleick, 2016; Haddeland et al., 2014; Hanjra and Qureshi, 2010; Kelley et al., 2015). This situation could be exacerbated by poor management of available freshwater resources.

Coupled to the growing global population is the challenge of rapid urbanisation, especially in developing countries (United Nations Department of Economic and Social Affairs Population Division, 2014). This has led to concentration of water demand in specific places thereby exerting pressure on available water resources in those places. Urbanisation also comes with the challenges of waste management. In most developing countries the waste is often not well managed and often ends up in the receiving environment without proper treatment thereby polluting the environment (Guerrero et al., 2013; Henry et al., 2006; Okot-Okumu and Nyenje, 2011; Zhang et al., 2010). This exerts extra pressure on the already strained water resources. The net effect is the reduction of the quantity of water that is suitable for direct human consumption. As this trend continues availability of fresh water becomes uncertain and society could be exposed to various risks related to inadequate freshwater supply.

Given the fact that fresh water is a finite resource, as its demand by different sectors continues to grow, its availability will inevitably continue to decline. This could lead to conflict between the different uses and users. Decisions will, therefore, have to be made on how to manage and use the available water resources in an equitable and sustainable manner.

Water Resources Management

In a bid to address the problem of declining freshwater resources, there has been a call to ensure that available freshwater resources are developed and managed in a sustainable manner (ICWE, 1992; Savenije and Van der Zaag, 2008; UN, 1992; UN-Water, 2007; UN-Water, 2015). To that end the concept of integrated water resources management (IWRM) was adopted at the Second World Water Forum held at The Hague in 2000, as a means of achieving this goal. However, despite enjoying decades of popularity and support, the concept has experienced implementation challenges and as a consequence examples of successful implementation from which to draw any recognised best practice remain few (Biswas, 2008; Blomquist and Schlager, 2005; Bunclark et al., 2011; Jeffrey and Gearey, 2006; Medema et al., 2008; Rahaman, 2009).

One of the fundamental requirements of IWRM is the involvement stakeholders in the management of water resources. It is believed that better decision making and improved resource management could be achieved if driven by the stakeholders (Carr et al., 2012; Leidel et al., 2012; Voinov and Bousquet, 2010; Carr, 2015). It is also believed that stakeholder involvement could ensure support of the decisions made and therefore increase the likelihood of successful implementation of such decisions (Carr et al., 2012; Carr, 2015; Leidel et al., 2012; Voinov and Bousquet, 2010). These benefits of stakeholder involvement are based on the belief that local knowledge and experiences of water resources issues can be used to improve water resources management (Anokye, 2013). The other benefit that is commonly associated with stakeholder participation is that it can lead to empowerment of stakeholders, particularly the marginalised groups in society (Anokye, 2013; Kessler, 2004). It is believed that this not only gives such people a voice but also enhances accountability among water resources managers, and that it raises the legitimacy of water policies.

However, stakeholder involvement has been, and continues to be, a major challenge in water resources management. This has been largely attributed to inadequate guidance of how it can be effectively realised in practice (Agyenim and Gupta, 2012; Butterworth et al., 2010; Connell and Grafton, 2011; Petit and Baron, 2009; Sgobbi and Giupponi, 2007; Teodosiu et al., 2013; Videira et al., 2006). Consequently this has undermined the realisation of the benefits associated with stakeholder involvement in the management of water resources. There is therefore need to find ways of improving stakeholder involvement in the management of water resources if the benefits of their involvement are to be harnessed.

1.2 Aim

The aim of this study was to identify means through which stakeholder participation in water resources management could be improved so as to enhance implementation of integrated water resources management.

1.2.1 Study Objectives

The objectives of this study were:

1. To investigate the potential of participatory modelling as a means of involving stakeholders in water resources management
2. To assess the extent to which participatory modelling can deliver benefits for water resources management
3. To investigate the feasibility of mobile data collection as a means of involving stakeholders in water resources management
4. To assess the extent to which the water resources management framework in Uganda provides an enabling environment that supports stakeholder participation

Based on these objectives the following research questions were formulated to guide the study:

i. Can participatory modelling be used as a method of involving stakeholders in water resources management?
ii. What benefits does participatory modelling deliver for water resources management?
iii. How viable is mobile data collection as a method of involving stakeholders in water resources management?
iv. Does creating and enabling environment for water resources management ensure stakeholder participation?

1.3 Rationale and Significance of the Study

With the growing global challenge of increasing freshwater scarcity, IWRM is widely regarded as a concept of choice for achieving sustainable development and management of available freshwater resources. However, its implementation in practice has been beset by challenges. This has been mainly attributed to failure to translate the principles on which it is based into practice (Biswas, 2008; Blomquist and Schlager, 2005; Bunclark et al., 2011; Jeffrey and Gearey, 2006; Medema et al., 2008; Rahaman, 2009). Of particular interest for this study is the challenge of realising participatory involvement of stakeholders in the management of water resources.

There is growing popularity and increasing recognition of participatory modelling approaches and the potential they hold to support stakeholder involvement in the management of natural resources (Campo et al., 2010; Gaddis et al., 2010; Robles-Morua et al., 2014; Tsouvalis and Waterton, 2012; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010). However, that potential has not been fully exploited in the field of water resources management. In the field of water resources management, participatory modelling has mainly been used for the purpose of developing models as decision support systems (Carmona et al., 2013; Castelletti and Soncini-Sessa, 2007; Chan et al., 2010; Henriksen et al., 2007; Ritzema et al., 2010; Ticehurst et al., 2007; Winz et al., 2009; Sgobbi and Giupponi, 2007). However, relatively few studies have attempted to evaluate a participatory modelling process to assess the extent to which it delivers benefits for water resources management (Carmona et al., 2013; Zorrilla et al., 2010; Maskrey et al., 2016). Even among those studies that have attempted to evaluate the process, none of them has assessed the means through which a participatory modelling process can support stakeholder involvement in the management of water resources. As a result there is scarcity of knowledge about the tools and methods used in participatory modelling and how they can help support stakeholder participation in the management of water resources. It is within this context that this study set out to investigate the potential of a participatory modelling process to support stakeholder involvement in water resources management.

A number of benefits have been claimed for participation. However, relatively few studies have attempted to assess the extent to which many of the claims made for stakeholder participation are realised, especially in the context of water resources management (Young et al., 2013; Carmona et al., 2013; Maskrey et al., 2016). Within this context the study also sought to assess the extent to which a participatory modelling process could achieve the claimed benefits of participation.

Many countries that have attempted to implement the concept of IWRM have instituted policy and institutional reforms to create an enabling framework to support implementation of the IWRM principles (Agyenim and Gupta, 2012; Petit and Baron, 2009; Rahaman, 2009). However, few studies have attempted to assess the extent to which creating such a framework does in fact result in implementation of the IWRM principles (Agyenim and Gupta, 2012; Gupta, 2010; Ioris, 2008). It is within this context that this study assessed the extent to which the water resources management framework in Uganda provides an enabling environment that supports stakeholder participation.

With the advent of mobile phone technology, data collection methods that use handheld devices such as mobile phones, as alternatives to the traditional paper-based methods, have been developed (Hartung et al., 2010; Lwin and Murayama, 2011; Tomlinson et al., 2009; Lugo and Ortega, 2015). Given the way these methods have been applied in the fields of health and agriculture, and the widespread availability of mobile phones, mobile data collection appears attractive as a method that could be applied to involve stakeholders in water resources management. However, that potential has not yet been explored. It is within this context that this study also set out to investigate the feasibility of mobile data collection as a method of involving stakeholders in the management of water resources.

It is anticipated that the findings from this study will be useful for improving the guidance available for involving stakeholders in the management of water resources. This is expected to contribute to the achievement of the requirement of Chapter 18.12 (n) of Agenda 21 (UN, 1992) regarding development of participatory techniques and their use in decision making to improve integrated water resources management. It is also expected to contribute to the realisation of target 6.5 of the SGDs regarding implementation of IWRM. This is essential in advancing the practice of IWRM. It is also essential for realising the potential benefits associated with stakeholder involvement in the management of water resources.

It is anticipated that insights from this study will contribute to the state of knowledge and improvements in participatory modelling practice. This study is also anticipated to contribute in raising awareness of the potential benefits of participatory modelling in water resources management.

It is also anticipated that the study will contribute to the state of knowledge in the area of evaluation of participatory modelling processes.

1.4 Study Area

This study was carried out in the River Rwizi Catchment, which is located in the south-west of Uganda (see Figure 1.1 below). The River Rwizi catchment covers a total area of about 8,400 km^2, with the altitude ranging between 1,262 m and 2,165 m above sea level. The catchment is mainly characterized by subsistence and commercial farming, local industries, and tourism as the main economic activities. Mbarara town is the main urban centre in the catchment. The River Rwizi is the main source of water for various uses across the catchment and the only source of water for Mbarara town. The water users in the catchment can be placed into three main categories as shown in Table 1.1 below.

Figure 1.1: Map of Uganda showing the location of the River Rwizi catchment

Source: DWRM (2014b)

Table 1.1: Categories of water uses in the River Rwizi catchment

Agricultural	**Industrial**	**Municipal**
Aquaculture	Breweries	Domestic supply
Crop irrigation	Wineries	Public institutions
Watering animals	Beverages factories	Private business
	Dairy processing	
	Brick making	
	Recreational	
	Hotels	

The River Rwizi catchment is experiencing a number of challenges that have contributed to the accelerated deterioration of the available water resources. These include high population growth, environmental degradation, wetland encroachment, poor land use and management, poor management and disposal of waste, and poor water resources management among others (DWRM, 2011c; GIZ, 2014; MDLG, 2009). The situation has been aggravated by the increasingly variable climatic conditions experienced in the region which has led to erratic rainfall patterns and consequently high variability in the river flow during the wet and dry seasons.

The water resources in the catchment are very important for the livelihoods of the people and for the economic development of the area. However uncontrolled environmental degradation is threatening the potential of the water resources to continue supporting livelihoods and economic development in the area. Recently there was an outcry from the local community on the fringes of the River Rwizi, concerning the declining quantity and quality of water available from this river as shown in Figure 1.2. This problem has been widely reported in the local press in Uganda (GIZ, 2014; Songa et al., 2015), and has also been recognised internationally as a major challenge (UNESCO, 2006; World Resources Institute, 2016).

Figure 1.2: River Rwizi gauging station

The river level has receded significantly over the last two decades.

To try and address the water resources challenges in the country, the government of Uganda has embarked on implementing catchment-based water resources management (DWRM, 2010; DWRM, 2014a). The River Rwizi catchment is one of the catchments in the country that has made significant strides in establishing the institutional structures necessary for implementing catchment-based water resources management. To that end a catchment management organisation (CMO) has been established to promote coordinated planning and management of water and related resources in the catchment. The CMO provides a platform through which the stakeholders meet and discuss water resources issues in the catchment. The CMO is managed by a catchment management committee (CMC) which is composed of 22 members, representing key stakeholder in the catchment. The key stakeholders in the catchment are: local & central governments, non-governmental organisations, private sector, civil society organisations, development partners, and the local community.

A public private partnership has also been established with Coca Cola International and GIZ, through the Directorate of Water Resources Management. The partnership is being implemented under the supervision of the CMO and aims at enabling sustainable management and use of water resources in the catchment.

The River Rwizi catchment was selected as a study area for this research because it was found to be experiencing a number of water resources challenges arising from rapid population growth, environmental degradation and effects of climate change among others. The catchment, therefore, provided a suitable site for the study because it had a reasonable mix of water and other environmental related challenges.

Because of the vast extent of the catchment and the limited resources available in terms of time and funds, the study was limited to the Mbarara district section of the catchment (see Figure 1.3). This section is located in the upstream portion of the catchment and was considered a critical part of the catchment because it was experiencing all the issues mentioned above and therefore had the greatest impact on the River Rwizi in terms of its water quality and quantity.

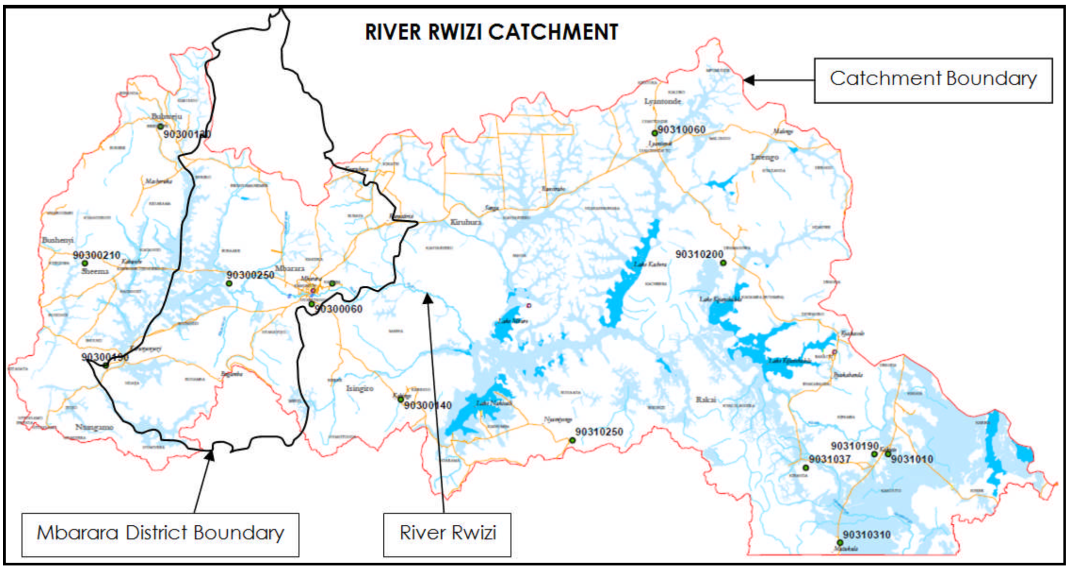


Figure 1.3: The River Rwizi catchment

Source: Adapted from Songa et al. (2015)

1.5 Thesis Structure

This chapter has:

1. Given the background to the study
2. Indicated what the study set out to do
3. Provided the rationale and significance of the study
4. Described the study area

The rest of the chapters have been organised as follows: Chapter 2 reviews the literature relevant for the study. Chapter 3 describes the research methodology. Chapter 4 presents the results of the participatory modelling exercise, while Chapter 5 presents the results of mobile data collection. Chapter 6 presents an analysis of the water resources management framework in Uganda. In Chapter 7, a general discussion of the results is presented, while Chapter 8 presents the conclusions and recommendations of the study.

Chapter 2

Water Resources Management

2.1 Introduction

There is a declining trend in the state of the global freshwater resources both in terms of quantity and quality. This has been largely attributed to increasing global population, urbanisation/industrialisation, and the effects of climate change (Gleick, 1998; Gleick and Ajami, 2014; Haddeland et al., 2014; Hanjra and Qureshi, 2010). Over the years several efforts have been made to address the freshwater resources challenges culminating in the adoption of IWRM; a concept that is believed can be able to ensure that freshwater resources are managed and used sustainably (Rahaman and Varis, 2005; Savenije and Van der Zaag, 2008). The underlying principle of IWRM is the involvement of stakeholders in the management water resources. It is believed that better decisions and improved resource management can be achieved if driven by stakeholders. In the same vein it is believed that stakeholder involvement can ensure legitimacy and support for the decisions made and therefore increase the likelihood of successful implementation of such decisions (Carr et al., 2012; Leidel et al., 2012; Voinov and Bousquet, 2010; Carr, 2015; Voinov et al., 2016). However, there are challenges with stakeholder participation and as a consequence efforts to involve stakeholders in water resources management, as required by IWRM, have often registered little success (Agyenim and Gupta, 2012; De Stefano, 2010; Petit and Baron, 2009; Teodosiu et al., 2013).

This chapter presents a review of literature relevant to this study. The chapter begins with a review of the current state of global freshwater resources. This is followed by a review of the contemporary approach to water resources management, specifically looking at the concept of integrated water resources management, the need for stakeholder participation in the management of water resources and some of the challenges related to stakeholder participation. The chapter concludes with a consideration of some of the possible approaches for involving stakeholders in the management of water resources.

2.2 State of Global Freshwater Resources

Water resources literature suggests that there is a global problem of declining freshwater resources which has led to freshwater scarcity in many regions across the world (Gleick, 1998; Gleick and Ajami, 2014; Haddeland et al., 2014; Hanjra and Qureshi, 2010). Some of the critical factors that have been attributed to the decline include increasing population, rapid urbanisation/industrialisation and effects of climate change (Gleick, 1998; Gleick and Ajami, 2014; Haddeland et al., 2014; Hanjra and Qureshi, 2010). Whereas all these factors have the potential to affect water resources, it is also likely that the decline registered could be due to poor management of the available water resources.

Decline in freshwater resources, however, is a major challenge that could expose society to risks related to inadequate water supply. These include failure to produce enough food for human consumption, water-borne and water-related diseases largely due to failure to meet the essential human requirements for drinking water and basic sanitation, and environmental degradation, amongst others (Gleick, 1998; Gleick and Ajami, 2014; Gleick, 2016; Haddeland et al., 2014; Hanjra and Qureshi, 2010; Kelley et al., 2015). These risks could be mitigated by ensuring that the available water resources are sustainably used and managed (Al Radif, 1999; Loucks and Beek, 2005).

2.2.1 Declining Water Resources

It has been variously reported that shrinking water resources have already had devastating effects in some of the world's largest water bodies and resulted in water scarcity in many other regions across the world (NASA Earth Observatory, 2016; Notaras and Aginam, 2009). Some examples of the water bodies and countries reported to be experiencing severe water scarcity are presented in the following subsections. These examples show the magnitude of the threat facing the worlds water resources and indicates the urgency of the problem.

2.2.1.1 Shrinking Water Bodies

Some of the world's water bodies that are reported to have been greatly affected by the decline in their water resources include the Aral Sea, Lake Chad and Lake Powel as shown in the satellite images in Figure 2.1, Figure 2.2 and Figure 2.3 below. In all these cases it is believed that prolonged drought and massive irrigation projects that diverted water flows for agricultural production contributed to the shrinking of these water bodies (NASA Earth Observatory, 2016; Notaras and Aginam, 2009; Onuoha, 2009). This suggests that the combined effects of climate change and human activity are responsible for the shrinking of these water bodies.

As the global population continues to grow it is likely that such a trend could be experienced in other places as well if no efforts are taken to avert it. The problem could become worse in developing countries where population growth is projected to be highest and therefore demand for fresh water is likely to increase even more (United Nations Department of Economic and Social Affairs Population Division, 2014; United Nations Department of Economic and Social Affairs Population Division, 2015). It is therefore important to ensure that appropriate action is taken now by involving all water users so as to avert a water crisis in future.

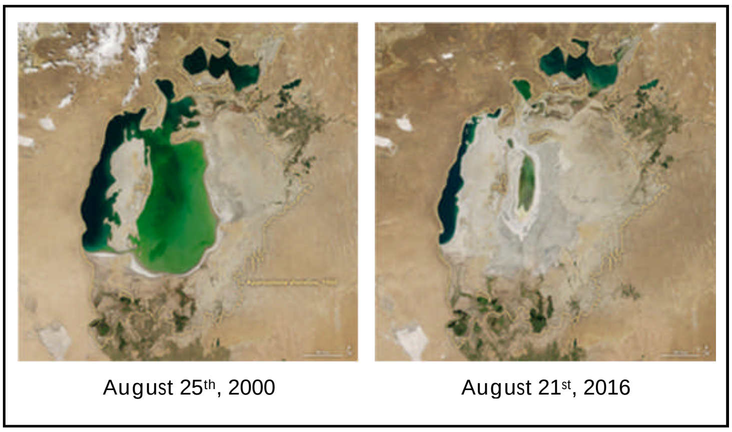


Figure 2.1: Satellite images of the Aral Sea.

These images show the effect of a massive irrigation project on the Aral Sea.

Source: NASA Earth Observatory (2016)

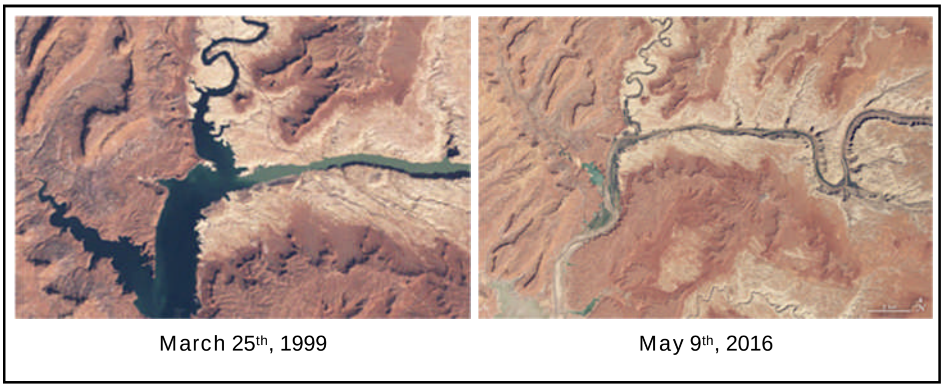


Figure 2.2: Satellite images of Lake Powell, USA.

These images show how Lake Powell has contracted over the years.

Source: NASA Earth Observatory (2016)

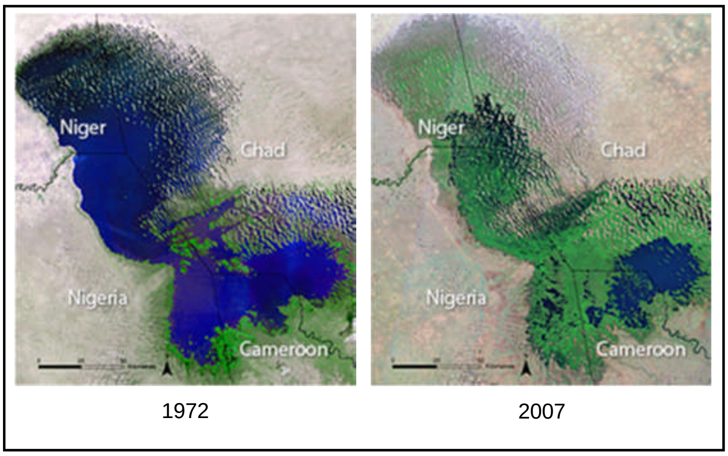


Figure 2.3: Satellite images of Lake Chad.

These images show how Lake Chad has contracted between 1972 and 2007.

Source: Notaras and Aginam (2009)

2.2.1.2 Freshwater Scarcity

Water resources are generally not evenly distribute across the world and because of this water scarcity in different places is manifested in different ways. In some places the demand for water is greater than what the natural water system can supply. This results in physical water scarcity. This is mostly the case in arid regions. In other places there is enough water to meet the demand, however the challenge lies in getting the water to the people; largely due to lack of or limited infrastructure. This often results from inadequate investment in water infrastructure and/or ineffective water institutions that fail to distribute water to consumers (Comprehensive Assessment of Water Management in Agriculture, 2007). This type of scarcity could be addressed by targeting investment on the development of infrastructure for storage and distribution of water, as well as improving the efficiency of institutions responsible for water. Freshwater scarcity is further complicated by factors such as population growth, urbanisation and climate change.

Freshwater scarcity affects all sectors of society and in particular the health and agricultural sectors. Freshwater scarcity has already caused a lot of devastation to humans and the environment in a number of place across the world (AFP, 2016b; AFP, 2016a; Ejaz Qureshi et al., 2013; Kharraz et al., 2012; NASA Earth

Observatory, 2016; Notaras and Aginam, 2009), and could continue to do so if appropriate action is not taken.

A recent assessment of global freshwater scarcity indicates that around two-thirds of the world’s population experience severe water scarcity for at least one month in a year (Mekonnen and Hoekstra, 2016). This translates to about 4.9 billion people, given that the world population as of mid-2015 stood at about 7.3 billion people with an average growth rate of about 1.18% per annum (United Nations Department of Economic and Social Affairs Population Division, 2015). This is a considerable proportion of the world population and it demonstrates the magnitude of the freshwater scarcity problem. With the ever increasing global population the problem could only get worse. Meeting water demand for human and environmental requirements could therefore be a major challenge for the 21st century (Mekonnen and Hoekstra, 2016; UN-Water, 2007), which will require a concerted effort by all sectors.

The increasing freshwater scarcity does not only pose a major threat to humanity and health of the environment but could also be a major security risk, with potential of causing conflict between and within communities (Dabelko and Aaron, 2004; Gleick, 1998; Gleick, 2016). Such conflicts could destabilise communities and undermine development. This state of affairs therefore calls for better management of the available freshwater resources by involving all relevant stakeholders so as to minimise the risks posed by scarcity to humans and the environment, and to avert possible future conflicts.

2.2.2 Factors Affecting Freshwater Resources

2.2.2.1 Climate Change

It is believed that climate change is responsible for the increased variability and frequency of extreme weather events, such as drought and heavy rainfall, that are currently being experienced globally. This therefore means that one of the ways through which climate change manifests itself is water; either by too little or no rainfall thereby resulting in drought or too much rainfall thereby resulting in flooding. Climate change, therefore, has a direct impact on water availability and as a consequence, it is causing water stress and scarcity in many regions across the world (AMCEN, 2009; Haddeland et al., 2014; Hanjra and Qureshi, 2010; Kelley et al., 2015; INBO, 2015).

However, despite its apparent impact on water resources, previous efforts to adapt to climate change have not adequately addressed adaptation of water resources (Bryan et al., 2009; Howden et al., 2007; Lobell et al., 2008; Stringer et al., 2009). Even in the agricultural sector adaptation strategies that seek to ensure availability of water have not been adequately articulated (Bryan et al., 2009; Howden et al., 2007; Lobell et al., 2008; Stringer et al., 2009), yet water is a critical input in this sector. In agriculture, adaptation strategies tend to focus on introduction of different varieties of crops and, to some extent, technologies to ensure efficient use of water (Bryan et al., 2009; Lobell et al., 2008; Stringer et al., 2009). Little focus is given to strategies to protect and ensure sustainability of water resources. This apparent lack of focus on the sustainability of water resources in the climate change adaptation strategies could be a recipe for disaster in future. However, with the integration of water into the “Climate change Action Agenda” (INBO, 2015), it is likely that future climate change adaptation strategies could take into account water resources management issues.

Future projections of the effects of climate change on water resources paint a grim picture of the future situation; particularly in regions with high population growth because of the effects associated with human activity (Haddeland et al., 2014; Kelley et al., 2015; McDonald et al., 2011). In some areas, particularly in the tropical regions (between 23°27′ north and south of the equator) and high latitude regions (beyond 60° north and south of the equator), rainfall extremes are expected to increase (Bates et al., 2008). Whereas increase in rainfall in these regions could improve the water resources situation there, excess rainfall could also result in flooding which could lead to loss of land, infrastructure and life. This could affect the livelihood of the affected communities.

On the other hand some areas, particularly sub-tropical regions (between 23°27′ – ≈35° north and south of the equator) and mid-latitude regions (between 30° – 60° north and south of the equator), are expected to experience reduced rainfall and longer periods between rainfall events (Bates et al., 2008). During periods of limited or no rainfall events, water consumption and evaporation could lead to a marked reduction in available water and drying out in some cases, hence resulting into drought. Absent or reduced runoff during such periods could also lead to reduced groundwater recharge which could result in the decline of groundwater resources. In regions, such as rural Africa, where groundwater is the primary source of drinking water (MacDonald et al., 2012), this could result in increased water stress during the dry seasons. This state of affairs is a cause for concern as it exposes society to risks associated with inadequate supply of water such as food insecurity, water borne and water related diseases, and starvation (Kharraz et al., 2012).

Whereas the decline in the quality and quantity of water resources may be difficult, but not necessarily impossible, to reverse, better management of available water resources could be key to avoiding further damage and mitigating water stress in the future. This could be achieved through measures that ensure sustainable development and management of available water resources. However, since availability of water resources is being affected by climate change, there is also need to simultaneously address the causes of climate change. Therefore "business-as-usual" approach to management of water resources is no longer acceptable and there is need for a more proactive approach to tackle the problem by involving all water users as agents of change (Briscoe and Porter, 2010; Rault et al., 2013; UN-Water, 2012; Spang, 2007).

2.2.2.2 Population Growth

The increasing global population is believed to be one of the main factors responsible for declining water resources (Gleick, 1998; Hanjra and Qureshi, 2010). As the global population grows, so does the demand for water because of the need to meet requirements such as drinking water, food production and energy production. These requirements are fundamental for the sustenance of the population (Flint, 2006; Hanjra and Qureshi, 2010; Population Action International, 2011; UNESCO, 2006; UN-Water, 2007; UN-Water, 2012; WWAP (United Nations World Water Assessment Programme), 2015).

However, as fresh water is taken out of the natural water system to meet these requirements it is often returned as wastewater; which undermines the quality of freshwater sources (Groll et al., 2015; Schwarzenbach et al., 2010). This is compounded by poor agricultural practices which allow agricultural waste products to get directly into the natural water system. The cumulative effect of this is a reduction of freshwater resources that are suitable for human consumption.

Whereas the natural water system is known to recover from pollution shock loads (Hammer and Bastian, 1989), the composition and concentration of the wastewater it receives compared to the volume of flow in the natural system, could determine the extent to which it recovers. As the water resources continue to decline their capacity to recovery from pollution could be affected. The cumulative effect of continued disposal of wastewater to such a receiving environment could lead to deterioration in the quality of water. Where such water also acts as a source for drinking water or municipal supply the deterioration in its quality could lead to an increase in the cost of treating it for supply to consumers. For example, more chemicals may be required for disinfection and this has a direct implication on the overall treatment costs. It is therefore important to ensure that the wastewater that is disposed of is adequately managed to minimise any deleterious effects on the receiving environment (Gücker et al., 2006).

As the global population continues to grow it is inevitable that the water resources situation could become dire in the future due to increasing demand, deteriorating quality and decreasing freshwater availability. The consequences of not taking appropriate action now could mean potentially huge costs for implementing strategies aimed at addressing the situation later on (Hanjra and Qureshi, 2010; Vorosmarty, 2000). Poorer countries could be hard hit by such a situation because they may not have the necessary resources required to implement such strategies. Because water plays a major role in economic development of any country, failure to implement strategies to address the water resources challenges could curtail economic growth of many poor countries (Vorosmarty, 2000).

2.2.2.3 Urbanisation

Urbanisation another factor that is believed to be exerting pressure on available freshwater resources (Comprehensive Assessment of Water Management in Agriculture, 2007; Srinivasan et al., 2013; McDonald et al., 2011). As the world continues to urbanise (see Figure 2.4 below), the rate of urbanisation is believed to be particularly highest in developing countries (Cohen, 2006; Jacobsen et al., 2012;

United Nations Department of Economic and Social Affairs Population Division, 2014).

The challenge with urbanisation is that it leads to concentration of water demand, and wastewater production, in one place. This is particularly problematic where shared water resources, such as rivers, are concerned. Withdrawing large volumes of water upstream to meet the demand of the urban centres could affect the users downstream. Similarly disposing wastewater from the urban centres upstream could affect the users downstream, especially if the wastewater is not adequately managed prior to disposal to the receiving environment (Groll et al., 2015). This could be a source of conflict between the upstream and downstream users (Groll et al., 2015). Involving both upstream and downstream users in the management of the shared water resources could be key to mitigating such conflicts.

Urbanisation and industrialisation often go hand in hand. Industries often tend to be setup in urban areas where infrastructure is established, labour is readily available albeit expensive, and market is easily accessible (Deichmann et al., 2008). The increasing rate of urbanisation in developing countries is therefore bound to lead to industrial growth as countries strive to meet the demand for goods and services of the growing population. This could inevitably result in the production of more solid and liquid waste which will be disposed of, treated or untreated, to the receiving environment. This poses a major threat to freshwater resources and calls for measures to mitigate the threats.

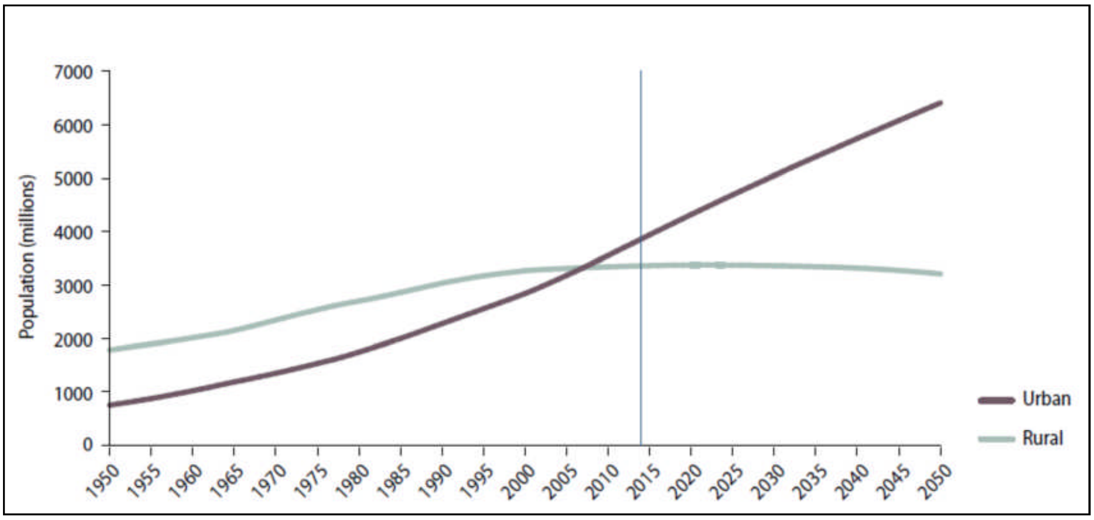


Figure 2.4: Urban and rural population of the world, 1950–2050

Source: United Nations Department of Economic and Social Affairs Population Division (2014)

2.3 Paradigm Shift in Water Resources Management

The common objectives regularly cited for managing water resources are twofold, all of which are critical for human and environmental sustainability. The first objective is to minimise the effects of too much water such as during floods, inadequate water supply such as during a drought and dirty water resulting from pollution (Loucks and Beek, 2005). All these states of water resources could potentially have devastating effects on both humans and the environment. The second objective is to optimise the availability of water for food production, domestic use, industrial use and ecosystems services. Identifying appropriate management interventions to achieve these objectives is therefore a critical component of water resources management.

In the last century the approach to water resources management was mainly through centralised, government-led efforts whereby individual sectors took care of their own water requirements without taking into account how the decisions they took to meet their water requirements impacted other water users (Liu et al., 2008). In areas where water resources were plentiful and of good quality water resources management was supply-driven, based on analyses carried out by water resources engineers and other specialised experts (Al Radif, 1999; Loucks and Beek, 2005). The supply-driven approaches often provided water for individual sectors without adequately considering the impacts of such actions on other users and on the health of the natural system (Keskinen, 2010; Liu et al., 2008). Whereas such approaches have undoubtedly brought about well-being for society, they have also created some environmental and social problems such as drying up of some water bodies; largely due to diversion of rivers that fed them for agricultural irrigation (NASA Earth Observatory, 2016; Notaras and Aginam, 2009; Micklin, 2007). Such approaches therefore had a limited view of the use, development and management of water resources and are not adequate to address the current water challenges (Agyenim and Gupta, 2012).

As water resources challenges began to mount, discussion on water issues received attention at international forums. Savenije and Van der Zaag (2008) and Rahaman and Varis (2005), discuss a chronology of international meetings and developments in which water was discussed. Key outputs from some of these meetings include the "Dublin Principles" (ICWE, 1992; Solanes and Gonzalez-Villarreal, 1999), adopted at the International Conference on Water and the Environment, held in Dublin in 1992. These became the guiding principles for water resources management. They are:

1) Fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment
2) Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels
3) Women play a central part in the provision, management and safeguarding of water
4) Water has an economic value in all its competing uses and should be recognised as an economic good.

These principles also formed an important input in the UN Conference on Environment and Development, held in Rio de Janeiro in 1992, that resulted in the adoption of Chapter 18 of Agenda 21 (UN, 1992). This chapter was concerned with the "protection of the quality and supply of freshwater resources through application of integrated approaches to the development, management and use of water resources" (UN, 1992).

Other key outputs from some of the meetings where water was discussed were:

- Organisations such as the Global Water Partnership (GWP) and the World Water Council (WWC) were established in 1996, to coordinate management of water resources worldwide.
- The Millennium Development Goals (MDGs) were adopted by world leaders during the United Nations Millennium Summit in New York in 2000.
- The concept of Integrated Water Resources Management was adopted at the Second World Water Forum held at The Hague in 2000.
- The Sustainable Development Goals (SDGs) were adopted by world leaders at the United Nations Sustainable Development Summit in New York in 2015. These goals include a dedicated goal for water and sanitation that sets out to "ensure availability and sustainable management of water and sanitation for all" (UN-Water, 2015).
- Water was integrated into the Climate change Action Agenda at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21/CMP11) in Paris in 2015 (INBO, 2015).

The integration of water into the climate change action agenda (INBO 2015), and the formulation of a dedicated goal for water as one of the SDGs (UN-Water 2015), is a clear indication of the importance that the international community has attached to the management of water resources. This comes against the backdrop of mounting water resources challenges (Gleick and Ajami, 2014; Mekonnen and Hoekstra, 2016), and a recognition that water plays a critical role in agricultural, industrial, social and economic development.

Because IWRM is believed to hold potential for water resources management, it has now been set as a target under the goal for water and sanitation of the SDGs. It is therefore critical that adequate attention is given towards enhancing the implementation of IWRM.

In response to the inadequacies of the previous water resources management approaches, there has been an increased recognition of a multidisciplinary approach to water resources management (Bunclark et al., 2011; Butterworth et al., 2010; ICWE, 1992; UN-Water, 2007). This acknowledges the fact that no single profession or set of experiences may be able to provide the knowledge required to resolve the world's water challenges. Instead a concerted effort is required from various disciplines and experiences (Bielsa and Cazcarro, 2014). This comes in light of a growing awareness and understanding that fresh water is a limited resource and its availability is under threat from competing requirements and demands of a growing global population as well as the effects of climate change (Haddeland et al., 2014; Hanjra and Qureshi, 2010). Consequently the concept of integrated water resources management has been widely promoted as an approach that could ensure sustainable management of available water resources (Al Radif, 1999). This concept incorporates the social, economic and ecological aspects of water and emphasises the importance of stakeholder involvement in the management of water resources.

2.3.1 The Concept of Integrated Water Resources Management

The concept of integrated water resources management (IWRM) is believed to have first emerged at the United Nations Conference on Water in the Mar del Plata in 1977 (Biswas, 2004; Petit and Baron, 2009; Rahaman and Varis, 2005; Savenije and Van der Zaag, 2008). However, it was not until the year 2000 that the concept was formally endorsed, at the Second World Water Forum held at The Hague, as a means of ensuring better water resources management. It was believed that the concept had potential for realising sustainable development, management and use of available water resources. Since then the concept has grown in popularity to the extent of being set as a target under the goal for water and sanitation of the SDGs (UN-Water, 2015).

Integrated water resources management seeks to ensure coordinated development, management and use of available water resources. The concept takes into consideration the social, economic and environmental concerns, and incorporates good governance (Agyenim and Gupta, 2012; Al Radif, 1999). IWRM also ensures a multidisciplinary approach to water resources management by incorporating expertise from different sectors to address the various challenges in the management of water resources. This is a departure from the approaches of the past where water resources were managed in a fragmented individual sector basis (Liu et al., 2008).

The IWRM approach is therefore relevant for addressing the current water challenges that require expertise from different disciplines (Agyenim and Gupta, 2012; Bunclark et al., 2011; Butterworth et al., 2010; ICWE, 1992; UN-Water, 2007).

However, despite decades of popular support among proponents, the IWRM concept has not lived to its expectations. The concept has had a dismal implementation history and examples of successful implementation from which to draw any recognised best practice are scarce. Consequently the concept has drawn criticism (Biswas, 2004; Biswas, 2008; Jeffrey and Gearey, 2006; Medema et al., 2008; Rahaman, 2009) for failure to realise the claimed benefits of better water resources management.

2.3.1.1 IWRM Implementation Challenges

IWRM's implementation challenges are largely twofold. On one hand there is inadequate guidance on how to translate the theoretically agreed principles, on which the concept is based, into reality. On the other hand there is no universally acceptable definition of the concept. These challenges are explored in more detail in the following subsections.

Interpretational Challenge

One of the main challenges facing IWRM relates to a lack of a universally recognised definition of the concept. This poses major implementation challenges as it exposes the concept to different interpretations and implementation approaches (Hering and Ingold, 2012; Biswas, 2008; Petit and Baron, 2009; Agyenim and Gupta, 2012). This could subsequently lead to failure to address the real issues the concept was intended to address. To try and address this challenge the GWP came up with a definition based on the "Dublin Principles" of 1992. It defined IWRM as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Agarwal et al., 2000). This definition is the one that is now widely used.

Despite this attempt to address the definitional challenge, there is still no agreement as to what IWRM actually entails. Critics of the concept seem to concentrate their arguments on the issue of integration (Biswas, 2008; Butterworth et al., 2010; Medema et al., 2008; Watson et al., 2007; Biswas, 2004). They argue that what needs to be integrated is not clear since there are so many aspects to water resources such as quality, quantity, surface water, ground water, urban water, different types of uses and users etc. They also argue that integrating the management of two or more resources, such as water and land, could be almost impossible as would be the task of integrating the departments responsible for their management.

Whereas these arguments refer to “integration”, the definition provided by the GWP refers to “coordination” and does not talk about integration. Even the “Dublin Principles”, on which the GWP’s definition of IWRM is based, do not refer to integration either implicitly or explicitly. Coordination and integration are two different issues that may need to be carefully interpreted in the context of IWRM. Coordination of water and land issues, for example, can be achieved without necessarily integrating the departments responsible for their management. What would be required is to put in place a coordination framework between the different sectors.

It is, therefore, apparent that the IWRM concept has, to some extent, been misinterpreted and this could partly be responsible for some of the implementation challenges faced. Clear guidance on the key elements of the concept, and how they could be achieved, is necessary to enhance its implementation and avoid further misinterpretation. These could also provide a sound basis against which implementation of the concept could be assessed. Short of this the concept runs the risk of remaining “elusive and fuzzy” (van der Zaag, 2005), and could continue to be poorly understood and interpreted by the different users.

Inadequate Guidance

In order to guide the implementation of IWRM at catchment level the GWP developed user handbooks (GWP, 2004; GWP, 2009; Agarwal et al., 2000). The handbooks give information on the important elements of IWRM and what is expected in order to implement IWRM. However, they fall short of providing the guidance required on how those expectations may be translated to reality.

The GWP, however, recognises the fact that a “one size fits all” approach does not apply in water resources management due to the magnitude and diverse nature of the challenges involved in different local contexts (GWP, 2017). This suggests that individual countries could formulate their own approaches to meet their individual needs. The danger however is that: (i) there is a risk of complacence and therefore little or nothing gets done, and (ii) there is a risk of misinterpreting the concept and hence failure to implement it as expected. Some generic guidelines or insights of how to translate the key elements of IWRM into reality could be helpful. These would then act as a point of departure from which individual countries would formulate customised approaches to meet their specific local needs.

Successful implementation of IWRM entails bridging the gap between the theoretical principles on which the concept is based and their practical implementation (Rahaman, 2009; Wilkinson et al., 2016). However, in order to achieve this it is essential that the contextual conditions support implementation of the IWRM principles. To that end the GWP suggests instituting appropriate reforms to create an enabling environment with clearly defined institutional roles and practical management instruments (GWP, 2004).

Most countries that have attempted to implement IWRM have taken that route and instituted policy and institutional reforms to create an enabling framework to support implementation of the IWRM principles (Agyenim and Gupta, 2012; Anokye, 2013; Petit and Baron, 2009; Rahaman, 2009). However, emphasis on institutional reforms has in some cases resulted in the creation of parallel institutions all carrying out the same functions. In India, for example, it is reported that new water institutions were created alongside existing government institutions (Agyenim and Gupta, 2012; Gupta, 2010). In the case of Brazil, the institutional and regulatory reforms have created institutions that favour the political players at the expense of the stakeholders (Ioris, 2008). It is, therefore, important to assess the extent to which such reforms have been successful in creating an enabling framework for IWRM implementation so as to provide knowledge and evidence necessary to support the case for such reforms. It could also be helpful for other countries considering carrying out similar reforms in future.

One of the challenges that weaves through most of the IWRM literature relates to involvement of stakeholders in the management of water resources (Agyenim and Gupta, 2012; De Stefano, 2010; Petit and Baron, 2009; Teodosiu et al., 2013). Stakeholder participation in water resources management is a key requirement of IWRM and it relates to two of the IWRM guiding principles. One way of translating this requirement into practice is by finding mechanisms through which stakeholders can constructively participate in the management of water resources.

Despite the implementation challenges there is still a common understanding and a general agreement on the fundamental principles underlying IWRM, and the potential it holds for water resources management, that cannot be adequately achieved through the fragmented management approaches of the past (Anderson et al., 2008; Cook and Spray, 2012; Watson et al., 2007). This is a position that seems to be supported by world leaders who met and adopted the SDGs at the United Nations Sustainable Development Summit in New York in 2015.

2.4 Stakeholder Participation

A stakeholder is generally defined as a person, or a group of people, that is affected by or can affect a given situation (Freeman, 2010; Kessler, 2004). On the other hand participation is considered as the “active contribution by people to development, and involvement of people in decision making at all levels of society” (United Nations report (1979:225), cited in Desai (2002)). Stakeholder participation, therefore, refers to the active involvement of people in addressing issues that affect their society. Stakeholder participation is intended as a means of enhancing decision-making processes and the quality of decisions by ensuring that the decisions made are based on, and influenced by the views, concerns, knowledge and experiences of the people affected by such decisions.

Table 2.1: Levels and aims of stakeholder participation

Level	Type	Aim
1	Inform	To provide stakeholders with balanced and objective information to assist them in understanding the problem, alternatives, opportunities and/or solutions
2	Consult	To obtain stakeholder feedback for decision makers on analysis, alternatives and/or decisions
3	Involve	To work directly with the stakeholders throughout the process to ensure that their concerns and aspirations are consistently understood and considered in decision making processes
4	Collaborate	To partner with the stakeholders in each aspect of the decision including the development of alternatives and the identification of the preferred solution
5	Empower	To place final decision making in the hands of the stakeholders

Adapted from: Arnstein (1969) and Gray (2013)

Stakeholder participation is often viewed with respect to the level of involvement in decision making or the purpose for which stakeholder involvement is sought (see Table 2.1). The most common approaches to stakeholder participation include: sensitisation, consultations, public hearings and focus group discussions. However, irrespective of the purpose of the process and the approach adopted, there are two main routes through which real active stakeholder participation can be achieved. These are through the decision making process and through the process of implementing those decisions (Desai, 2002; Agarwal et al., 2000). Through these routes stakeholders can make meaningful contributions that can shape the overall outcome of a participatory process. These routes can ensure a greater level of stakeholder involvement.

2.4.1 Benefits of Stakeholder Participation

There is an increasing call for stakeholder participation in decision making processes. In developing countries this has become an indispensable component of almost every development programme or project funded by international financial institutions (Desai, 2002; Morinville and Harris, 2015). It is believed that involving stakeholders in decisions that affect them is beneficial both to the individual stakeholders and to the community. The benefits that are regularly cited in this regard are categorised as normative, substantive and instrumental benefits (Blackstock et al., 2007; Chilvers, 2010; Fiorino, 1990; Stirling, 2006).

The claimed normative benefits focus on enhancing empowerment, democracy and equity. It is believed that participation empowers people to have a say in decisions that affect them and gives the marginalised groups in society a voice (Anokye, 2013; Arnstein, 1969; Kessler, 2004; Chilvers, 2010). This could ensure that all sections of society are represented in decision making. It is also argued that people have a democratic right to participate in the decisions that affect them and their community, and that by participating democracy is enriched (Chilvers, 2010; Fiorino, 1990). It is believed that participation enhances the legitimacy of the decisions made, and increases the likelihood that such decisions will be better implemented and managed (Carr et al., 2012; Carr, 2015; Leidel et al., 2012; Voinov and Bousquet, 2010).

The claimed substantive benefits focus on enhancing knowledge. It is believed that stakeholder participation can empower participants through co-production of knowledge, which promotes social learning (Blackstock et al., 2007; Pahl-Wostl et al., 2007). Social learning is where participants learn from each other thereby improving their own understanding of issues around them. It is also believed that learning from each other could lead to growth of relationships amongst stakeholders and minimise possible conflicts (Kessler, 2004; Reed, 2008; Stringer et al., 2006). It is further argued that stakeholder participation enables development of interventions that are better adapted to the local conditions by taking into account the interests and concerns of the local community (Dougill et al., 2006; Kessler, 2004; Reed, 2008). This suggests that participation has potential to enhance the decision making process.

The claimed instrumental benefits focus on enhancing trust, credibility and acceptability of decisions and policies. It is argued that participation could increase stakeholder trust in the decisions made especially when: (i) participants perceive the participatory process to be fair and transparent, and (ii) participants feel that their input was valued (Kessler, 2004; Reed, 2008). It is also believed that participation can facilitate integration of perceptions, knowledge and experiences of different stakeholders into meaningful outcomes (Carr et al., 2012; Gaddis et al., 2010). This could ensure that decisions are made from an informed point of view.

However, relatively few studies have attempted to assess the extent to which many of the claims made for stakeholder participation are realised, particularly in the context of water resources management (Young et al., 2013; Carmona et al., 2013; Maskrey et al., 2016). As a consequence there is little evidence to support most of the claims made. Such assessment would provide information that could support the case for participation in water resources management and help in improving future participatory efforts.

2.4.2 Stakeholder Participation Challenges

2.4.2.1 Contextual Challenges

It is important to recognise that stakeholder participation always takes place in a particular physical context. Because of this, it is bound to be influenced by the social, political, economic and environmental factors prevailing in that context. For example, owing to power differentials that exist in society along class, gender and ethnic lines, there are often bound to be tensions, rifts and power struggles among stakeholders (Perkins, 2011). These could escalate if the participatory process is not well managed, especially where some stakeholders are excluded from participating (Glicken, 2000). Such cases may require conflict management to overcome tensions among stakeholders. The tensions and power struggle among stakeholders could impede the participatory process.

Similarly, because of the multidisciplinary nature of water resources management issues a diverse range of stakeholders, sometimes with divergent interests and opinions, may be involved. Consequently disagreements and power struggle among stakeholders could arise. These need to be recognised and appropriately managed so as to avoid the risk of the process being manipulated by powerful or influential stakeholders; which could lead to unintended negative consequences such as legitimisation of decisions favoured by few individuals (Carr et al., 2012; Sgobbi and Giupponi, 2007).

Politics could influence participation in a number of ways. For example, when it comes to control of decisional processes politicians may not be willing to relinquish some of their decision making power to stakeholders and could, therefore, frustrate participatory efforts. On the other hand the prevailing political environment could restrict stakeholder participation, especially if it does not encourage people to freely express themselves.

In Tanzania, where examples of successful stakeholder participation in water resources management have been reported (Dungumaro and Madulu, 2003), the prevailing social and economic development policies favour participation. These policies are based on the concept of "*Ujamaa"* (familyhood or brotherhood) (Cornelli, 2012), which promotes togetherness and "an attitude of mind ….needed to ensure that the people care for each other's welfare" (Nyerere, 1977 cited in Cornelli (2012)). This suggests that an enabling environment may be necessary for participation to take place.

In cases where administrative structures are centralised the decision making process tends to be centrally controlled (Oakley, 1991). Such structures favour top-down decision making processes. This could be an obstacle to stakeholder participation.

Participatory processes are often organised by governments or their agencies to explore stakeholders views when there are issues of concern. Stakeholders therefore attend as invitees. This poses a risk of the participatory process being manipulated and used as "a means for top-down planning to be imposed from the bottom-up" (Hildyard *et al.* 2001, cited in Sgobbi and Giupponi (2007)). This challenge is compounded by the absence of clearly defined mechanisms for identifying relevant stakeholders (Sgobbi and Giupponi, 2007); a situation that could be exploited to involve individuals who will support the initiatives proposed by the organisers of the process.

2.4.2.2 Inherent Challenges

A participatory process involves identifying and mobilising relevant stakeholders to be involved in the process, and holding meetings with them. Organising a participatory process can be time consuming, costly, and delays the decision making process (Anokye, 2013; Carr et al., 2012; Kessler, 2004; Perkins, 2011). A participatory process could, therefore, be an inefficient way of utilising resources, particularly if the participating stakeholders arrive at the same decision that could otherwise have been arrived at by a single person (Irvin and Stansbury, 2004).

In addition there are no clearly defined and agreed mechanism for (i) identifying and selecting stakeholders to be involved in the participatory process, (ii) constructively engaging stakeholders during the process, and (iii) integrating local and expert stakeholders' views, knowledge and experiences (Blomquist and Schlager, 2005; Sgobbi and Giupponi, 2007; Kessler, 2004). In the case of water resources management these challenges could be complicated by the diversity of stakeholders in a catchment, all with different and sometimes conflicting interests, perspectives and priorities.

Despite these challenges, there is still increasing emphasis on stakeholder participation in decision making processes. However, without sound guidance, and appropriate tools, for implementing stakeholder participation it could be hard to realise beneficial outcomes from participation.

2.4.3 Approaches to Stakeholders Participation

Several approaches have been used to implement stakeholder participation. The choice of approach is largely guided by the purpose of the participatory process (Kessler, 2004). The approaches include: sensitisation workshops, public hearings, focus group discussions, participatory modelling, and mobile data collection. These are discussed briefly in the following subsections.

2.4.3.1 Sensitisation Workshops

This is an approach that is often used to provide information to stakeholders in a community. This approach ensures that stakeholders are well informed and therefore knowledgeable about issues taking place in their community. Possession of relevant information empowers stakeholders to make informed decisions. The downside of sensitisation workshops, however, is that the flow of information is often one-way; from the facilitator to the participants (Arnstein, 1969). This approach therefore gives little or no room for stakeholders opinions to be heard. This means that with this approach stakeholders have limited opportunity to influence decisions that affect them.

2.4.3.2 Public Hearings

These are often used as forums for consulting stakeholders. As the name suggests, they are open to the public and no pre-selection of participants is required. Public hearings are often initiated by local authorities. They allow local authorities to provide information to the stakeholders and also allow stakeholders to comment. Public hearings therefore provide forums in which stakeholders opinions can be heard.

However, public hearings can be dominated by hidden interests and do not offer assurance that stakeholders opinions and interests will be taken into account when the final decisions are made (Arnstein, 1969; Kessler, 2004). Because they are often large gatherings, they can easily intimidate some people who are not comfortable speaking out in public (Anokye, 2013; Mostert, 2003). They may also not allow sufficient time for deliberating on key issues (Konisky et al., 2001). These issues pose significant obstacles that could limit meaningful dialogue from taking place using this approach.

2.4.3.3 Focus Group Discussions

These are facilitated group discussions that are often used to discuss a specific topic or subject. They usually involve a small group of people, the composition of which is often carefully constituted with the aim of getting the best from the discussions (Anokye, 2013; Gill et al., 2008). The strength of focus group discussions lies in their ability to promote open and interactive dialogue among participants (Anokye, 2013). This enables stakeholder views and concerns to be heard.

However because focus group discussions only involve a small number of people, the views, knowledge and experiences shared may not be representative of those of the wider stakeholder base in the community. This could be a challenge if the issue under consideration affects the entire community as is often the case with shared resources. It may therefore necessitate holding several separate focus group discussions so as to get views that are fairly representative of those held by the wider stakeholder community. This could make the exercise costly.

2.4.3.4 Participatory Modelling

This approach is almost similar to focus group discussions. The difference lies in the use of models as tools for facilitating discussions among participants in participatory modelling. There are several participatory modelling methods all with different names and foci. However, Participatory Modelling is the general name that is commonly used for all of them. Some of these methods include Mediated Modelling, Group Model Building, Shared Vision Planning, and Companion Modelling. All these methods are basically similar in that they all involve stakeholders in a traditional modelling process.

Participatory modelling is believed to have the capability to integrate local and expert stakeholders' views, knowledge and experiences to support decision making (Carmona et al., 2013; Krueger et al., 2012; Voinov and Bousquet, 2010; Voinov et al., 2016). This capability, it is argued, allows participants to works towards goals of common interest (Carmona et al., 2013; Gaddis et al., 2010). This could enhance the decision making process by ensuring that the decisions made are based on a shared understanding of issues.

It is also believed that participatory modelling has an educational potential that offers opportunity for mutual learning among participants and between the modeller/facilitator and participants (Carmona et al., 2013; Gaddis et al., 2010; Liu et al., 2008; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010; Winz et al., 2009; Zorrilla et al., 2010). This could enable the modeller/facilitator to gain a broader and more balanced view of issues under consideration. It could also enable the participants to gain a better understanding of the issues under consideration as well as the possible consequences of any decisions that may be taken. The improved understanding could also empower participants to make informed decisions.

However, like focus group discussions, participatory modelling only involves a small number of people whose views, knowledge and experiences may not be representative of those of the wider stakeholder base in the community. This may require several participatory modelling sessions to be conducted to obtain views and experiences that are fairly representative of those held by the wider community.

2.4.3.5 Mobile Data Collection

This is an approach that utilises mobile phones, or similar portable devices, to involve stakeholders in collecting and transmitting data of particular interest. Mobile data collection methods have proved popular in the agricultural and health sectors, especially in developing countries. In the agricultural sector, mobile phones are being used for monitoring and reporting prices of commodities in the market (Asare-Kyei, 2013; Muto and Yamano, 2009). This has encouraged farmers and traders to carry out market surveys and to participate in finding appropriate markets for their produce. As a consequence it has enabled them to get fairer prices for their produce.

In the health sector, mobile data collection methods are being used for collecting surveillance and monitoring data for health related issues (Lozano-Fuentes et al., 2012; Tomlinson et al., 2009; WHO, 2013). Participants are recruited to report incidents of disease outbreaks or potential risks in the communities thereby providing timely information for necessary actions to be taken. The method has also been used for monitoring patients’ response and adherence to treatment by collecting feedback from the patient’s and/or their caregivers (Blake, 2008; Gaggioli et al., 2013; Haberer et al., 2010).

Mobile data collection therefore presents an opportunity for active stakeholder participation in issues in their communities. It also appears to be a more convenient method because the participants often live in or close to the places where the data required is found.

This approach, however, has some inherent challenges. These include: (i) the high initial cost of the mobile devices, (ii) the need for user training, (iii) the risk of loss of data if the device is lost or damaged before data is transmitted, and (iv) input errors on the part of the data collector (Tomlinson et al., 2009). In addition, mobile data collection does not offer opportunity for stakeholders to come together for dialogue. This limits the opportunity for stakeholders to share their views, knowledge and experiences.

2.4.4 Stakeholder Participation in Water Resource Management

In the field of water resources management, the concept of stakeholder participation is underpinned by statutory frameworks (ICWE, 1992; UN, 1992; UNESCO, 2006; EC, 2000). It is increasingly recognised that expert knowledge alone is inadequate for informing decisions needed to address the current water challenges especially those that relate to specific local contexts (Cinderby and Forrester, 2005; Maskrey et al., 2016; Robbins, 2000; World Water Council, 2009), and therefore a concerted effort, involving both local and expert knowledge and experiences, is required. It is also increasingly acknowledged that the "one size fits all" approach cannot be applied to water resources management, and therefore solutions to water resources issues should be flexible and adapted to specific local or regional circumstances (World Water Council, 2009). This implies that area specific water related issues will require area specific solutions.

It is believed that stakeholders are better placed to identify more practical area-specific solutions because of their experience with issues in their areas (Bunclark et al., 2011; Voinov and Bousquet, 2010). This suggests that area specific water issues could be better addressed by adopting a participatory approach which could enable stakeholders to participate in identifying water issues as well as possible strategies for resolving them. However, efforts to involve stakeholders in water resources management have often registered little success (Agyenim and Gupta, 2012; Irvine and O'Brien, 2009; Jingling et al., 2010; Teodosiu et al., 2013; De Stefano, 2010). As a consequence examples from which to draw any useful knowledge and insights about participatory processes and any beneficial outcomes they can deliver are scarce.

Given the global concerns over diminishing water resources, particularly in light of climate change and the increasing global population, examples of successful participatory processes could provide useful lessons that could guide other participatory efforts and enable beneficial outcomes to be harnessed. Such examples could also provide a basis for supporting the case for participation. Scarcity of such examples is therefore a significant constraint to promoting future participatory efforts in water resources management.

Previous studies on stakeholder participation in water resources management have largely focused on (i) examining how participation has been implemented in the management water resources (Anokye, 2013; Garis et al., 2003; Irvine and O'Brien, 2009; Jingling et al., 2010; Teodosiu et al., 2013), (ii) development of decision support systems to support decision making in water resources management (Bromley et al., 2005; Carmona et al., 2009; Chan et al., 2010; Chen et al., 2004; Giné Garriga et al., 2009; GWP, 2013; Henriksen et al., 2007; Mysiak et al., 2005), and (iii) the challenges of implementing IWRM (Agyenim and Gupta, 2012; Funke et al., 2007; Gallego-Ayala and Juízo, 2011; Rahaman, 2009; Wagdy and AbuZeid, 2006; Stucki, 2011). Few studies have attempted to assess the extent to which the theoretical concept of IWRM has been translated into practice (Jeffrey and Gearey, 2006; Wilkinson et al., 2016), or assess whether participation does actually deliver benefits for water resources management (Carmona et al., 2013; Maskrey et al., 2016). There is, therefore, scarcity of knowledge, experiences and insights that could: (i) provide guidance on how to effectively involve stakeholders in water resources management, and (ii) provide a sound basis for supporting the case for stakeholder participation in water resources management.

The need for stakeholder involvement in the management of water resources is a key requirement of IWRM. As the water resources challenges continue to mount and more countries adopt the IWRM concept to address these challenges there is a strong motivation to improve stakeholder participation in the management of water resources. However, guidance on how stakeholders may be effectively involved in the management water resources, and the benefits that their involvement can deliver, is inadequate. As a consequence there is a variation in the nature of participation across different water resources management efforts ranging from stakeholder sensitisation (Jingling et al., 2010) to involvement of stakeholders in problem identification, strategy formulation and implementation (Dungumaro and Madulu, 2003).

2.5 Chapter Summary

Literature on the state of global freshwater resources shows that there is a global problem of declining freshwater resources largely due to increased demand for water from the growing global population, pollution, and climate change. Inevitably cases of water scarcity are on the increase in many parts of the world. Consequently there has been a call to manage the available water in a sustainable manner. Hence there has been a paradigm shift in the management of water resources from the fragmented supply-driven sectoral approaches of the past to coordinated demand-driven integrated approaches. To that end the concept of integrated water resources management has been adopted and widely promoted as a means of realising sustainable management of the available water resources. However, despite decades of popularity the concept has not lived to its expectations and has had a dismal implementation history.

One of the key requirements of IWRM is the participatory involvement in the management of water resources. The intention is to enhance the decision making process by ensuring that the decisions made are based on, and influenced by the views, concerns, knowledge and experiences of the people affected by such decisions. It is believed that by so doing the decisions made will be relevant to the specific local contexts and increases the chances of their successful implementation. However, efforts to involve stakeholders in water resources management have often registered little success.

There are some claimed benefits for stakeholder participation which are generally categorised as normative, substantive and instrumental. However, relatively few studies have attempted to assess the extent to which many of the claims made for participation are realised, particularly in the context of water resources management.

Some challenges with participation have been recognised. Participatory processes do not occur in a vacuum and as a result of this they are bound to be influenced by the social, political, economic and environmental factors prevailing in a particular context where they take place. Participatory processes are also time consuming, costly to implement, and delay decision making. However, despite these challenges there is still increasing emphasis on stakeholder participation in decision making processes.

The approaches that are commonly used for stakeholder participation are: sensitisation, consultation, public hearings, focus group discussion, mobile data collection, and participatory modelling. These have had varying degrees of success in ensuring that stakeholders views and concerns are heard. The participatory modelling approach is gaining popularity because it is believed to hold potential to support stakeholder involvement in the management of natural resources. However, that potential has not been fully exploited in water resources management. Mobile data collection is particularly popular in the agriculture and health sectors, especially in developing countries. However, it has hardly been applied in the field of water resources management.

Chapter 3

Approach and Methodology

This chapter describes the approach and methodology used in this research. The description covers the research approach, methods of data collection and analysis, and the evaluation process. It also highlights the ethical issues considered and the data protection measures taken.

3.1 Research Approach

This study set out to investigate the potential for participatory modelling and mobile data collection to enhance implementation of IWRM. This involved identifying and selecting participants to take part in a participatory modelling exercise and mobile data collection. It also involved developing a mobile data collection system.

The philosophical basis for this research was grounded on pragmatism in the sense that attention was focussed more on the research problem and finding possible solutions. The pragmatists recognise the fact that research takes place in a real-world environment with the intention of solving real-world problems and as such multiple methods of collecting data may be required so as to gain a comprehensive understanding of the problem under study (Creswell, 2014; Creswell and Clark, 2014; Patton, 2002). This approach helps improve understanding of processes and individual actions within a given context and is valuable for development of interventions (Baxter and Jack, 2008; Merriam, 1998).

This research used a mixed methods approach. This is an approach that involves collecting and analysing both qualitative and quantitative data at the same time (Creswell, 2014; Yin, 2014). This approach was found appropriate because a combination of both types of data was necessary for answering the research questions and interpreting the results, hence ensuring a comprehensive account of the research problem. The use of both qualitative and quantitative data was planned from the outset and the procedures for data collection were implemented as planned.

The research design therefore fitted within the fixed mixed methods design approach (Creswell and Clark, 2014).

The steps taken in carrying out this study are summarised in Figure 3.1 below. A brief description of the steps is presented thereafter.

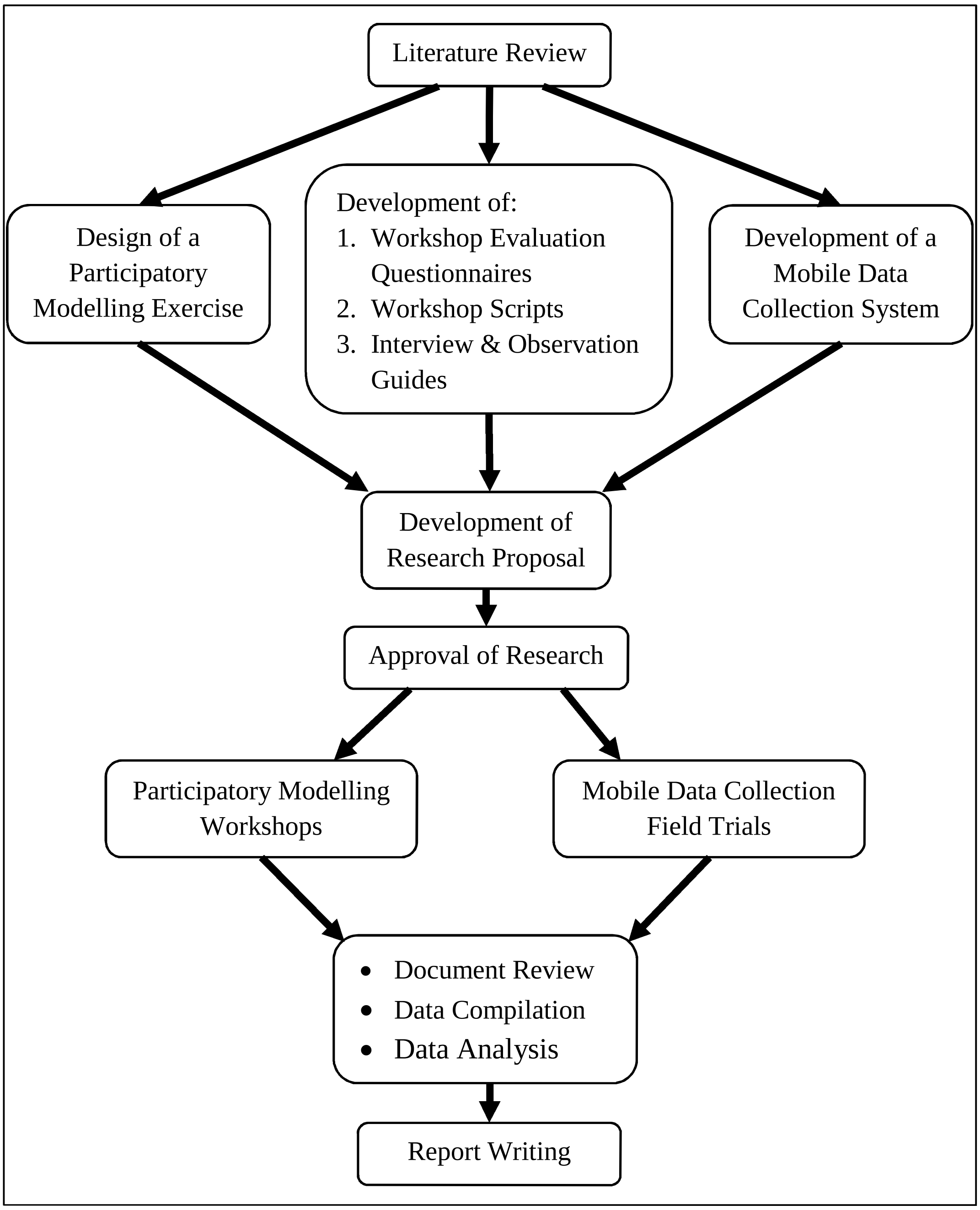


Figure 3.1: Research flow chart

3.1.1 Review of Literature

The literature that informed this study was gathered, and analysed, from multidisciplinary works produced in recent years covering the aspects of: (i) the state of global water resources, (ii) integrated water resources management, (iii) stakeholder participation in water resources management, (iv) participatory modelling, and (v) mobile data collection. The Web of Science, an online scientific citation indexing service with access to interdisciplinary research in multiple data bases, was used as the main source of the literature reviewed. The searches were conducted using a set of predefined keywords and were restricted to articles published in English.

Within the Web of Science, the search criteria were restricted to the Scientific Citation Index Expanded and Social Science Citation Index citation databases, as these were the databases that covered the subject area of interest. The search results obtained were analysed and ranked by research area. This generated a list of publications that were then selected for review.

The publications selected using this search strategy were supplemented by those recommended by colleagues and supervisors, and those obtained from the bibliographies of the selected publications.

3.1.2 Research Approval

Since the study involved interaction with people, formal approval of the study was required before data collection could start. This was sought and received from the Faculty Research Ethics Committee (see Appendix A). The study was conducted in Uganda where a research approval was required by government before conducting any study in the country. This approval was sought and received from the Uganda National Council for Science and Technology (see Appendix B).

3.1.3 Selection of Participants

In participatory modelling, the model building exercise is essentially driven by the participants. As a result of this, the outcomes of the modelling exercise will reflect their knowledge and experiences. It is therefore important to ensure that participants with broad and diverse knowledge and experiences of issues to be considered are identified and involved in the exercise (Bryson, 2004; Reed et al., 2009; Maskrey et al., 2016).

Participants for the study were selected based, primarily, on how much their activities were affecting or were affected by the state of water resources in the catchment. Such participants were considered to be “information rich” and could therefore provide crucial information required for the study. A purposive sampling method was used to guide in selecting relevant participants. Purposive sampling is a deliberate selection of specific participants because of their capacity to provide crucial information to enable a study to be conducted in depth (Patton, 2002).

Purposive sampling was used because some participants were considered to be more knowledgeable than others by virtue of their experience and/or education and therefore such individuals could provide better insight for the study (Bryson, 2004; Thomas, 1993). The emphasis of purposive sampling is on quality rather than quantity. This was important for this study as it sought to ensure that those stakeholders with broad and diverse knowledge and experience of water resources issues in the catchment were identified and involved in the modelling exercise.

Drawing on guidance from literature (Chevalier and Buckles, 2008; Gray, 2013), a checklist was developed to help in analysing and identifying participants. This was meant to avoid bias and ensure that key participants were not unintentionally excluded. It also helped in categorising the stakeholders that were identified according to their knowledge, experiences and expertise as shown in Table 3.1. The following questions adapted from Chevalier and Buckles (2008) and Gray (2013), were used in the checklist to guide the selection process:

- Which government department in the area is officially responsible for water resources management?
- Which individuals, organisations, businesses or industries will be affected by any decisions on water resources in the area?
- Are there any water-related research, development or conservation projects in the area?

- Which local non-government organisations (NGOs) operating in the area have interest in water resources?
- Who manages the organisations with interest in water resources?
- Who is influential in the area and in the local communities?
- Who has been involved in water resources management in the past?
- Who can obstruct a decision if not involved?
- Which individuals have expertise or experience with water resources issues in the area?

Table 3.1: Categories of stakeholders identified and involved in the study through workshops and/or interviews

Category	**Modelling Workshops**	**Interviews**
Government department responsible for water resources management	X	X
Individuals, organisations, businesses or industries affected by any decisions on water resources in the area	X	X
Water-related research, development or conservation projects in the area	X	X
Local non-government organisations (NGOs) with interest in water resources	–	X
Managers of organisations with interest in water resources	X	X
Influential individuals in the local communities	–	X
Individuals who have been involved in water resources management in the past	X	X
People who can obstruct a decision if not involved	–	X
Individuals with expertise or experience in water resources issues in the area	X	X

Where: X means stakeholders were involved, and – means stakeholders were not involved

The purposive sampling method was complemented by the snowball technique (Goodman, 1961), to identify the potential participants. Using the checklist as a reference/guide a local expert on water resources issues in the catchment was contacted to help in identifying potential participants. The local expert was identified through a contact at the Directorate of Water Resources Management in the Ministry of Water and Environment.

The potential participants identified with the local expert were contacted and preliminary consultations were conducted with them. The purpose of these consultations was: (i) to explain the aim and method of the research, (ii) to help identify other potential participants, and (iii) to build rapport. These consultations were also used to collect some background information on common water resources issues in the catchment and to identify what stakeholders considered as the major water resources problem.

The use of a checklist in these meetings helped to avoid bias that could arise from the social networks of the individuals met. After the first three consultation meetings the same names of potential participants kept coming up and there was not much additional information being gained from the subsequent meetings. Further consultation meetings were then stopped after the sixth meeting.

After the first participatory modelling workshop participants were asked to identify any other stakeholders that they felt should be involved in addressing the water issues identified during the workshop. This was meant to ensure that all relevant stakeholders were identified and involved so as to increase the knowledge base. The new stakeholders identified at this stage were involved in interviews where data was collected for model validation. They were not involved in the workshops because by then workshops had already started and introducing new participants could have delayed the exercise because the new participants would have to be inducted into the process so as to bring them to the same level as the others.

Utilising the purposive sampling method and the snowball technique resulted in identification of a group of 33 participants. The group was divided into two subgroups according to their availability to take part in the study. One group (15 participants) was invited to take part in the model building exercise while the other group was invited for interviews. The distribution of participants between groups according to the categories is shown in Table 3.1.

3.1.4 Choice of Modelling Tool

The objectives of the modelling exercise were used as key factors in determining the type of modelling tool used. This was important for ensuring constructive engagement with the participants. To that end the following requirements were considered vital:

(i) ability to integrate both qualitative and quantitative data
(ii) flexibility to accommodate changes
(iii) suitability for scenario-based analysis
(iv) ability to consider uncertainty

Following a review of literature the characteristics of two modelling tools commonly used in integrated assessments were assessed in relation to the requirements stated above (see Table 3.2). These tools were System Dynamics and Bayesian networks. Following the assessment the Bayesian networks was selected because it was found to meet all the requirements stated above unlike System Dynamics (Bromley, 2005; Bromley et al., 2005; Carmona et al., 2013; Jakeman et al., 2013; Voinov and Bousquet, 2010; Winz et al., 2009).

Several software were commercially available for building Bayesian networks models, these include Hugin, BayesLab and NETICA. Of these software NETICA had a version that was freely available. The freely available version and the full version of NETICA were the same in their operation, the difference was in the number of variables that each of them could handle and a few additional functions available in the full version. Given the limited resources available for the study the freely available version of NETICA was used. This version of NETICA was able to accommodate the number of variables that the study was considering. The software was available from the NORSYS Software Corp. website.

Table 3.2: Comparison of System Dynamics and Bayesian networks

	Type of Modelling Tool	
	System Dynamics	**Bayesian Networks**
Types of input data	Mainly quantitative	Both qualitative and quantitative
Types of output data	Qualitative	Quantitative
Capacity to address uncertainty in inputs/parameters	Challenging	Explicitly done through the conditional probability tables
Capacity to accommodate new ideas	No	Yes
Suitability for Scenario analysis	Yes	Yes

Ref: (Bromley et al., 2005; Bromley, 2005; Carmona et al., 2013; Jakeman et al., 2013; Ticehurst et al., 2007; Voinov and Bousquet, 2010; Wang et al., 2009; Winz et al., 2009)

3.1.5 Developing a Mobile Data Collection System

Investigating the potential of mobile data collection as a method of involving stakeholders in water resources management required involving some stakeholders in a mobile data collection exercise. To that end a web-based mobile data collection system was developed to facilitate the exercise. This was essentially a system that allowed anyone with a general packet radio service (GPRS) enabled mobile device to remotely collect and submit data such as text, images, and videos to a storage server from where it would be retrieved and analysed.

Based on the information gathered during the preliminary consultations with some stakeholders a preliminary mobile data collection system was developed using the Open Data Kit (Hartung et al., 2010; Open Data Kit, 2014). This tool kit was freely available from the Google Earth Outreach and the Open Data Kit websites. It was an open-source suit of tools that was specifically designed to meet mobile data collection requirements (Hartung et al., 2010). The Open Data Kit was selected because: (i) it was freely available. This was important because of the limited resources available for the study, and (ii) it had capability of transmitting text, images and GPS locations. This was important for providing complementary information for the data collected.

The main components of the Open Data Kit were the application designer, phone clients and server storage (see Figure 3.2). The application designer allowed users to design applications and provided the logic needed for interaction with a user of a mobile device, as well as creating databases from where data could be retrieved. The phone client allowed users of mobile devices to download the application and use it to remotely collect and send data such as text, images, videos, locations and audio to the server. The server storage was for storing the data collected.

The steps taken to develop the mobile data collection system are summarised in Appendix K.

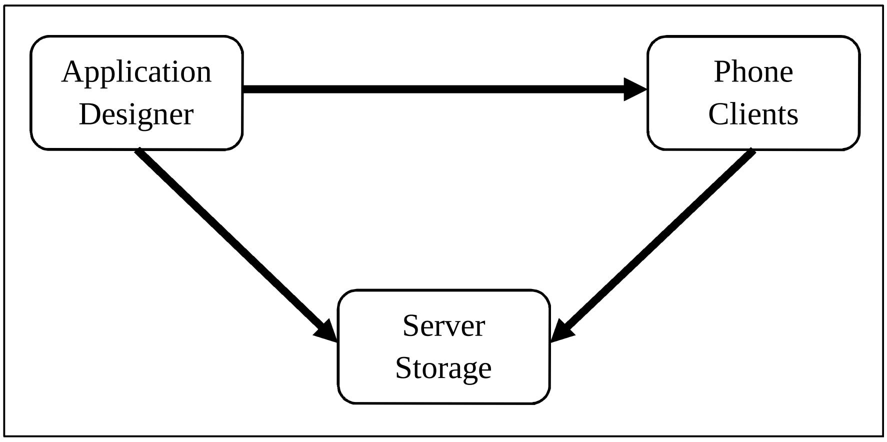


Figure 3.2: Components of ODK

Source: Adapted from Hartung et al. (2010)

3.2 Data Collection Methods

Five main data collection methods were used to gather data that informed this study. They include: workshops, questionnaires, document reviews, individual interviews and observation. The use of different methods to collect data was found to be useful for gaining an in-depth understanding of issues being studied and ensuring complementarity of the information collected. The design of the study allowed both qualitative and quantitative data to be collected concurrently as the study progressed.

3.2.1 Workshops

Three workshops were conducted in a three-stage participatory modelling exercise. Each stage was covered in a separate workshop. The first workshop involved identifying the main water resources issue in the catchment and developing a qualitative conceptual model. Building on from the first workshop, the second workshop involved converting the qualitative conceptual model into a quantitative model. The third workshop involved validating the model, identifying management interventions, and carrying out a scenario analysis. Each workshop lasted approximately two hours. The workshops took place in Mbarara town, located in the south-west of Uganda.

Some ground rules were set to govern the conduct of participants during the workshops. These were: (i) every participant has a right to make a contribution and they are entitled to their opinion, (ii) participants should respect each other's views/opinions, (iii) participants shall speak one at a time, and (iv) mobile phones shall be set to silent mode or switched off during the workshops.

3.2.1.1 Preparatory Activities

As a first step a local water resources expert in the area was identified and consulted. The purpose was to introduce the aim of the research and to help identify potential participants in the catchment. The potential participants identified were then contacted and preliminary consultations made with some of them.

The preliminary consultation meetings held with some stakeholders helped build relationships, gain their trust and identify useful background information. It was also useful for identifying other potential participants. This is considered an essential step prior to the modelling exercise as it helps to build rapport with the stakeholders and increase their level of sincerity during the exercise (Krueger et al., 2012).

The preliminary meetings also helped me to meet the team leader of the Victoria Water Management Zone. He was very instrumental in helping to identify the key stakeholders in the catchment. The Victoria Water Management Zone was one of the four water management zones established in the country for purposes of decentralising water resources management so as to implement catchment-based Integrated Water Resources Management.

Drawing on guidance from literature (Bromley, 2005), a preliminary model was constructed following initial consultations with some stakeholders. This preliminary model was helpful for learning and practice purposes. Prior practice with this model helped reduce the time that would otherwise have been spent constructing the model with participants. Workshop programmes (see Appendix C) and workshop scripts (see Appendix D) were also prepared to help guide and keep the workshops focussed.

3.2.1.2 Working between Workshops

In between workshops document review was carried out to collect information that was used to (i) verify what participants discussed in the workshops, (ii) verify the model outputs, and (iii) gain additional background information. The documents reviewed were obtained from the Ministry of Water and Environment, Uganda Bureau of Statistics, Mbarara District Local Government, National Water and Sewerage Corporation, GIZ and private consultants.

Interviews were also conducted with a separate group of participants to collect information that was used to complement as well as verify information provided by participants attending the workshops. Follow up meetings were also arranged and held with some of the participants who could not attend the workshops.

This time was also used to fine-tune and update the model and the mobile data collection system.

3.2.2 Observation

Observation is a data collection method which involves noting events in a systematic way during a study (Marshall and Rossman, 2014). Observation provides an opportunity for gathering first-hand information on participants’ actual experience, as it enables their discussions to be heard and their interactions to be seen as they happen. To facilitate the observation technique an observation guide was developed and used (see Appendix E).

Observation technique was used during workshops, meetings and field visits. During workshops the technique was used to note the critical stages of the participatory modelling exercise that had a major influence on the overall process and its outcomes. The technique was also used to note participants' interactions and involvement in the workshop activities, as well as the issues being discussed.

During field visits observation technique was used to note the real issues affecting the water resources in the study catchment, particularly sources of water pollution – covering solid and liquid waste collection and disposal points, points of environmental damage and other threats to the water sources.

3.2.3 Questionnaires

Questionnaires are essentially a set of organised questions requiring responses. The questions may be closed or open ended. Questionnaires were used to evaluate the participatory modelling process as well as the mobile data collection method. The questionnaires used the five-point Likert-type statements but also contained some open questions (see Appendix G). Questionnaires were distributed to participants at the end of the final workshop. Participants were given about fifteen minutes to fill out the questionnaires and return them.

3.2.4 Document Review

Document review involves obtaining information by reading through existing documents and without questioning people or observing their behaviour. The information collected using the document review technique was used for writing the background information about the study area, validating the model and verifying what participants discussed during the workshops.

3.2.5 Interviews

An interview is “a conversation with a purpose” (Kahn & Cannell 1957), cited in Marshall and Rossman (2014). The interview method was used to collect information to complement and verify issues discussed during the workshop. Interview method was also used to complement observations as well as questionnaire data collection methods. A semi-structured format was adopted for the interviews because it was found to be more flexible compared to other interviews approaches and therefore appropriate for obtaining detailed information from interviewees. An interview guide was developed to keep the interviews focussed (see Appendix F).

3.3 Participatory Process Evaluation

It is important to evaluate a participatory process so as to document the process and its related outcomes. This provides information that could enhance understanding about the process, its outcomes and the factors that influence it. Such information could be used to improve similar applications in future.

The framework used to evaluate the participatory modelling process and mobile data collection was derived by combining the frameworks outlined by Abelson et al. (2003), Jones, N.A. et al. (2009), Curnan et al. (1998) and Zorrilla et al. (2010). This framework allows the assessment of: (i) the extent to which the process achieves its intended objectives, and (ii) the factors that influence the process outcomes. The idea is to identify specific tools and methods associated with particular process outcomes so as to gain a better understanding of the impact of the process and its most influential elements (Curnan et al., 1998). The framework is summarised in Figure 3.3.

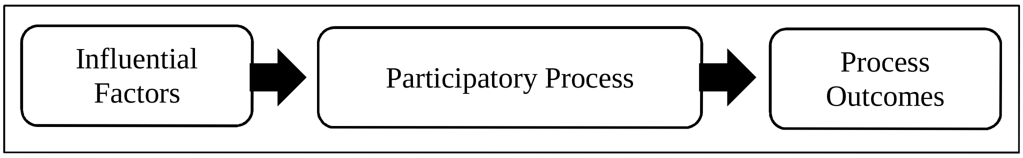


Figure 3.3: Framework for evaluating the participatory process.

Adapted from: Abelson et al. (2003), Curnan et al. (1998), Jones, N.A. et al. (2009) and Zorrilla et al. (2010).

Three methods were used to carry out the evaluation. These were: (i) evaluation questionnaires, (ii) participant discussions, and (iii) researchers' overall assessment of the process (Jones, N.A. et al., 2009; Zorrilla et al., 2010). The use of different methods was necessary for gaining a more comprehensive understanding of the process. The evaluation questionnaires were distributed to participants at the end of the final workshop and discussions with participants were held during and after the workshops.

To facilitate the evaluation exercise an evaluation guide was developed (see Table 3.3). Based on the evaluation guide, evaluation questionnaires were developed and used in the evaluation exercise. In addition to the evaluation guide a set of evaluation criteria were identified to assess the extent to which the participatory modelling process achieved the normative, substantive and instrumental benefits (see Table 3.4).

When evaluating participants general knowledge improvement a retrospective "post-then-pre" evaluation approach was adopted (Davis, 2002; Moore and Tananis, 2009; Pratt, 2000; Rockwell and Kohn, 1989). This approach enables participants to report on their current and previous levels of knowledge, understanding and involvement based on a common frame of reference after going through the process. Compared to the "pretest-posttest" approach, this approach has the major advantage of minimising "response-shift bias" that is associated with change in participants understanding of issues after they have gone through the process (Davis, 2002; Howard and Dailey, 1979; Moore and Tananis, 2009; Pratt, 2000; Rockwell and Kohn, 1989). It is also more convenient because it gives the respondents opportunity to respond to both questions at the same time therefore making it less time-consuming.

The study was also informed by material gathered through document reviews, interviews as well as observations during the workshops and field visits. The data from the evaluation questionnaires was compiled and summarised using IBM SPSS Statistics as described in Section 3.4.

Table 3.3: Evaluation Guide

<u>CONTEXT</u>

Physical Setting

- What do the participants consider to be the resource(s) at stake?

Socio-Political Setting

- Why are the participants interested in the issue?
- Who else should have been involved? Why?
- Who is responsible for managing the resource at stake?

Objectives

- What do the participants consider to be the objective(s) of managing the resource?

<u>PROCESS</u>

Method

- ✓ What did the participants get out of participating using this method?
    - ➢ Did the method enhance participants understanding of the issues raised?
    - ➢ Was there an agreement on issues to be addressed?
    - ➢ Where participants' ideas, opinions and concerns taken into account?
    - ➢ Did the method enable communication among participants?
    - ➢ Are participants confident of the outputs?

- ✓ What are the participant's thoughts on the method overall?
    - ➢ What are the participant's thoughts about the method overall?
    - ➢ What did the participant like/dislike about the method?
    - ➢ How does the participant think the method could be improved?

Tool

- ✓ Did the process of developing a model encourage discussion among participants?
- ✓ Did the process of developing a model facilitate active involvement of participants?
- ✓ Did the model help to focus discussions during the exercise?
- ✓ Did the model building process enhance participants understanding of the issues raised?
- ✓ Did the model integrate the ideas, opinions and concerns of stakeholders?

Source: Adapted from Abelson et al. (2003), Jones, N.A. et al. (2009), Curnan et al. (1998) and Zorrilla et al. (2010)

Table 3.4: Criteria used to evaluate the outcomes of a participatory modelling process

#	Criterion	References
	Normative	
1	A participatory modelling process provides a platform for dialogue	(Carmona et al., 2013; Carr, 2015; Reed et al., 2009; Videira et al., 2009)
2	Participants are representative of the wider stakeholder community and interest groups	(Abelson et al., 2003; Blackstock et al., 2007; Carr et al., 2012; Chilvers, 2010; Voinov and Gaddis, 2008)
3	A participatory modelling process is transparent	(Carmona et al., 2013; Carr et al., 2012; Voinov and Gaddis, 2008)
	Substantive	
4	A participatory modelling process enhances social learning among participants	(Blackstock et al., 2007; Carmona et al., 2013; Carr, 2015; Dougill et al., 2006; Gaddis et al., 2010; Leidel et al., 2012; Pahl-Wostl et al., 2007; Videira et al., 2010; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010; Zorrilla et al., 2010)
5	A participatory modelling process enables participants to get involved in decision making	(Carmona et al., 2013; Carr, 2015; Fiorino, 1990; Gaddis et al., 2010; Liu et al., 2008; Stirling, 2006; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010; Winz et al., 2009)
6	A participatory modelling process enhances relationships among stakeholders	(Gaddis et al., 2010; Kessler, 2004; Reed, 2008; Stringer et al., 2006)
	Instrumental	
7	A participatory modelling process fosters stakeholder trust of decisions	(Carr et al., 2012; Chilvers, 2010; Fiorino, 1990; Gaddis et al., 2010; Kessler, 2004; Voinov and Gaddis, 2008)
8	A participatory modelling process enables integration of stakeholder knowledge and experiences	(Carr et al., 2012; Gaddis et al., 2010; Prell et al., 2007; Voinov and Gaddis, 2008)

3.4 Data Analysis

Data analysis is a process of systematically organising and summarising data that has been collected into research findings (Bloomberg and Volpe, 2012). Data analysis started while data collection was still on going. Notes were prepared immediately after each workshop to record the workshop proceedings and the observations made therein. Notes and pictures were taken while carrying out field visits. Notes were also taken during interviews and document reviews. At the end of the final workshop all the evaluation questionnaires were collected and carefully organised.

The responses to the open questions were compiled and analysed by comparing them, picking out key issues presented and seeking emergent patterns. Responses to the closed statements in the questionnaires were analysed using IBM SPSS Statistics software. For SPSS to be able to analyse the data it had to be entered as numerical values. To enable this to be done the questionnaires were coded by assigning a numerical value to each response to a statement in the questionnaires.

A data entry sheet was set up to enable data to be entered into SPSS. This involved setting up the following attributes for each question: the question, question number, response type, number of decimal places, response values and measure. This was done in the “variable view” screen in SPSS. Once the data entry sheet was set up, data from the questionnaires was entered to SPSS by switching to the “data view” screen.

Summary results were generated using “Frequencies” in the “Analyse” menu in SPSS. This was considered the most appropriate way of getting summary statistics for the Likert-type data as it produced results that were logical and easy to interpret (Boone and Boone, 2012; Marston, 2009).

3.5 Data Protection and Ethical Considerations

The data collected was handled in accordance with the Information Protection Policy of the University of Leeds and principles of the Data Protection Act.

The research involved direct contact with individuals who were participating in the study and for this reason some ethical issues, such as informed consent and confidentiality, were considered. To address this issues, the research was conducted in accordance with the University of Leeds research ethics policy. To that end an application was completed and submitted to the Faculty Research Ethics Committee for formal approval before beginning data collection. The application contained all the ethical considerations and steps that were to be taken to protect those involved. The following ethical issues were particularly taken into consideration.

3.5.1 Informed Consent

All individuals who participated in the research were adequately informed of the nature of the research. An invitation letter was sent to potential participants formally inviting them to take part in the study (see Appendix H). This was accompanied with a participant information sheet that gave details of what the study was all about, and a consent form that participants were expected to sign. Participants were given up to one week to choose whether or not to participate. Participants were also informed of their right to withdraw from the study should they decide to do so at any time during the study.

3.5.2 Confidentiality and Anonymity

All data and information collected from participants was treated in a confidential manner and used solely for this study. No names were recorded during interviews and in questionnaires, instead participants' reference numbers were used. A separate password-protected document which listed the participants' reference numbers alongside their real name was prepared. This was to make it easy to identify a participant and erase their data should they decide to withdraw after data was collected from them.

The data and information collected during the study was classified as confidential and handled in accordance with the requirements of the Information Protection Policy of the University of Leeds and the principles of the Data Protection Act. The data collected was stored in the M: drive storage space of the University of Leeds server. While in the field this storage space was accessed remotely via citrix. Where internet access was limited data was temporarily stored in a personal laptop computer ensuring that files were properly password-protected. The data was then transferred to the University server as soon as internet access allowed. Hard copies of all other data were kept securely at all times.

3.5.3 Reimbursements

All individuals who participated in the workshop sessions were paid a transport refund of UGX 30,000 (about £5.50) per session. This was meant as a contribution to their transport expenses to and from the workshop venue.

3.5.4 Intrusiveness

In conducting this study participants' convenience was taken into consideration. Unreasonable intrusion into participants time, space and personal lives was avoided. To that end convenient appointments were agreed with participants, and workshops were scheduled at a time and location convenient to most participants.

Chapter 4

Participatory Modelling

4.1 Introduction

Stakeholder participation in the management of water resources is a key requirement of IWRM. However, its realisation in practice remains a major challenge. On the other hand, however, there is increasing recognition and growing popularity of participatory modelling approaches and the potential they are believed to hold to support stakeholder involvement in the management of natural resources (Campo et al., 2010; Gaddis et al., 2010; Robles-Morua et al., 2014; Tsouvalis and Waterton, 2012; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010). That potential has not been fully exploited in the field of water resources management.

In the field of water resources management, participatory modelling has mainly been used to develop models as decision support systems (Carmona et al., 2013; Castelletti and Soncini-Sessa, 2007; Chan et al., 2010; Henriksen et al., 2007; Ritzema et al., 2010; Ticehurst et al., 2007; Winz et al., 2009; Sgobbi and Giupponi, 2007). Relatively few studies have attempted to evaluate a participatory modelling process to assess the extent to which it delivers benefits for water resources management (Carmona et al., 2013; Maskrey et al., 2016). As a result there is scarcity of knowledge about the tools and methods used in participatory modelling and how they can support stakeholder participation in the management of water resources. It is within this context that this study set out to investigate the potential of a participatory modelling process to support stakeholder involvement in water resources management. In addition the study also sought to assess the extent to which participatory modelling delivers benefits for water resources management.

In order to achieve these goals a participatory modelling exercise was designed and implemented with a select group of stakeholders in the River Rwizi catchment, in western Uganda. The aim was to directly and interactively involve participants in: (i) identifying the main water resources issues in the River Rwizi catchment, (ii) identifying intervention options needed to address those issues, and (iii) assessing the effect of applying different interventions, and combinations thereof, on the issue identified. The participatory modelling process was evaluated to assess the extent to which these aims where achieved and identify the factors that influenced the outcomes.

This chapter presents the findings of the study. In the next section a brief description of the methodology used is presented. This is followed by an analysis of the key findings. The final section presents a brief discussion of the findings.

4.2 Methodology

To understand how a participatory modelling process can help support stakeholder participation in the management of water resources, it is necessary to conduct and evaluate a participatory modelling process in a catchment experiencing water resources issues. By working with the stakeholders in a participatory framework it is possible to identify the factors that influence the process and also relate the process outcomes to specific tools and methods used (Curnan et al., 1998; Jones, N.A. et al., 2009).

The participatory modelling exercise was conducted through workshops as described in Section 4.3.1 below. Participants were purposively selected as described in Section 3.1.3, and the modelling tool used was selected as described in Section 3.1.4.

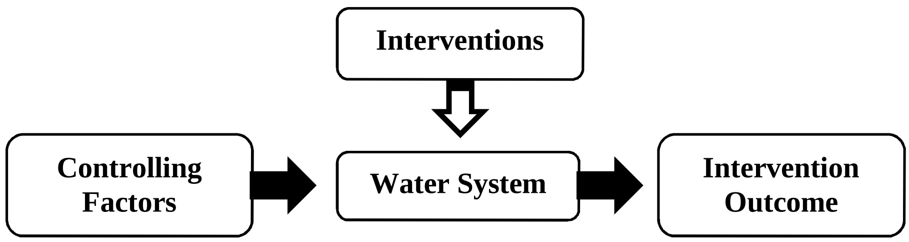
The Bayesian networks model development approaches described by Cain (2001), Marcot et al. (2006), and Castelletti and Soncini-Sessa (2007) were used as guides for developing a model with participants. The approach adopted in this study was to involve all the participants in all stages of the model building exercise. The reason for this was to ensure that participants knowledge, experiences and views have a real and not merely a cursory impact in building the model (Voinov and Bousquet, 2010). This was a departure from some previous approaches where the models were developed by experts but informed by stakeholders either through interviews (Wang et al., 2009) or through part involvement in some stages of the modelling exercise (Chan et al., 2010), hence making it novel in the context of water resources management. The participatory modelling process was evaluated as described in Section 3.3 above.

4.3 Analysis of the Participatory Modelling Process

4.3.1 The Model Building Exercise

The selected participants were engaged in a model building exercise through workshops using a framework conflated from Cain (2001) and Wang et al. (2009), (see Figure 4.1). The framework requires relevant variables in the system to be identified and the relationships between them to be defined. This was done by the participants in a model building exercise depicted in Figure 4.2.

Three modelling workshops were conducted. In the first workshop participants identified the main water resources problem in the catchment and developed a qualitative conceptual model. In the second workshop participants converted the qualitative conceptual model to a quantitative model and populated its conditional probability tables. In the third workshop participants validated the model, identified possible interventions, and discussed the results of the scenario analysis.



Controlling Factors: Factors that affect the water system but cannot easily be changed by intervening at local scale, e.g. population.

Water System: A depiction of the water system that describes the relationships between the input and output variables.

Intervention Outcome: The result obtained when interventions are implemented, e.g. improved water quality.

Interventions: Measures taken in order to influence outcomes.

Figure 4.1: Framework for the modelling exercise.

Adapted from: Cain (2001)and Wang et al. (2009).

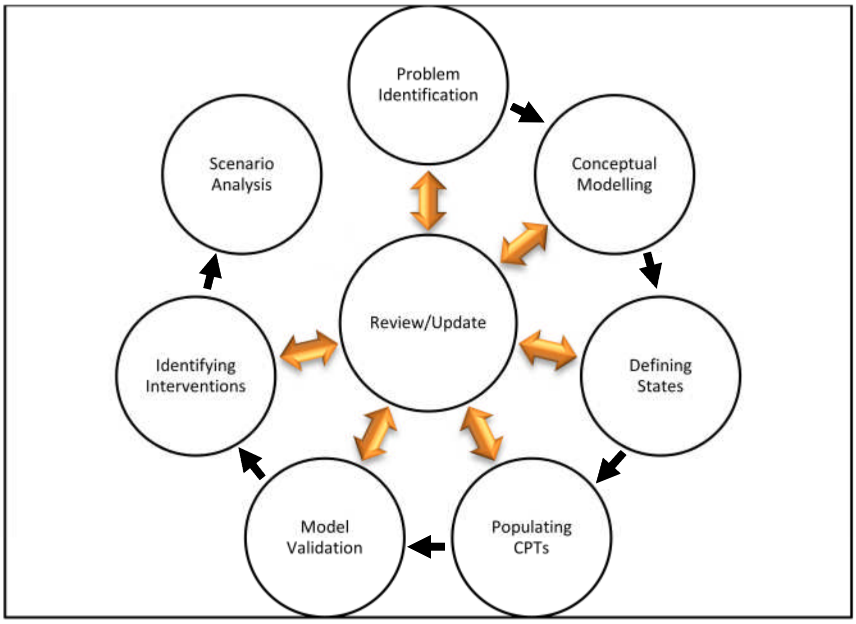


Figure 4.2: Stages in the model building exercise

4.3.1.1 Problem Identification

Identifying the main water resources problem in the catchment was the most important initial step in the modelling exercise. This provided the modelling exercise with direction and ensured that attention was focussed on key variables that had a bearing on the problem identified. It also ensured that stakeholders' concerns were taken into account.

During the first workshop participants were asked to name the main natural resource in the catchment that was at stake. Discussion ensued among participants where they observed that water was increasingly becoming a major concern to the community in the catchment because of the deteriorating quality and quantity. They felt that water was the main resource at stake in the catchment as opposed to the other resources such as land and vegetation.

Participants were then asked which of the issues, between water quality and quantity, was a major concern that needed immediate attention. Initially there was a divided opinion on this issue with arguments for both quantity and quality. After considering both points of view in a lengthy discussion participants finally agreed that whereas both quantity and quality were of concern, improving the quality of water needed to be given priority and then consider the issue of quantity soon after. They, however, felt that if possible both issues could be handled concurrently.

A useful piece of information that came as a relief for some participants was about the water risk and sustainability assessment that had been carried out in the catchment. A participant reported that the assessment had revealed that there was enough water to meet the current demand in the catchment. The challenge however was that it was not evenly distributed across the catchment.

Participants were then asked to identify the major issues affecting the water resources in the catchment. A number of issues were listed as shown in Table 4.1 below. Participants said that these issues had not only resulted in the deterioration of the state of water resources in the catchment but had also affected the health and lives of the people in the community who depend on it. They also said that some of these issues, particularly poor farming methods, overstocking of livestock and felling of trees for charcoal and firewood, had led to depletion of the natural vegetation cover leaving the ground bare and prone to erosion.

The problem identification exercise was vital for analysing water resources issues in the catchment. It helped participants gain a common understanding of water issues in the catchment. Knowledge and experience of local issues in the area proved essential at this stage of the exercise because it helped in identifying the actual issues on the ground. This was vital for formulating meaningful strategies, later in the modelling exercise, to address the problem identified.

Table 4.1: Major concerns raised by participants regarding the deteriorating water resources situation in the River Rwizi catchment

#	Concerns
1	Encroachment in wetlands and forest reserves for agriculture and settlement mainly due to increased population and poor fertility of soils
2	Poor farming methods used on the slopes of the hills
3	Corruption. People are not doing what they are supposed to be doing because some of them are easily compromised
4	Urbanisation. Rapid development of urban centres in the catchment
5	Indiscriminate disposal of solid waste in urban centres
6	Industrial growth. Many industries being set up
7	Changes in climatic conditions and weather patterns
8	Overgrazing due to overstocking of livestock
9	Erratic rainfall pattern
10	Felling of trees for timber, charcoal and firewood, and to give way for settlement and agriculture
11	Inadequate enforcement of relevant laws
12	Chemicals used to spray crops and animals
13	Bush burning – exposes the soil to agent of erosion and affects its fertility. It also destroys the natural habitat for wild animals
14	Poor collaboration between relevant institutions
15	Illegal diversion of water from the river for irrigation and to facilitate sand mining
16	Herbicides and pesticides used to spray crops and livestock end up in the water courses when it rains
17	Watering of animals directly in the river and most often at the same point where people draw water for domestic use
18	“I don’t care” attitude
19	Clay mining for brick making

4.3.1.2 Developing a Qualitative Conceptual Model

Once the problem was identified the next step was to construct a conceptual model. Constructing the conceptual model network helped participants to visualise how the various issues in the catchment relate to each other. It also enabled participants' ideas to be integrated into the model.

Involving participants in developing the conceptual model was one way of ensuring transparency in the model building process. Transparency is considered to be important for building stakeholder trust and confidence, and ensuring their support for the outcomes of the modelling process (Castelletti and Soncini-Sessa, 2007; Gaddis et al., 2010; Zorrilla et al., 2010). The transparency of the model building process enhanced the educational aspect of the process by enabling participants to share information and experiences. This enhanced their own knowledge and understanding of water issues in the catchment.

Constructing a conceptual model network did not require any specialised skills. However, some degree of imagination, thinking and reasoning was necessary so as to ensure a realistic representation of issues. Participants therefore had to explain and justify any relationship proposed in the network as demonstrated by the example given in the next paragraph. The exercise was good for generating useful discussion among participants. The network was initially constructed manually by drawing the proposed relationships on paper and involved several iterations and modifications before a draft version of the network was produced. The draft version was then constructed using NETICA software as shown in Figure 4.3 below.

The following is an example of how participants argued when constructing conceptual model network. Considering the route from socioeconomic development via climate change up to water quality (see Figure 4.3), participants argued that socioeconomic development is one of the factors responsible for climate change. They argued that socioeconomic development has, for example, led to construction of industries to produce various kinds of goods and services for human consumption. The same industries also produce various kinds of waste products. They said that some of the waste products, such as carbon dioxide, have been attributed to the various changes taking place in the atmosphere resulting in global warming which affects the climate. Following this reasoning it was argued that one of the causes of climate change is socioeconomic development and one of the effects of socioeconomic development is climate change.

Similarly it was argued that one of the cause of the variable rainfall patterns experienced in the area is climate change. They also argued that one of the causes of surface runoff is rainfall. Finally on that route participants argued that one of the causes of poor water quality is surface runoff from the catchment. Similar arguments were followed for all the other routes terminating on water quality.

Participants were generally knowledgeable of global and local issues related to water resources and climate change. Their knowledge and experience of local issues in the catchment stood out during the model building exercise and was very helpful for analysing water resources issues.

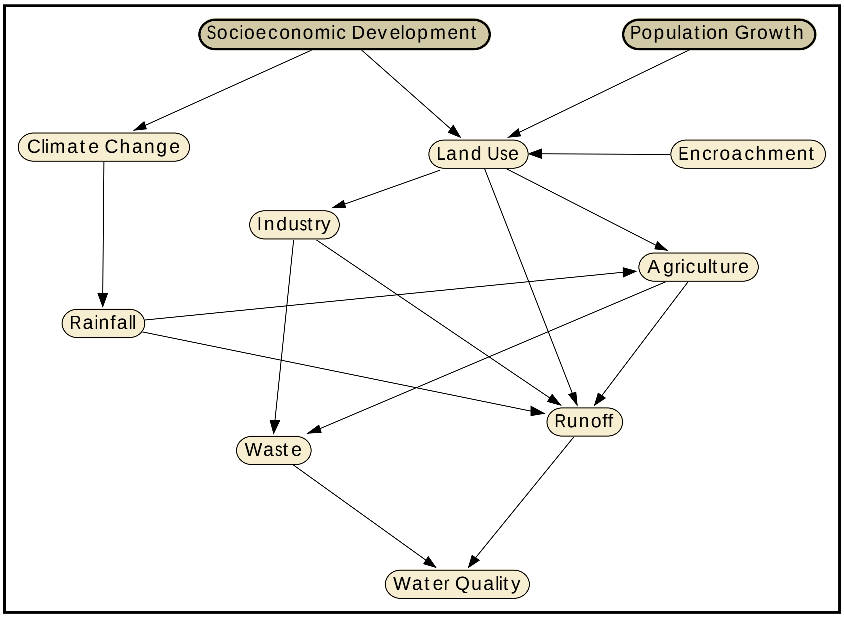


Figure 4.3: Qualitative conceptual model network

In the subsequent workshops participants continued to review and adjust the model network as their knowledge and understanding of issues in the catchment evolved. The improved understanding allowed them to develop a better conceptual model. For example, during the second workshop participants made an observation regarding population growth. They argued that population growth in itself may not directly lead to increased land use but rather increase in population could lead to increase in demand for goods and services provided by the land. They argued that it was the need to satisfy the demand that could lead to increase in land use. Participants also noted that it was demand that was a driver for socioeconomic development and ultimately land use. To represent their ideas better the "demand" variable was introduced and the network rearranged accordingly. Similarly the variable "population growth" was changed to "population" to represent the idea better.

One of the participants also pointed out that human activity had been attributed to many negative effects on the environment including climate change and therefore the issue of human activity needed to be clearly represented in the network. This view was supported by other participants who agreed to introduce the variable “human activities”. Participants scrutinised the network further and, after some discussions, agreed that encroachment, agriculture (which in this case included animal husbandry) and industrial activities were all human activities and should be combined and named as such. This helped to simplify the network thereby making it clearer and easier to understand. It also later eased the task of populating the conditional probability tables. The revised qualitative conceptual model network is shown in Figure 4.4.

The development of the conceptual model network engaged participants in thinking and reasoning and helped them understand the relationships between various variables in the catchment. The graphical representation of the network was particularly helpful as a visualisation aid and helped participants understand the relationships better. This characteristic of a Bayesian networks model has also been recognised by other authors who also found it useful as an aid for discussion when dealing with stakeholders (Carmona et al., 2013; Henriksen and Barlebo, 2008; Kragt et al., 2011). The flexibility of the Bayesian networks model was also demonstrated during conceptual modelling exercise allowing changes to be made so as to incorporate new ideas.

This was one of the stages of the process where the educational potential of the modelling exercise was realised. During discussions with participants they described how the network construction exercise helped them to learn from each other and improved their understanding of water issues. That was a vital outcome at this stage of the modelling exercise. With the qualitative conceptual model network developed the next stage was to define the states of the variables in the network.

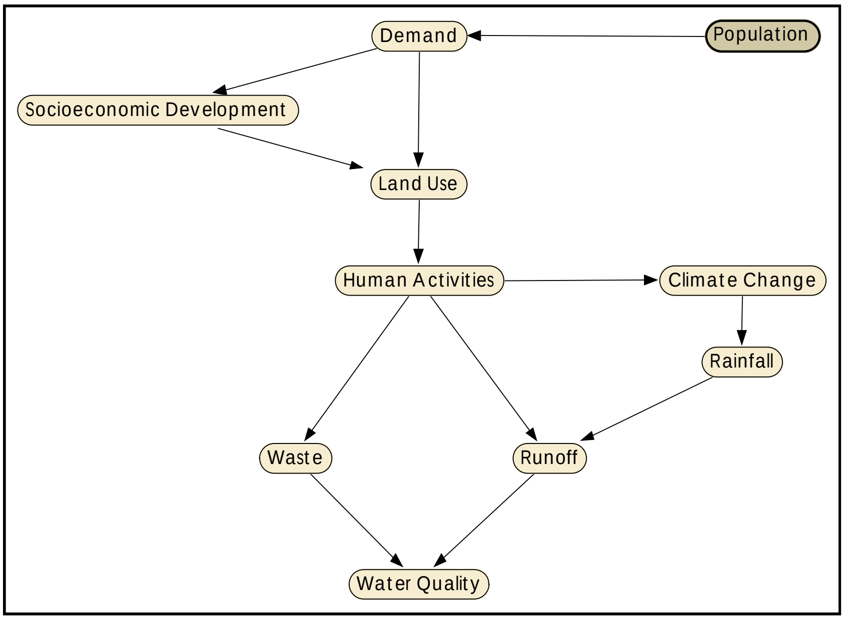


Figure 4.4: Revised qualitative conceptual model network

4.3.1.3 Choosing Possible States for Variables

This was the initial step in converting the qualitative conceptual model into a quantitative model. States are essentially observable changes in the condition of a variable. In coming up with the possible states for each variable it is important to ensure that the model is kept simple and understandable by all participants/stakeholders (Cain, 2001; Marcot et al., 2006). In this case the number of states for each variable was limited to two (see Table 4.2). This later also eased the task of populating the conditional probability tables and ensured that the size of the conditional probability tables was manageable. This is important for enhancing the computational efficiency of the model because the computation rate of a Bayesian networks model is directly proportional to the size of the conditional probability tables (Nielsen and Jensen, 2009; Wang et al., 2009).

Table 4.2: Table of variables and their possible states

Variable	Definition	Possible States
Population	Number of people living in an area	Low, High
Demand	The need for particular items and/or services	Low, High
Socioeconomic development	The capacity to produce goods and services so as to improve the social and economic wellbeing of the population in the area	Low, High
Human activity	Actions by people that influence the state of the environment	Low, High
Land use	The extent to which the available land is used	Low, High
Climate change	Changes experienced in the climate conditions in the area	Moderate, Significant
Rainfall	The amount of rain falling in an area over a specified period	Low, High
Runoff	Water that drains away from the surface of land especially after rainfall	Low, High
Waste	Unwanted material or substances that are disposed of after a process	Low, High
Water quality	The state of water in terms of its physical and chemical properties	Poor, Good

Participants defined the states of the various variables by adopting terms they commonly used to describe such variables. For example the terms “Low” and “High” were adopted to define the two possible states of the variables of Population, Demand, Socioeconomic Development, Land Use, Human Activity, Waste and Runoff. For Climate Change the terms “Moderate” and “Significant” were adopted to define the possible states. At the end of this session participants had defined the possible states of each of the variables according to their own experiences and understanding of the respective variables (see Table 4.2).

4.3.1.4 Quantifying the Model

A Bayesian networks model is based on the relationships between the variables in the network. The variables are linked in cause-effect relationships by conditional probability distributions to form a causal probabilistic network. It is the conditional probability distributions in the network that define the probability of a variable assuming a particular state (Nielsen and Jensen, 2009). The relationships in the Bayesian networks model are based on Bayes' rule, which is expressed as follows: Given any two events, A and B,

$$P(B \mid A) = \frac{\mathrm{P(A \mid B)\ x\ P(B)}}{\mathrm{P(A)}}$$

Where $P(B \mid A)$ is defined as "the probability of event B occurring given that event A has occurred", and $\mathrm{P(A)}$ is defined as "the probability of event A occurring". Bayes' rule gives a method of updating belief about an event B occurring given that new information about event A is obtained.

Before participants begun the task of estimating conditional probabilities it was deemed necessary to explain to them the logic behind conditional probabilities. This was done by giving an example of a person who regularly travelled between two towns A and C, via town B. Given that this person's average travel time between the two towns was two hours, with no other information available to them about the route they would be almost 100% certain that on any given day their travel time between the two towns A and C would take about two hours. However, if they received information that there were road repairs along the way and that one of the lanes was closed to traffic, then their level of certainty of covering the journey within two hours would reduce, say to about 80%, depending on the magnitude of the works on the road. If they received additional information that there were riots in town B and the road had temporarily been closed, then their level of certainty would reduce even further probably to less than 50%.

This example helped participants appreciate the logic behind conditional probabilities. With this logic in hand participants proceeded to jointly estimated the conditional probabilities for the possible states of each variable. Figure 4.5 shows part of this exercise in progress. The conditional probabilities were manually estimated following a procedure described by Cain (2001), for information elicited from stakeholders and experts based on their best judgement. This procedure ensures that the participants knowledge and experiences are built into the model.

Figure 4.5: Part of the model quantification exercise

Participants discussed the relationships between the various variables and for each combination of parent variable states, they estimated the probability of the output state for each child variable. These were tabulated into conditional probability tables as shown in Table 4.3 below. A full set of the final conditional probability tables for the model is presented in Appendix I. As an example, the fourth row in the table may be interpreted as implying that if no restoration activities are carried out at all and rainfall is high and land use is also high, there is a 5% possibility that the surface runoff will be low and a 95% possibility that it will be high.

This was the most critical stage of the modelling exercise because the Bayesian networks model is essentially based on conditional probabilities. The outputs of the model are calculated based on the conditional probabilities that are built into the model. Because of the importance attached to this activity careful attention was given to it by ensuring that enough time was given to participants to think through, discuss and agree on sets of probabilities that best represented the states of the variables. Some probabilities were revisited to make sure that participants were confident of the figures they had proposed. As a result of these iterations some probabilities were revised.

This was another stage where participants' knowledge, experience and expertise were required and where it proved vital. All the probabilities were estimated purely from participants' knowledge and experience which was a remarkable achievement for such an exercise.

Table 4.3: Conditional probability table for surface runoff

#	Restoration	Rainfall	Land Use	Surface Runoff	
				Low	**High**
1	No	Normal	Low	0.40	0.60
2	No	Normal	High	0.30	0.70
3	No	High	Low	0.30	0.70
4	**No**	**High**	**High**	**0.05**	**0.95**
5	Yes	Normal	Low	0.80	0.20
6	Yes	Normal	High	0.60	0.40
7	Yes	High	Low	0.80	0.20
8	Yes	High	High	0.50	0.50

The process of developing the model was iterative and the network was revised several times before the final version was agreed upon. Each time the network was revised the conditional probabilities of the affected variables were also revised. This was made possible by the Bayes' rule that allows updating of probabilities in the model as the network changes or whenever new information becomes available. This characteristic of Bayesian networks proved useful for incorporating participants' ideas and knowledge which kept evolving as the exercise progressed. It also demonstrated flexibility of a Bayesian networks model; a characteristic that is considered to be fundamental for engagement with stakeholders (Carmona et al., 2013; Henriksen and Barlebo, 2008). The model that resulted from this stage of the modelling exercise is shown in Figure 4.6 below.

The task of populating the conditional probability tables drew mixed reactions among participants. Some of the participants found the exercise interesting, while others felt it was a bit difficult especially when it came to assigning a number to a probability. The initial explanation of the logic behind conditional probabilities was useful in highlighting the effect of change of state of one variable on another. Some participants indicated that they often used the same kind of reasoning in everyday situations, however they were not used to expressing the degree of likelihood of possible outcomes in figures. For that reason they found it a bit difficult to estimate appropriate numbers to represent the probabilities during the modelling exercise.

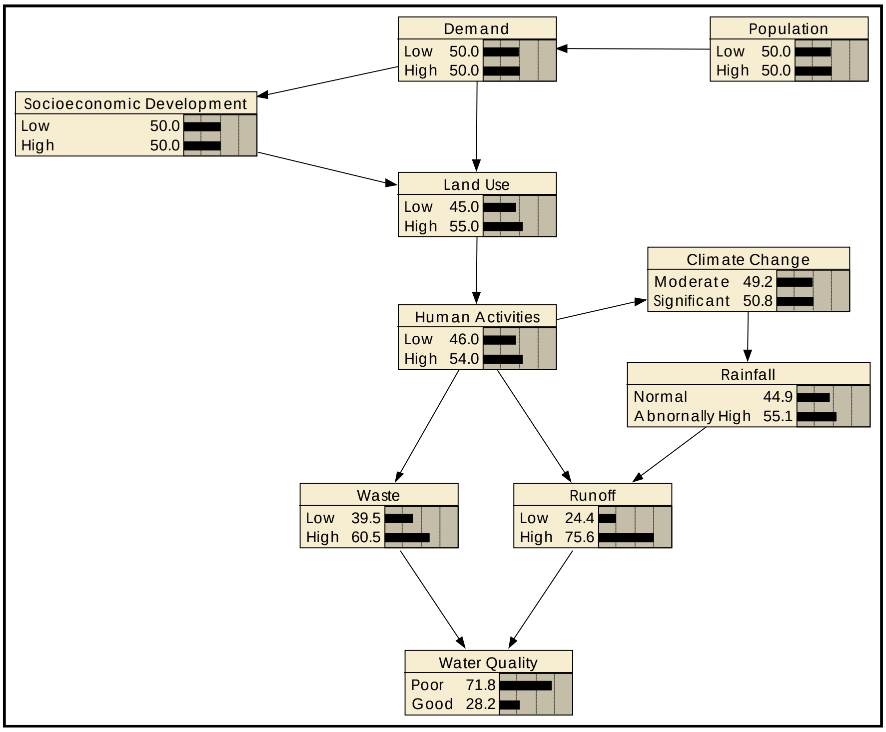


Figure 4.6: Initial quantitative model

However participants felt doing it as a group had made it a little easier, and that the diverse knowledge and experiences from the different participants present enabled them to come up with figures that represent a common understanding of the issues. The graphical representation of the Bayesian networks model once again proved to be useful as a visualisation tool, particularly the numerical outputs. Participants appreciated the numerical output more because it helped them to compare the possible states of the variables.

Involving stakeholders in estimating the conditional probabilities was also another way of ensuring transparency of the process; a requirement that is considered to be important for successful implementation of a participatory modelling exercise (Gaddis et al., 2010; Korfmacher, 2001; Voinov and Gaddis, 2008; Krueger et al., 2012). As indicated earlier, transparency is vital for gaining stakeholder trust and support and as such was a key element in the participatory modelling exercise.

Another characteristic that was demonstrated at this stage of the exercise was the ability of a Bayesian networks model to integrate knowledge and information from a diverse group of participants. The knowledge and information were used to refine the probabilities before arriving at an agreed value. This characteristic is considered to be particularly important when dealing with local experts (Jakeman et al., 2013; Voinov and Bousquet, 2010).

The use of probabilities ensured that uncertainty in the information provided was taken into account and built into the model. Consideration of uncertainty is considered to be important when dealing with stakeholders (Castelletti and Soncini-Sessa, 2007; Henriksen and Barlebo, 2008; Voinov and Gaddis, 2008). This is mainly because of differences in perspective, and the subjective nature of the information often provided.

4.3.1.5 Validating the Model

Given that each of the conditional probability tables in the model was independently determined it was necessary to check the completed model to ensure that it was behaving as expected. This enables any anomalies to be detected and rectified accordingly. The model was validated following a procedure identified in the literature (Aguilera et al., 2011; Greiner et al., 2014; Marcot et al., 2006; Ticehurst et al., 2007; Wang et al., 2009). The model was systematically checked against (i) the understanding of the participants, (ii) data from documents reviewed, and (iii) observations made during the study.

First, the participants examined the relationships expressed in the network to ensure that they made logical sense. While carrying out this task participants realised that the relationship between the variables “Land Use” and “Human Activity” did not make logical sense (see Figure 4.6). They said that land use cannot lead to human activities as depicted in the model, but rather the reverse was possible. They decided to switch these variable so that the network makes logical sense. The rest of the network was double checked to ensure that it was all logical.

Rearranging a network has an effect on the conditional probabilities of variables whose parents change in the process. Because of this it was necessary to revisit the conditional probabilities of all the variables whose parents had changed as a result of the adjustments to the network. Participants estimated new sets of conditional probabilities for the affected variables.

Secondly, the model was run and participants compared the outputs of key variables with their actual states based on their understanding of these variables and available reports (see Section 4.3.1.5.1 below).

Participants' knowledge and experience of the various variables was vital for assessing the model outputs. The graphical display of the model was again very instrumental at this stage of the exercise in that it enabled participants to interpret and understand the results produced by the model. It was because of this that participants were able to notice the anomaly with the arrangement of the network and to make adjustments accordingly.

The numerical output in the graphical display helped participants to compare the likely states of various variables with their actual states. After making these comparisons participants expressed confidence in the model outputs. They said the outputs were consistent with their understanding of the situation on the ground.

Thirdly, the outputs of the model were further verified by comparing with data collected through document review and observations. After this task a validated model was produced (see Figure 4.7).

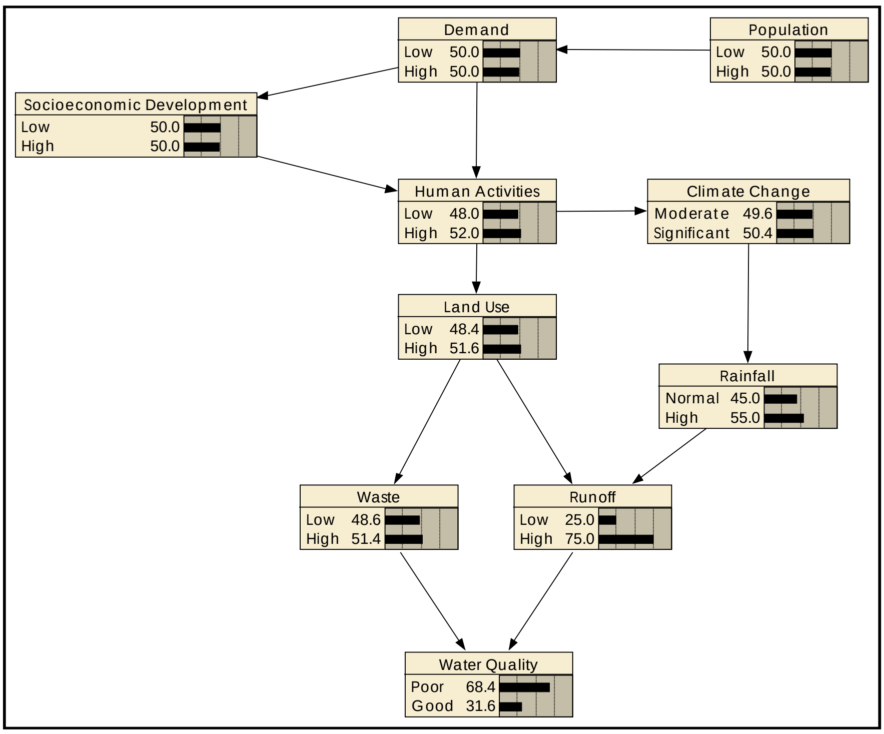


Figure 4.7: Validated Bayesian networks model

When assesing the model outputs some participants found it challenging to relate the probabilities displayed in the model to the actual states of the variables. To address this challenge, a Likert-type scale (see Figure 4.8) was used to help participants to interpret probabilities. The scale expresses the likelihood of a variable assuming a particular state.

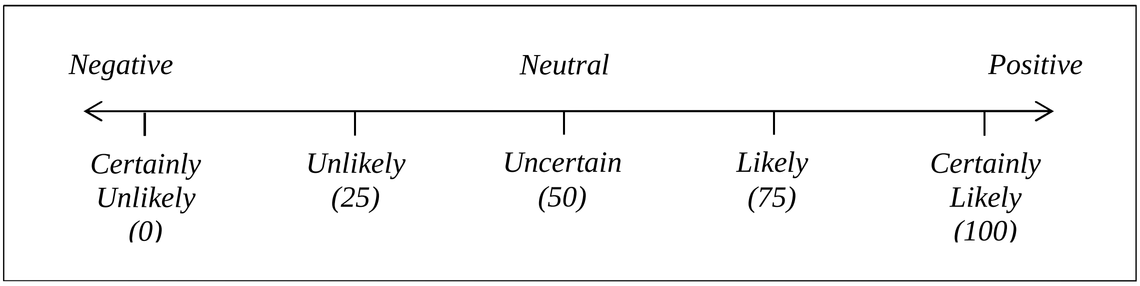


Figure 4.8: Scale used for interpreting probabilities

Participants generally exhibited high levels of concentration and interest in the discussions throughout the model development exercise. The fact that they were able to notice anomalies in the network was evidence that they paid keen interest in the model and what it was representing.

4.3.1.5.1 Assessing Model Outputs

Water Quality

The model output (see Figure 4.7), indicated a likelihood that the quality of water in the catchment was in a poor state. This was also apparent from the visual appearance of the water in the river. It was generally brown in colour and contained a lot of suspended material. All participants felt that the quality and quantity of water in the catchment, and particularly the River Rwizi, had greatly deteriorated compared to what it was several years before. Results of water quality tests (NWSC, 2015), carried out on raw water from the River Rwizi at the National Water and Sewerage Corporation’s water treatment plant in Mbarara town, also indicated that the quality of water in the river was poor (See Table 4.4).

In order to give an idea of the quality of water in the River Rwizi the European Commissions' Surface Water Directive (75/440/EEC) of 1975 is used. This directive covers the "*quality required of surface water intended for the abstraction of drinking water"* in the European Union member states. Taking an example of two water quality parameters, according to this directive the worst quality of surface water that can be abstracted for drinking water can have up to 2.0 mg/l of dissolved iron and up to 150 mg/l Pt/Co of colour. Beyond those values the Directive suggests that the cost of treatment to achieve drinking water quality could be prohibitively high. As can be seen in Table 4.4, the values for the water from River Rwizi are worse than these, with average dissolved iron of 3.27 mg/l and average colour of 1,036 mg/l PT/Co as of June 2015. With that quality of water there was reason for stakeholders to be concerned.

It was apparent that on some occasions some water quality issues would break through the water treatment system and appear in the water distribution system. Some participants reported seeing brown water in their taps. This was also evident in the venue where the modelling workshops took place during this study. National Water and Sewerage Corporation, the water supply company in Mbarara was aware of this situation and was equally concerned about the deteriorating water situation in the catchment. In response the Corporation was actively involved in the River Rwizi catchment management efforts aimed at addressing the water resources issues.

Table 4.4: Water quality data for River Rwizi

Month	pH	EC (µS/cm)	Colour (PtCo)	Turbidity (PTU)	TSS (mg/L)	Alkalinity (mg/L)	Hardness (mg/L)	Iron (mg/L)	Faecal Coliforms
Aug-13	6.70	ND	917	116	80	25	52	2.04	ND
Sep-13	7.27	107	950	119	43	16	29	6.20	700
Oct-13	ND	137	1,243	65	69	ND	62	2.97	1,690
Nov-13	ND	88	629	95	58	22	52	2.08	1,090
Dec-13	-	-	-	-	-	-	-	-	-
Jan-14	ND	74	675	110	69	18	50	3.15	45,000
Feb-14	ND	85	729	120	67	22	50	3.95	1,500
Mar-14	ND	ND	539	109	62	26	ND	2.87	1,600
Apr-14	ND	ND	849	129	68	16	ND	2.09	9,000
May-14	ND	78	1,150	116	70	ND	ND	ND	5,000
Jun-14	ND	ND	641	130	62	28	60	3.15	900
Average	**6.99**	**95**	**832**	**111**	**65**	**22**	**51**	**3.17**	**7,387**
Jul-14	ND	78	875	101	49	30	60	2.25	900
Aug-14	ND	85	906	124	69	30	62	2.85	30,000
Sep-14	6.78	96	1,025	134	46	28	62	ND	-
Oct-14	7.30	95	1,250	139	66	24	56	ND	1,800
Nov-14	7.14	79	983	113	65	21	57	ND	8,250
Dec-14	6.94	81	625	112	46	19	54	ND	7,750
Jan-15	6.50	90	592	113	53	21	55	ND	112,500
Feb-15	ND	ND	908	124	62	21	59	ND	8,750
Mar-15	6.66	65	1,472	136	66	21	59	ND	7,250
Apr-15	6.80	109	1,037	138	61	34	62	ND	6,500
May-15	7.20	ND	1,090	112	ND	ND	59	ND	7,500
Jun-15	7.30	132	1,673	196	ND	ND	58	4.70	9,000
Average	**6.96**	**91**	**1,036**	**129**	**58**	**25**	**59**	**3.27**	**18,200**

Source: NWSC (2015)

Surface Runoff

The model indicated a likelihood that there was much surface runoff in the catchment. Participant attributed this to activities that exposed the land to agents of erosion. They cited felling of trees for charcoal and firewood (the main sources of fuel for cooking in the catchment), and clearing bushes for settlement and agriculture. Participants also cited cases where people did not practice terracing as a form of cultivation on the slopes of the hills to reduce soil erosion.

This output was also supported by field observations. Field observations revealed activities that had left some of the land bare and exposed to erosion. Some of these activities include: mining of clay for brick making, mining of sand for construction, bush burning, roadworks and over grazing as shown in pictures 1 – 4, & 6 in

Table 4.10. Some people were also cultivating vegetable crops on the shores of the river. People often use pesticides to spray their crops against pests and whenever it rains both pesticides and soil are washed into the river and nearby streams by the rain water.

According to reports on the potential impact of climate change in the country it is projected that surface runoff will increase by up to 44% in many parts of the country by the middle of the century (GIZ, 2014; MWE, 2013). Consequently more pollutants from the catchments are likely to find their way into the water courses.

Land Use

The model indicated a likelihood that land use in the catchment was high. Participants attributed this to the fact that most of the people in the catchment depend on agriculture for their livelihood. This view was also supported by a report (MDLG, 2009) that indicated that over 95% of the land in the catchment is under agriculture.

The population in the area is rapidly increasing and this is putting pressure on the available land for food production and settlement. Population growth in the area was estimated at an annual average of 2.3% (UBOS, 2014a). This was among the highest rates in the country.

Waste

The model indicated a likelihood that there was much waste in the catchment. This suggested that its influence on the quality of water was equality high. There was no way of verifying this due to lack of information that directly linked the waste in the catchment to the quality of water. However participants felt that some of the waste produced in the catchment posed a high risk to the quality of water and the health of the community that depend on it for their livelihood. They cited examples as effluent from the wastewater treatment facilities and the abattoir, and solid waste from the urban centres, especially the hospitals.

These views were supported by field observations that indicated that waste from these facilities was not being adequately managed (see picture 5 in

Table 4.10 and pictures 1 – 6 in Table 4.11). Abattoir waste for example has potential to contaminate both surface and ground water if not properly managed (Jones, D.L., 1999; Sangodoyin and Agbawhe, 1992). Waste from the hospital has potential to spread infections downstream from the point of disposal since some people use the same water for domestic purposes and for watering their animals. Waste from a hospital can be catastrophically dangerous if it contains pathogens that cause contagious diseases such as Ebola and cholera.

Rainfall

The model indicated a likelihood that the catchment was experiencing high rainfall. This output was supported by the participants who indicated that the area had been receiving slightly higher rainfall than in the recent past albeit often falling outside the normal rainfall season.

Documents reviewed also indicated that the area had been receiving "generally higher rainfall than the long term average" (GIZ, 2014; UBOS, 2013; UBOS, 2014b). It should, however, be noted that the River Rwizi catchment lies in one of the drier parts of the country. Whereas there was an indication of increased rainfall in the catchment it was still generally low compared to other parts of the country.

Climate Change

The model also indicated a likelihood that the catchment was experiencing the effects of climate change. This output was supported by participants who reported that the area was experiencing variability in the onset of the rainfall season and the intensity of drought during the dry spell. These were some of the signs of climate change (AMCEN, 2009).

This result was also supported by documents reviewed that indicated that the country was already experiencing the effects of climate change as evidenced by the frequency of extreme weather events such as drought and heavy rainfall (MWE, 2013; Nyeko-Ogiramoi, 2011). These extreme weather events had also been experienced in the catchment and always featured widely in the local press whenever they occurred because of their devastating nature in terms of loss of life. They had also been recognised internationally as a major problem in the catchment (UNESCO, 2006; World Resources Institute, 2016).

Participants felt that climate change was likely to have far reaching consequences in the catchment especially because of its effects on water resources. Most of the people in the catchment depend on agriculture for their livelihood and because of this over 95% of the land in the catchment is under agriculture (MDLG, 2009). Extreme weather events such as drought and flooding could have devastating effects on peoples' livelihood by affecting agricultural production.

4.3.1.5.2 Sensitivity Analysis

A sensitivity analysis of the Bayesian networks model was carried out to establish the degree to which variations in the probabilities of the output variables were caused by changes to other variables in the network. The sensitivity analysis was also used to verify the model structure and parameterisation (Marcot, 2012). An automated function built within the Netica® modelling software was used to perform the sensitivity analysis. Netica® uses the method of entropy reduction to calculate sensitivity. Entropy reduction is the decrease in variation of an output variable due to changes in an input variable (Marcot, 2012).

Given an input variable *G*, with *g* states and an output variable *X*, with *x* states, entropy reduction *I*, is calculated as:

$$I = H(X) - H(X|G) = \sum_x \sum_g \frac{P(x,g)log_2[P(x,g)]}{P(x)P(g)}$$

Where: H(X) is the entropy of *X* before changes to variable *G* and $H(X|G)$ is the entropy of *X* after changes to variable *G* (Marcot, 2012).

The results of the sensitivity analysis are presented in Table 4.5. The “entropy reduction” column shows the degree to which the outcome probabilities of “water quality” decrease with respect to changes to each variable in the network. The higher the value of “entropy reduction” the more sensitive “water quality” is to changes in the corresponding variable.

Table 4.5: Sensitivity of 'Water Quality' to changes to other variables

Variable	**Entropy reduction**	**% of entropy reduction**
Water Quality	0.89961	100.00
Waste	0.15974	17.80
Land Use	0.13705	15.20
Runoff	0.12636	14.00
Human Activities	0.08605	9.57
Demand	0.06291	6.99
Socioeconomic Development	0.06291	6.99
Population	0.03990	4.43
Rainfall	0.00416	0.46
Climate Change	0.00404	0.44

By examining the results in Table 4.5, it can be seen that “water quality” is more sensitive to “Waste”, “Land Use” and “Runoff”. This is what was expected after the model was constructed. The sensitivity analysis results, therefore, show that the model was behaving as expected. This meant that the values in the conditional probability tables and the structure of the model were correctly specified (Marcot, 2012; Marcot et al., 2006).

Sensitivity analysis is helpful in pinpointing key variables in the model whose change of state can greatly affect the overall model outcome. This enables attention to be focussed on activities that can significantly influence the states of those variables so as to achieve the desired outcome. This is helpful for identifying appropriate intervention options.

4.3.1.6 Identifying Interventions

After validating the model the next step was to identify possible interventions required to address the water quality problem. This task started by participants examining the model network. The model network shows that the quality of water is directly affected by waste and surface runoff (see Figure 4.7). This means that for an intervention to have a significant impact on the quality of water, it has to have a direct impact on either of these variables.

Participants listed possible interventions that they felt could be implemented to address the water quality problem (see Table 4.6). Participants then separated the interventions into those that they felt could be applied to address the waste issue and those that could be applied to address the surface runoff problem. Considering one issue at a time participants discussed the intervention options from which they opted for law enforcement to address the issue of waste, and restoration of wetlands and vegetation cover to address the issue of surface runoff.

Table 4.6: Table of possible intervention developed by workshop participants

#	Possible Interventions	Options supported by	
		Interviews	Other discussion
1	Eviction of encroachers from wetlands and forest reserves and demarcation of these areas	X	X
2	Restoration of wetlands and vegetation cover in degraded areas	X	X
3	Put in place a mechanism (e.g. revolving fund) to enable people engage in alternative activities to support their livelihood	–	–
4	Sensitisation of stakeholders on a range of water resources management issues	X	X
5	Step up enforcement of relevant laws to protect the water resources	X	X
6	Carryout water source protection in the catchment	X	–
7	Ensure implementation of good farming methods such as terracing to reduce erosion	X	X
8	Facilitate the Catchment Management Committee to carry out its functions by providing adequate funds	–	X
9	Devise mechanisms of Involving all the relevant stakeholders in managing the water system especially local communities because they are the people who are affected most and are the ones involved in the day-to-day activities in the catchment	X	X

Where: X means the option is supported, and – means there was no mention of that option

A key argument that weaved through most of the discussion was that most of the degradation happening in the catchment was due to people disregarding the provisions of the laws on one hand and inadequate enforcement on the other hand. Citing encroachment on wetlands and forest reserves, and indiscriminate disposal of waste as examples, participants said that the country had laws that were sufficient to address these issues but were not being adequately enforced. They cited The National Environment Act of 1995 as an example of legislation that could help address such issues but was not adequately enforced. This was an Act that provided for sustainable management of the environment in the country. Participants felt that if the laws were adequately enforced most of the degradation experienced in the catchment could be reduced or even reversed. They therefore opted to step up enforcement of the relevant laws as one of the intervention options.

Regarding restoration of wetlands and vegetation cover on degraded land, participants noted that these activities had already been implemented in some parts of the catchment. They felt that these activities needed to be scaled up to cover more areas in the catchment because they had shown a positive result in areas where they had been implemented. Participant however recognised that restoration activities often face challenges because of the need to evict encroachers, in which case it was necessary to enforce the relevant laws first before restoration activities could be effected. The two interventions were therefore found to be complementary.

The model was updated to incorporate these interventions. Each of the interventions was assigned "Yes" and "No" as the possible states of being implemented. Since the interventions had no parents in the network each of them was assigned an initial probability of 50%, as the probability of assuming either state (Cain, 2001). The revised model is shown in Figure 4.9.

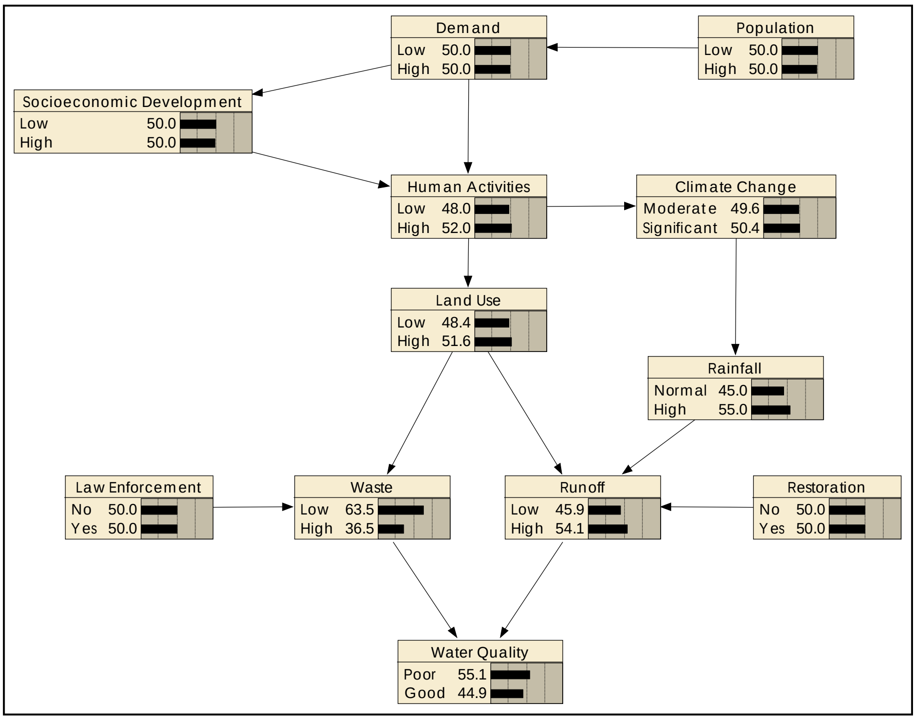


Figure 4.9: Revised Bayesian networks model

There seemed to be a common perspective within the catchment of the interventions required to address the water quality problem. Participants interviewed separately also supported the options suggested in the workshops, and so did various stakeholders with whom informal discussions were held (see Table 4.6).

There were some participants who would be affected by enhanced law enforcement. For example the sewerage services, beverages and diary companies. These companies operate wastewater treatment plants. The municipal council operates an abattoir that is supposed to have a wastewater pre-treatment facility. Effluent from these facilities is expected to meet some standards prior to discharge to the receiving environment. However, this has often been a major challenge. Participants from these organisations indicated willingness, on the part of their organisation, to improve the treatment systems so as to adhere to the required standards. Given that some investment could be required to achieve the necessary improvement in effluent quality, especially for the abattoir, compliance could become a real challenge.

There were also some stakeholders who did not participate but whose activities would be affected by enhanced law enforcement. For example, stakeholders who had encroached on wetlands and forest reserves to support their livelihoods. In Uganda such places are protected by law and people are not allowed to encroach. Encroachers would therefore have to be evicted from such places and the sites restored. Because those affected were absent, for some of the reasons mentioned earlier, it was not possible to get their views regarding this intervention or how it could be implemented. Given that it was about enforcing the laws of the country those affected would probably have limited options. However they could have used the forum to present their views or discuss their exit strategy to avoid a confrontational approach.

4.3.2 Using the Model to Make Decisions

The model developed can be run either in predictive mode or diagnostic mode. In predictive mode the model gives the most likely state of the quality of water whenever an observed state of any variable is entered into the model. In diagnostic mode whenever an observed state of the quality of water is entered into the model, the model will give the most likely cause of that observation. In order to use the model for decision making a scenario analysis was performed in predictive mode to simulate the effects of the different interventions on the quality of water under different scenarios.

By examining the model in Figure 4.9, it was observed that one of the main factors that controls the model outcome was population. A controlling factor is one that cannot easily be changed at local level but can have a substantial impact on the system (Cain, 2001). To enable assessment of the effects of the different interventions on the quality of water three possible scenarios of population were selected. These are “current population” – this was taken as the base case scenario, “low population” and “high population”.

The results of the scenario analysis, showing the possible effects of the interventions under different scenarios, were tabulated in interventions tables (see Table 4.7, Table 4.8 and Table 4.9 below). The results in the last column show the most likely effects of either implementing or not implementing a given intervention or combinations thereof on the quality of water, compared to the base case water quality. A positive change in the probability means an improvement in the quality of water is likely to occur while a negative change means deterioration in the quality is likely to occur. The larger the change in probability, the larger the most likely effect on the quality of water.

For example, the results presented in Table 4.7 indicate that if restoration activities were effectively implemented and law enforcement maintained at the current state of management (i.e. LE = X, R = 1), the quality of water was likely to improve. On the other hand if restoration activities were not implemented but law enforcement maintained at the current state of management (i.e. LE = X, R = 0), the quality of water was likely to deteriorate.

By examining the interventions tables for all scenarios it can be seen that good water quality is more likely to be achieved if both interventions are implemented at the same time under all scenarios. This is often the desired situation. However, due to resource constraints it may not be possible to implement all interventions at the same time. Participants also felt that implementing the interventions would require a lot of resources that the catchment management committee may find difficult to raise. For example, they said restoration activities will require seedlings, manpower, and compensation of people to be evicted among other things. On the other hand law enforcement will require recruitment and training of more law enforcement officers (the environmental police), sensitisation of communities, and demarcation of boundaries of protected areas. All these activities will requires resources.

Where it is not possible to implement all the interventions at the same time a choice can be made as to which intervention to prioritise for implementation. The interventions table enables such a decision to be made easily by considering an individual intervention that is likely to result in the highest positive change in probability (see last columns in the tables). In this case the intervention prioritised was “restoration” under current population scenario (8%) and low population scenario (8.5%). “Law enforcement” was prioritised under high population scenario (8.1%).

The scenario analysis enabled participants to appreciate the possible effects of the individual interventions, and combinations thereof, on the quality of water. The use of the model in this way enables stakeholders to make informed and justifiable decisions, especially when it involves selecting between competing alternatives. A participatory modelling exercise can, therefore, be a useful means of constructively involving stakeholders in decision making.

Though there was general support for law enforcement as one of the interventions, there was also a sense of frustration among participants because of past experiences where they said the laws had been “selectively applied”. Participants felt that political interference was a major obstacle to enforcing relevant laws in the country. This sentiment was also expressed in the National Development Plan 2010/11 – 2014/15, as one of the major constraints affecting the performance of the water resources management sector (GoU, 2010). However, there was a ray of hope because the army had started getting involved in enforcing some regulations to protect the environment in the catchment. The army’s intervention came through a presidential initiative code named “Operation Wealth Creation”, which was aimed at involving the army in poverty alleviation projects in the country. This, however, did not provide total assurance to some participants who expressed scepticism about the allegiance of the army.

Table 4.7: Interventions Table for Current Population Scenario

Current Population					
			Probability that state of water quality is		
#	Intervention	Implement	Poor	Good	Change in probability
1	LE , R	X , X	55.1	44.9	-
2	LE , R	X , 1	47.1	52.9	8.0
3	LE , R	X , 0	63.1	36.9	-8.0
4	LE , R	1 , 1	41.4	58.6	13.7
5	LE , R	1 , X	49.6	50.4	5.5
6	LE , R	1 , 0	57.7	42.3	-2.6
7	LE , R	0 , 0	68.4	31.6	-13.3
8	LE , R	0 , 1	52.7	47.3	2.4
9	LE , R	0 , X	60.6	39.4	-5.5

Table 4.8: Interventions Table for Low Population Scenario

Low Population					
			Probability that state of water quality is		
#	Intervention	Implement	Poor	Good	Change in probability
1	LE , R	X , X	46.2	53.8	-
2	LE , R	X , 1	37.7	62.3	8.5
3	LE , R	X , 0	54.8	45.2	-8.6
4	LE , R	1 , 1	34.7	65.3	11.5
5	LE , R	1 , X	43.4	56.6	2.8
6	LE , R	1 , 0	52.0	48.0	-5.8
7	LE , R	0 , 0	57.6	42.4	-11.4
8	LE , R	0 , 1	40.6	59.4	5.6
9	LE , R	0 , X	49.1	50.9	-2.9

Table 4.9: Interventions Table for High Population Scenario

High Population					
			Probability that state of water quality is		
#	**Intervention**	**Implement**	**Poor**	**Good**	**Change in probability**
1	LE , R	X , X	63.9	36.1	-
2	LE , R	X , 1	56.5	43.5	7.4
3	LE , R	X , 0	71.4	28.6	-7.5
4	LE , R	1 , 1	48.2	51.8	15.7
5	LE , R	1 , X	55.8	44.2	8.1
6	LE , R	1 , 0	63.5	36.5	0.4
7	LE , R	0 , 0	79.3	20.7	-15.4
8	LE , R	0 , 1	64.8	35.2	-0.9
9	LE , R	0 , X	72.0	28.0	-8.1

Where: LE = Law Enforcement, R = Restoration, 1 & 0 in the third column = Intervention implemented & not implemented respectively, and X = current state of management.

4.4 Factors that Influence a Participatory Modelling Process

The participatory modelling process afforded participants an opportunity to come together to share their experiences and knowledge of the water resources issues in their catchment. This enabled them to develop a shared understanding of the water resources issues affecting them. Overall the participants rated the participatory modelling process highly and expressed satisfaction with it. The major factors that influenced the overall participatory process were: (i) the selection of relevant stakeholders to participate in the modelling exercise, (ii) the type of model used during the modelling exercise, and (iii) the model building exercise. Each of these factors is explored in detail in the following subsections.

4.4.1 Selection of Relevant Stakeholders

It was crucial that "information-rich" participants were identified and involved in the modelling exercise. Participants were essentially the ones driving the modelling exercise by providing the required information. Their knowledge, experience and expertise of water resources issues in the catchment played a key role in identifying water resources issues as well as intervention options.

The method used to select participants enabled selection of a group of stakeholders (see Table 3.1), from whom a range of views, knowledge, expertise and experiences of water resources issues in the catchment were realised. These qualities proved vital during the model development exercise where they were required most. Individuals with these qualities could probably have been missed if the selection process had not taken into account these requirements.

As other authors have reported (Bromley et al., 2005; Chan et al., 2010; Zorrilla et al., 2010), it was found more practical to work with a small group of participants. The discussions were more orderly and focussed, all participants had opportunity to make contributions and key issues were adequately discussed. This assessment was shared by participants. This was reflected in their responses to the open questions in the evaluation questionnaires. One participant commented that "*all participants were given a chance to share their ideas based on their experiences and observations in the catchment*".

4.4.2 Choice of Modelling Tool

The Bayesian networks model used in the modelling exercise played a key role in realising active involvement of the participants because of some of its unique characteristics. These characteristics are:

(i) *Flexibility:* The Bayesian networks model is flexible and this allowed new ideas to be fed in and adjustments to be made in response to the changes in participants' knowledge of the water system and the issues therein. This characteristic was important because participants' knowledge of the system kept evolving as they discussed and shared their experiences during the modelling exercise, and this needed to be incorporated into the model. This characteristic enabled the modelling process to be adaptive and therefore responsive to participants needs.

(ii) *Use of networks:* The model uses networks to represent relationships between variables. The use of networks ensured that the model could accommodate a large number of variables. This was particularly useful for capturing participants ideas during the conceptualisation stage of the process. It also enabled simplification of the model during the modelling exercise. Simplification was necessary in order to remove redundant variables and improve clarity. This characteristic ensured that all aspects to water quality, including causes and possible intervention measures, were taken into account.

(iii) *Use of probability theory*: The Bayesian networks model structure essentially represents a probabilistic relationship between variables. The use of probabilities ensured that uncertainty in the information used to build the model was taken into account. This was important because the information provided by the participants during the modelling exercise was mainly a subjective evaluation or account of events in the catchment. This type of information can be fraught with uncertainty and therefore needs to be appropriately represented (Bromley, 2005; Cain, 2001).

(iv) *The graphical display of the model:* The Bayesian networks model's graphical display was helpful as a visualisation aid. This enabled participants understand the relationships between variables and to follow the discussions accordingly. Participants rated the graphical display highly and were particularly impressed by the logical and sequential way in which the variables were arranged. This, they said, made it easy for them to understand the relationships expressed; for example, the knock-on effects of increasing population.

(v) *The capability to perform scenario analysis:* A Bayesian networks model has capability to perform predictive and diagnostic analyses. When the model was run in predictive mode, this capability enabled participants to appreciate the possible effects of the proposed interventions, and combinations thereof, on the quality of water in the catchment, and to prioritise the different interventions. In diagnostic mode, this capability enabled participants to appreciate the actions that would need to be taken in the catchment in order to achieve the desired state of water quality. This capability was essential for identifying management interventions which offer the highest probability of addressing the water quality issues in the catchment. The Bayesian networks model, therefore, didn't only facilitate understanding for the participants but also offered quantitative rigour in decision making.

(vi) *Ability to consider both qualitative and quantitative data:* The participants included people with numerical expertise and others with little or no numerical experience. This capability ensured that all participants were involved in the discussions. It enabled them to express their knowledge of issues and variables according to their own experiences and understanding.

Participants generally rated the model building exercise highly. All of them indicated that the exercise helped improve their understanding of water resources issues in the catchment. This was also reflected in their responses to the evaluation questionnaire (see Figure 4.13).

The downside with the Bayesian networks model, however, is the time needed to populate the conditional probability tables. The task of populating the conditional probability tables was time consuming but generated lots of discussion. It also appeared to have tired out some participants. They often drifted to side conversations and to their mobile phones. However, they were regularly engaged in the discussion by asking their views on the issues being discussed. This helped to maintain their attention.

4.4.3 The Model Building Exercise

The model building exercise was the core activity of the whole process. The model building exercise played a key role in encouraging the discussions among participants and in maintaining the process focus. It enabled participants to raise and share their concerns, experiences and knowledge about water resources issues in the catchment. The model building exercise, and in particular the discussion that happened among the participants, was the most the most important aspect of the participatory process because it afforded participants opportunity (i) for dialogue, (ii) to learn from each other, (iii) to network and build relationships, and (iv) to be involved in making decisions on issues that affect them.

Workshop facilitation skills were an asset on the part of the facilitator for guiding the modelling exercise. These skills were found helpful for harmonising differences in perspective among participants. The facilitator also needed to have knowledge of the modelling tool. This was useful for explaining or clarifying model behaviour at some point during the exercise.

4.5 Benefits of Participatory Modelling

The extent to which the participatory modelling process delivered benefits for water resources management was assessed. The findings are presented in the following subsections.

4.5.1 Normative Benefits

The assessment of the normative benefits focussed on the extent to which the process: (i) provided a platform for dialogue, (ii) was transparent, and (ii) was representative of stakeholders in the community.

4.5.1.1 Platform for Dialogue

The participatory modelling exercise provided a platform through which stakeholders came together and jointly deliberated issues of concern, and came up with possible strategies for addressing them. The model played a key role as a tool for facilitating and focussing discussion. The model building exercise enhanced dialogue among participants enabling them to explore water resources issues, appreciate each other’s concerns and learn from each other. Participants generally felt that the modelling exercise provided a suitable platform that enabled them to come together for dialogue.

4.5.1.2 Transparency of the Process

Participants were involved in all stages and all tasks of the modelling exercise. This ensured that they were part of the process right from the outset and therefore knew how all the decisions were arrived at.

The Bayesian networks model used in the exercise was flexible to accommodate participants ideas as they evolved during the exercise. The graphical interface of the model played a key role as a visualisation aid and enabled participants to follow and understand the discussions. These characteristics of the model were key for ensuring constructive engagement and transparency of the process.

Ground rules were set to govern participants conduct during the workshops. These were helpful in ensuring order and respect for each other's views throughout the modelling exercise. They also ensured that each participant was given opportunity to be heard and controlled the verbally active ones from domineering the discussions.

4.5.1.3 Representation of Stakeholders

The choice of participants to be involved in the participatory modelling exercise was crucial for meaningful engagement to be realised. The participants were purposively selected on the basis of their knowledge, experiences and expertise of water resources issues in the River Rwizi catchment. They were, therefore, not representative of the wider stakeholder community. However, they had specific knowledge, experiences and expertise that was considered fairly representative of that of the wider stakeholder community. These requirements proved essential during the modelling exercise as they enriched the discussions leading to useful outputs.

Participant appreciated inclusion of a range of stakeholders with different backgrounds in the modelling exercise. They felt it allowed different perspectives to be heard and provided learning opportunity for all involved. It was therefore important that the method of selecting participants took this into account.

It was found more practical to work with a small group of participants. Discussions were orderly and it allowed direct interaction among participants. Some participants however felt that it would have been better to involve more stakeholders, especially the youth, so that they can also contribute to the management efforts. They seemed to suggest a need of more representation of different stakeholder groups in the process. This would make the number of participants bigger. Some studies, however, suggest that the gains in terms of additional useful contributions in a large group may be minimal compared to the cost (Krueger et al., 2012).

It was, however, not possible to involve all the stakeholders who had been identified. There were some individuals who were mining sand in the riverbed and banks of the river (see picture No. 4 in Table 4.10). There were also others who were making bricks on the shores of the river (see picture No. 2 in Table 4.10). These activities had an impact on the quality of water in the river by exposing the soil to agents of erosion. These individuals were therefore targeted for selection as key stakeholders. However they had been banned from carrying out those activities in the said sites; though some activities were still going on illegally. Some of them had been arrested and were due to be arraigned in court. Because of this there was tension between these individuals and the local authorities. Attempts to contact them were futile as they viewed most people with suspicion. It was therefore not possible to capture their views and concerns during the participatory process.

4.5.2 Substantive Benefits

The assessment of the substantive benefits focussed on the extent to which the process: (i) enhanced participants knowledge and understanding of water resources issues in the catchment in a social learning process, (ii) afforded participants opportunity to take part in decision making, and (iii) enhanced building of relationships among participants.

4.5.2.1 Social Learning

The participatory modelling exercise allowed participants to freely interact and share knowledge, ideas and information in a workshop environment. At the end of the exercise participants expressed a better understanding of water resources issues in the catchment and in particular the relationships between the various variables, and their contribution to the quality of water. This was reflected in the discussions and in their response to the evaluation questionnaires as shown in Figure 4.10, Figure 4.11

and Figure 4.12. The figures show participants knowledge of different issues before and after attending the modelling workshops.

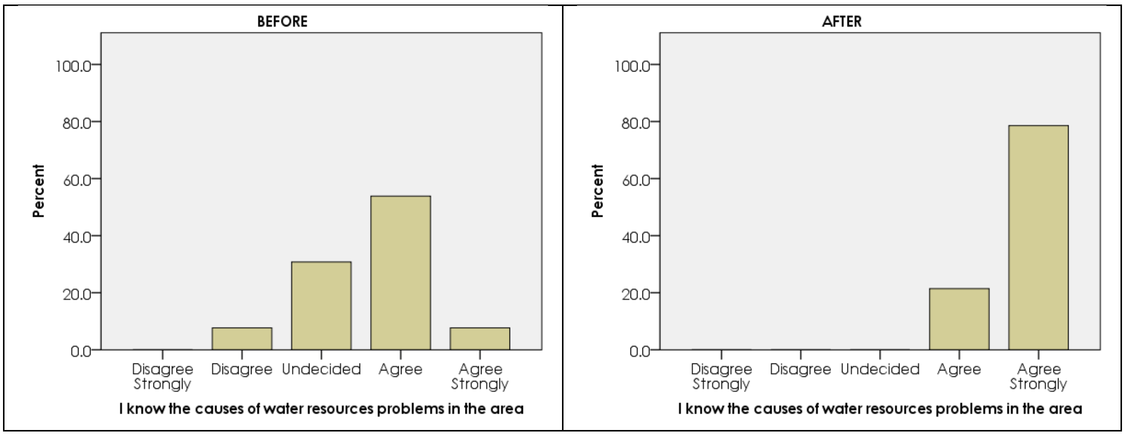


Figure 4.10: Evaluation results showing participants knowledge of causes of water resources issues

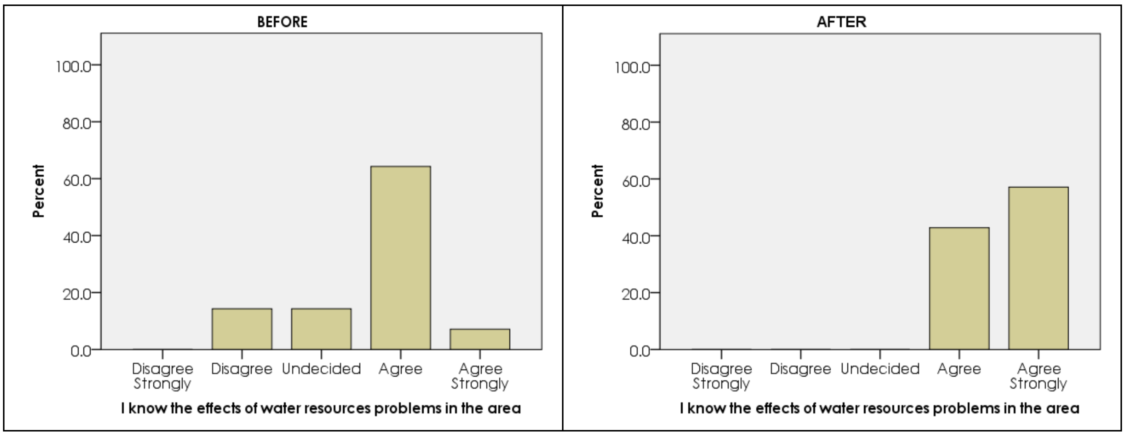


Figure 4.11: Evaluation results showing participants knowledge of effects of water resources issues

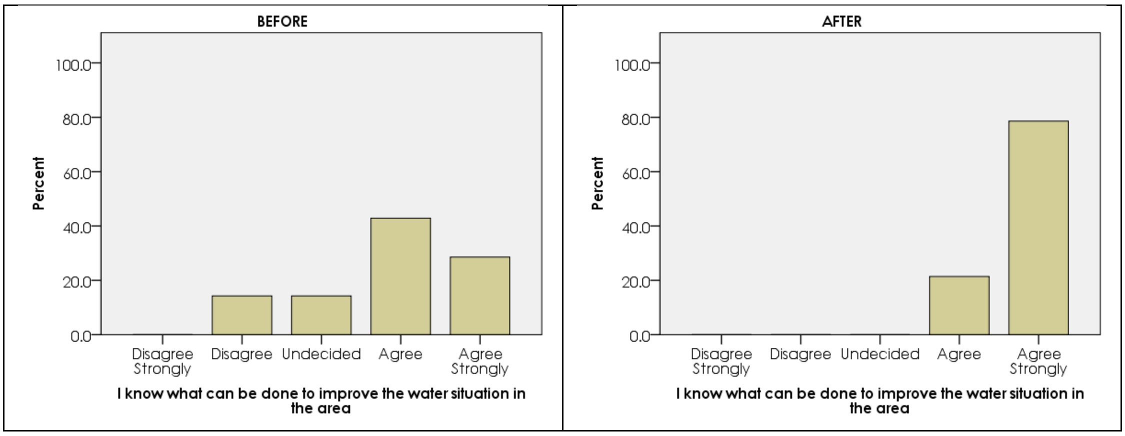


Figure 4.12: Evaluation results showing participants knowledge of solutions to water resources situation in the catchment

Evaluation results (see Figure 4.13), show that participants valued the exercise of jointly developing the model as the main contributor to the learning process. They felt the process enabled sharing of knowledge and ideas among the different participants thereby allowing them to learn from each other. For example, the water supply company shared their experience of how the deterioration in the quality of water in the River Rwizi, their main source of raw water, had made it increasingly expensive to produce potable water. A participant commented that "*I learnt a lot from colleagues that participated*", while another commented that he "*liked the sharing of knowledge which helped come up with solutions to water resources management issues*".

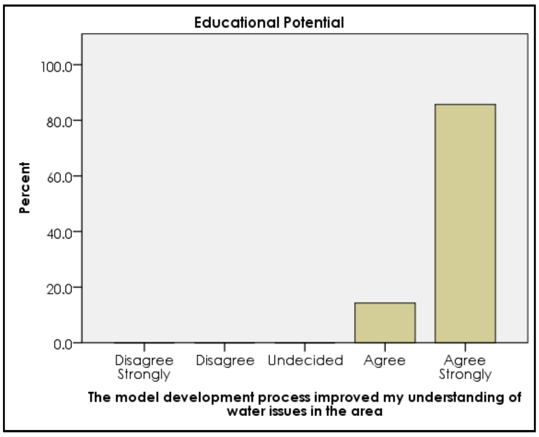


Figure 4.13 Evaluation results showing the educational potential of the process

Participants also valued the role played by the graphical display of the model to the learning process. It was particularly appreciated as a visualisation aid, enabling participants understand the relationships between various variables and the knock-on effects a change of state of a variable can have on other variables linked to it. The numerical output of the model was valued for enabling participants to compare the states of the variables.

Some participants, however, found the task of populating the conditional probability tables challenging because they had difficulty estimating the probabilities. This challenge was addressed by giving participants guidance to help them make appropriate estimates of the probabilities. Some participants also felt that the modelling exercise could be made more practical by including joint field visits as part of the exercise. They felt this would enable participants to get a better understanding and appreciate what was being modelled.

The participatory modelling exercise achieved two-way learning between the participants and the facilitator/researcher. On the one hand the researcher gained a better understanding of the actual water resources challenges in the catchment as a result of direct involvement in the process. This helped the researcher to get a balanced view of issues in the catchment. The improved understanding was useful for facilitating the modelling exercise. On the other hand participants learnt the aspects of participatory modelling and the logic of conditional probabilities. Referring to the logic of conditional probabilities a participant indicated that it was something that was applied in everyday situations when making decisions. He however hastened to add that they often didn't quantify the likelihood of events in terms of figures. The educational potential of a participatory modelling process has also been recognised by other authors (Carmona et al., 2013; Gaddis et al., 2010; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010; Zorrilla et al., 2010).

4.5.2.2 Decision Making

The participatory modelling exercise enabled participants to jointly identify and analyse water resources challenges affecting them. It also enabled them identify, test and prioritise strategies for addressing the water quality problem; which was identified as the main issue of concern. In so doing a participatory modelling exercise essentially constitutes a decisional process.

All participants felt that the model building exercise provided a suitable opportunity for them to participate in making decisions concerning the management of water resources in the catchment. This was reflected in the discussion with them and in their responses to the evaluation questionnaires as shown in Figure 4.14 below. Participants were generally satisfied with the interventions proposed. They felt the interventions would address the concerns on the ground if effectively implemented

Overall participants expressed satisfaction with the method used to identify the problem and interventions. A common theme in all their responses was appreciation for the involvement of all participants in "troubleshooting/brainstorming the water resources issues".

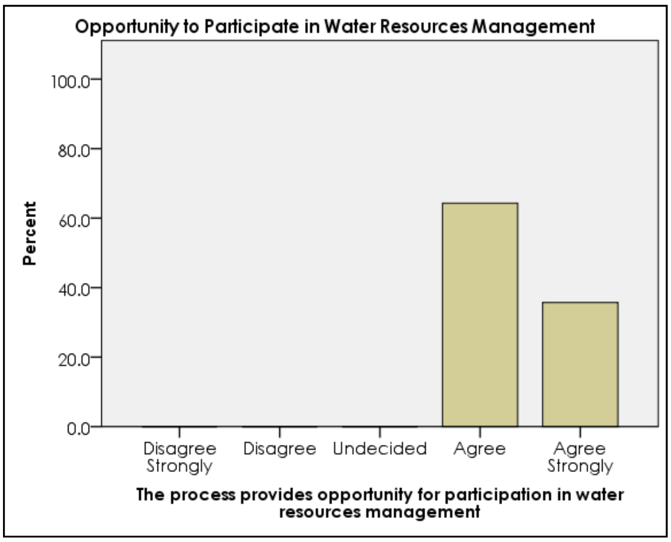


Figure 4.14: Evaluation results showing whether the process provided opportunity to participate in managing water resources

4.5.2.3 Relationship Building

Participatory modelling affords participants opportunity for networking and building relationships. By the end of the workshops the interactions between participants were clearly more fluid compared to the beginning. Most participants had not interacted closely before the workshops despite the fact that they all came from the same catchment. Participating in the workshops had enabled them to come together and know each other better. Some participants were seen exchanging contacts.

4.5.3 Instrumental Benefits

The assessment of the instrumental benefits focussed on the extent to which the process: (i) enhanced stakeholder trust, and (ii) integrated stakeholder and expert knowledge into useful outcomes.

4.5.3.1 Stakeholder Trust

Involving participants in all stages of the modelling exercise ensured that they knew how all the decisions were arrived at. It also ensured that they were part of the decision making process right from the outset and had opportunity to have a say. This was helpful for building participants sense of trust and confidence in the process and its outcomes.

Participants were generally positive about the modelling exercise. They felt that the exercise was good for collectively generating ideas and formulating strategies to address the water issues in the catchment. They appreciated the fact that the interventions suggested were based on their collective views. They all indicated approval of the interventions proposed as reflected in the evaluation results shown in Figure 4.15. A participant from the River Rwizi CMC showed keen interest in the process outputs and wanted them to be integrated into the catchment management plan which was due to be prepared. This seems to have boosted participants' optimism about possible implementation of the modelling outputs.

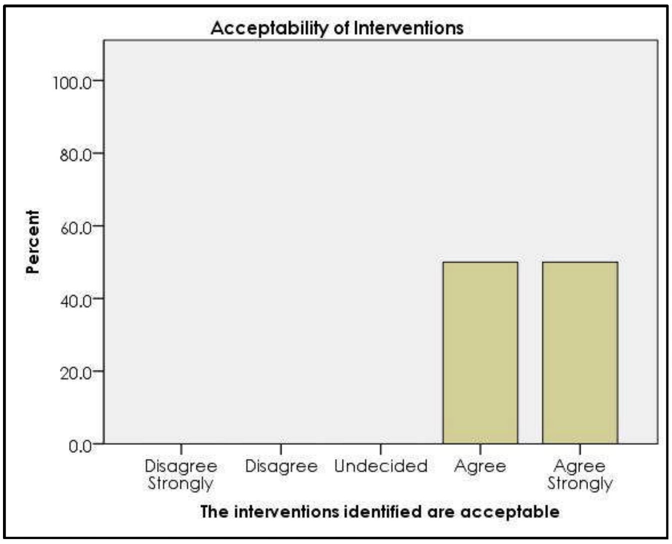


Figure 4.15: Evaluation results showing acceptability of the interventions

4.5.3.2 Knowledge Integration

Participants for the modelling exercise were drawn from the wider stakeholder community. Each came with their own perceptions, knowledge and experiences of water resources issues in the catchment. Ability to combine these into coherent mutually useful outcomes was important.

The Bayesian networks model used in the study provided a framework for integrating participants knowledge and experiences. Its ability to capture both qualitative and quantitative information was a useful attribute that enabled all participants to be actively involved. The result was a model that reflected participants understanding of the water resources situation in the catchment. Participants valued the fact that their views had been integrated into the model. They felt that by so doing their views could contribute to decisions geared towards addressing the water situation in the catchment

4.6 Chapter Summary

A participatory modelling exercise was set up to directly and interactively involve participants: (i) in identifying the main water resources problem in the River Rwizi catchment as well as the possible intervention options needed to address the problem, and (ii) in assessing the effects of applying different interventions, and combinations thereof, on the problem identified. Participants were involved in all stages of the model building exercise. This chapter has provided a detailed analysis of the participatory modelling process.

Following an assessment of the water resources issues in the catchment participants identified water quality as the main water resources challenge being faced in the catchment. This was at the problem identification stage of the model building exercise. Participants quantified the model by populating the conditional probability tables and proceeded to identify possible interventions to address the water quality problem. The interventions identified were law enforcement to address the issue of waste, and restoration of wetlands and degraded land to address the issue of surface runoff. The model was validated and used to assess the effects of applying different interventions, and combinations thereof, on the quality of water in the catchment. This enabled participants to prioritise restoration of wetlands and degraded land as the intervention that could provide the best possible outcome.

Analysis of the participatory modelling process revealed three main elements that influenced the process. These were: (i) the stakeholders selected to take part in the modelling exercise, (ii) the modelling tool used, and (iii) the model building exercise.

Process analysis also revealed some benefits of participatory modelling. These include: (i) it provides a platform for dialogue; (ii) it provides support for decision making; (iii) it provides opportunity for learning; (iv) it enhances stakeholder trust; and (v) it enhances stakeholder relationships. These results provide a basis to support the case for stakeholder participation.

4.7 Field Observation Photos

Table 4.10: Field observation photos – Table 1

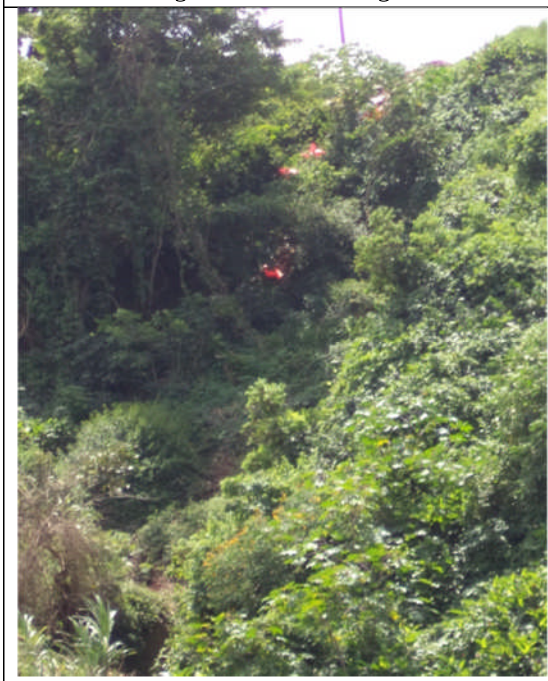
 1. Road works north of Mbarara town	 2. Effect of clay mining for brick making next to the River Rwizi
 3. Cattle resting area after drinking water	 4. Sand mining from the riverbed
 5. Biohazardous hospital waste washed down towards the river	 6. Cattle track on a hill slope leading to the river

Table 4.11: Field observation photos – Table 2

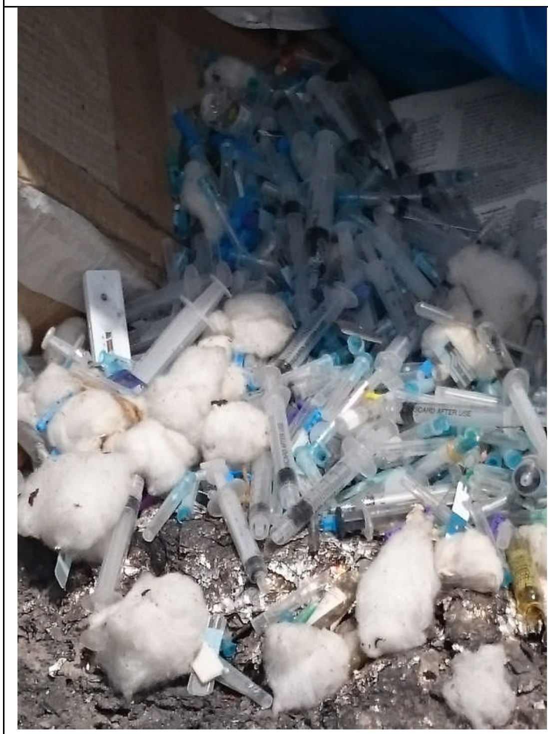
 1. Hospital open damping site & an incinerator	 2. Cattle horns and hooves at the abbatoir compound
 3. Wastewater from the abbattoir draining to the river	 4. Poorly managed cattle dung in the abbatoir compound
 5. Hospital waste in a nonfunctional incinerator	 6. Abbatoir drainage draining to the river

Table 4.12: Field observation photos – Table 3

 1. Effluent from a dairy factory’s non-functional wastewater treatment facility discharging to the river	 2. A dairy factory’s non-functional wastewater treatment facility
 3. Sewage treatment ponds	 4. A disused sampling canoe in the sewage treatment plant
 5. Poorly managed solid waste from	

Chapter 5

Mobile Data Collection

5.1 Introduction

Water resources management requires field information about the various activities and changes taking place in a catchment to be collected and analysed for planning purposes. The traditional way of collecting such data is the paper-based method whereby individuals fill out forms in the field and deliver them to the office from where the data collected is entered into a computer and analysed. Whereas this is a well-established method, it is also labour intensive, time consuming and prone to transcription errors (Lozano-Fuentes et al., 2012; Lugo and Ortega, 2015; Tomlinson et al., 2009).

With the advent of mobile phone technology, mobile data collection methods have emerged as attractive means of involving stakeholders in water resources management activities such as collecting field information about various activities and changes taking place in a catchment. However, this method has not yet been explored in the field of water resources management. It is within this context that this part of the study set out to investigate the feasibility of mobile data collection as a method of involving stakeholders in the management of water resources.

In order to achieve this goal a mobile data collection system was developed and tested with a select group of stakeholders in the River Rwizi catchment, in western Uganda. The objective was to involve participants in collecting and transmitting field data using a mobile data collection system.

This chapter presents the findings of this part of the study. In the next section a brief description of the methodology used is presented. This is followed by analysis of the key findings. The final section presents a brief discussion of the findings.

5.2 Methods

An open source tool kit, Open Data Kit (ODK) (Open Data Kit, 2014), was identified through desk study. This tool kit was used to develop a web-based mobile data collection system as described in Section 5.2.1 below. The ODK tool kit was selected because: (i) it could be used to develop a system capable of transmitting text, images and GPS positions. This feature was important for ensuring complementarity of the data collected. and (ii) it was freely available, given the limited resources available for the study.

The system developed enabled field data to be collected using a smartphone or similar GPRS enabled device. Seven volunteers with smartphones were identified and trained on how to use the system to collect data. These volunteers were among the participants who had already been purposively selected to take part in a parallel study in water resources management using a participatory modelling approach. They were, therefore, already suitable candidates for this exercise. All that was required of them was possession of a smartphone or similar device and willingness to take part in the field trials. The functionality of the system was tested by conducting preliminary data collection.

5.2.1 Developing a Mobile Data Collection System

Following initial consultations with some stakeholders a preliminary mobile data collection system was developed using the ODK open source tool kit. The steps followed in developing the system are summarised in Appendix K. The only hardware required to use the system is an Android-based GPRS enabled mobile device.

To use the system one needs to download, install and appropriately configure the ODK Collect app to their mobile device. The ODK Collect app is freely available from Google Play Store. The configuration involves assigning an appropriate URL for the App Engine, which in this case is “cen9c2e.appspot.com”. This allows the device to connect to the App Engine so as to download the data collection form and also submit data to the storage server.

5.2.1.1 Preliminary Data Collection

The system was tested by carrying out preliminary data collection. This was meant to ensure that the system was working properly before introducing it to the selected participants. The system is simple to use once it is properly setup in the mobile device. Once at the site where data is to be collected, what is required is to open the ODK Collect app in the device, select to fill a blank form, and then select the appropriate form from the options available (see Figure 5.1). Proceed to the subsequent screens as shown in Figure 5.2 and enter the required information. Save the completed form to the device before moving on to the next site. The completed forms can be kept in the device and uploaded to the server any time after collecting the data. A new form is required for each data point.

On all occasions the completed forms were stored in the phone mainly for two reasons. Firstly because the mobile network coverage out in the field was so poor, and often not available, to allow upload of the data to the server. Secondly, there was need to crosscheck and edit some of the data, especially the names of locations, before uploading. Once back from the field the forms were checked and, were necessary, edited prior to uploading to the server. The data collected include sand mining points, cattle watering points, water and wastewater treatment facilities, solid waste disposal points, agricultural activities, brick making activities, among others. When the preliminary data collection was completed, the data collected was analysed.

The setup of the system did not allow the coordinates of a location to be manually entered into the system. The GPS position was automatically recorded by the device by a touch of a button. It therefore meant that the person collecting data had to be physically present at the site so as to record the correct GPS position. This was meant to ensure accuracy of the data point for mapping purposes. It was also meant as a way of reducing data fabrication. The GPS coordinates would complement the field notes and photographic evidence. The setup also prohibited advancing to the next steps before capturing the GPS coordinates, taking a photo or entering field notes, depending on the window open at the time.

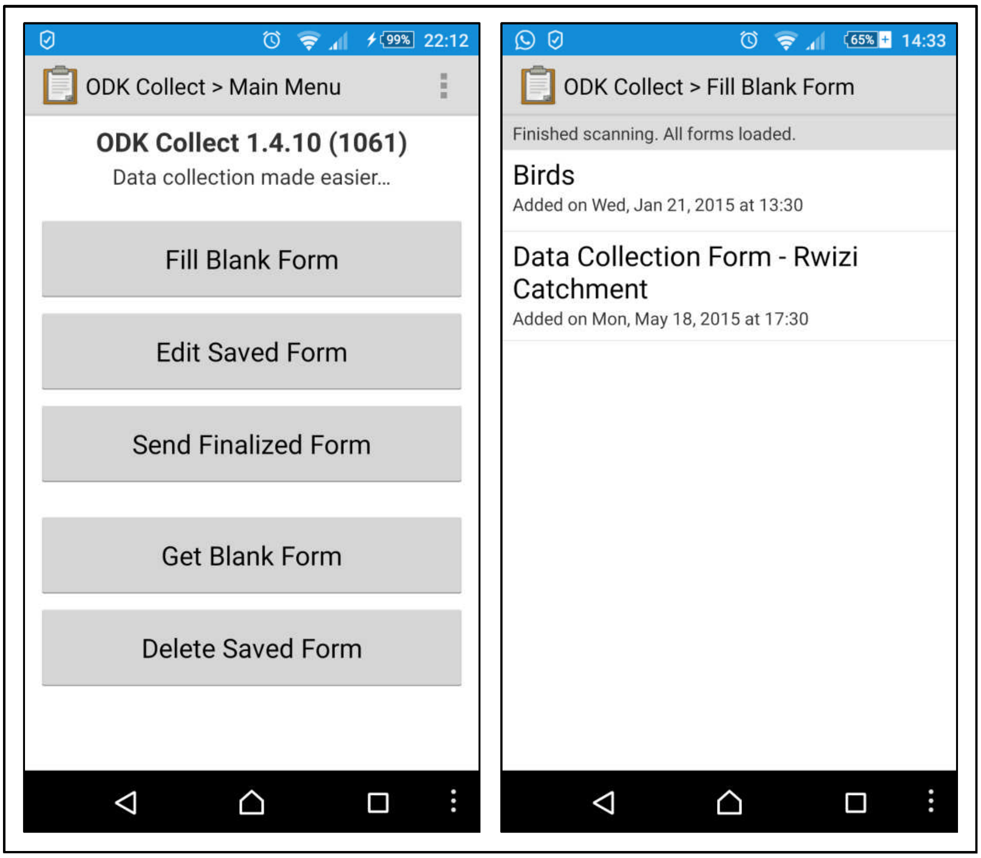


Figure 5.1: A screenshot of the ODK Collect app

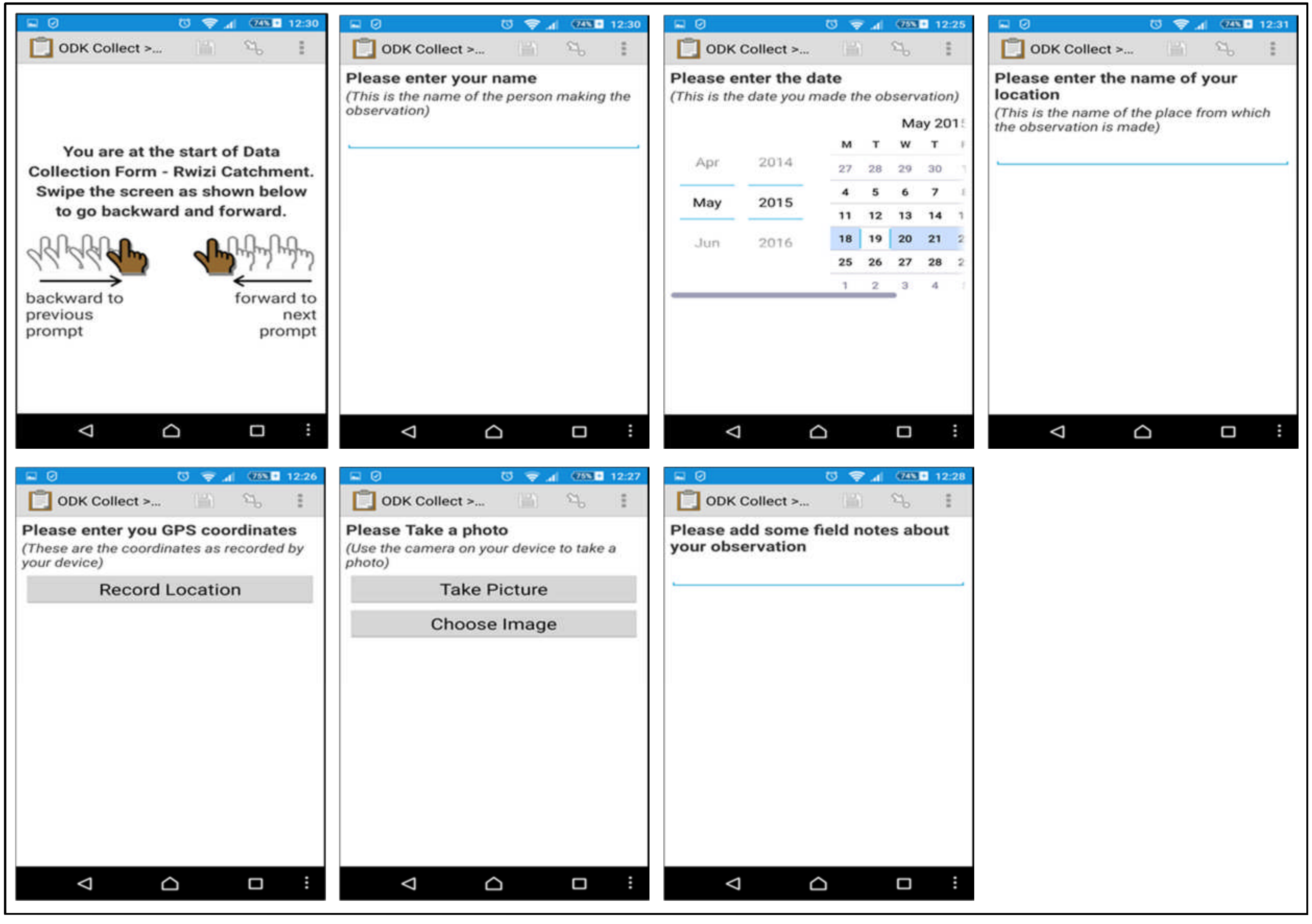


Figure 5.2: Screenshots of the data collection form downloaded to the phone using the in ODK Collect app

5.2.1.2 Preliminary Field Results

Figure 5.3 shows some of the data collection points displayed on Google maps. Each point on the map represents a data collection form submitted for that point. To view the information associated with a submission for a particular point on the map, select the point by clicking on it and the information will appear as for the point shown in Figure 5.3. These results were presented to the selected participants during the training session to show them how the results appear on Google maps after submission.

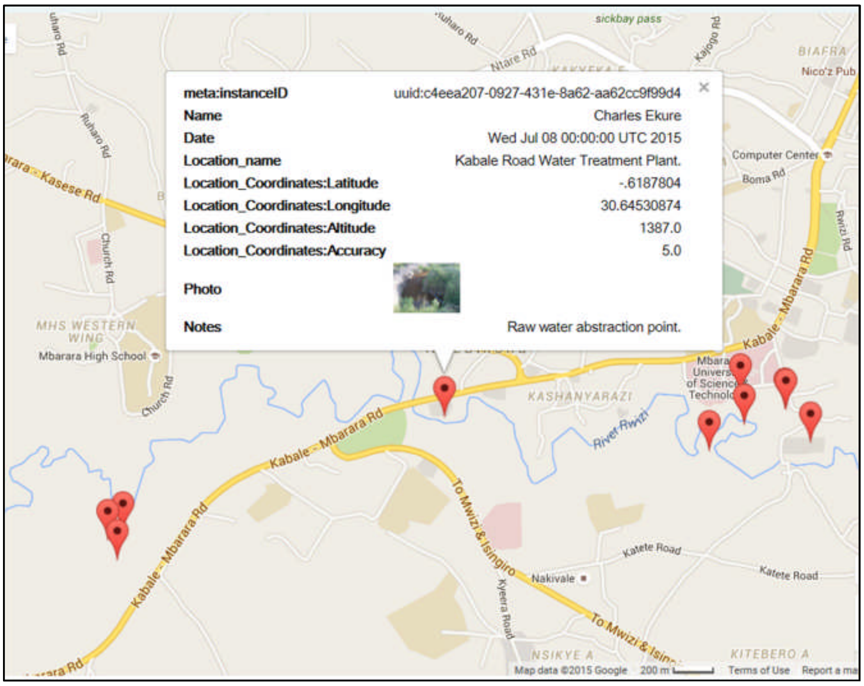


Figure 5.3: Results of the preliminary mobile data collection exercise. Data collection points displayed on Google maps

5.2.2 Participant Training

The seven participants selected to take part in the pilot mobile data collection exercise were trained how to use the system. Participants were taken through the steps of manually developing a data collection form on paper. This involved specifying a few parameters that were required on the form such as name, date, location, and field notes. The field notes give brief comments about the observation made. The same form was then developed using the ODK Build module of the tool kit. This part of the training was meant to show participants that the forms that are used in the system are not different from those that are used in a manual data collection exercise. The completed form was uploaded to the App Engine, from where it was available for participants to download to their devices.

Participants were then taken through the process of downloading and configuring the ODK Collect app to their devices so that they could be able to download the form and use the system for data collection. At this point we started experiencing challenges. Of the seven participants only one was able to download and successfully configure the app to his device. The reasons for the participants' failure to download the app were not immediately clear. However, it later became apparent that there were problems with the specifications of most of the participants devices, and internet network connectivity.

The participant's phone that had successfully installed the ODK Collect app was used to download the data collection form from the App Engine. It was also used to demonstrate the process of collecting data while in the field and how to submit the completed form to the online server. Finally the data submitted was shown to participants. At this point the preliminary data collected was also shown to participants who looked visibly impressed when they saw the data displayed on the internet.

5.3 Analysis of Key Findings

The challenge with the devices highlighted above did not allow the participants to take part in mobile data collection. As a result it was not possible to assess their hands-on experience of mobile data collection. However, the participants' theoretical perspective of mobile data collection as a method of involving stakeholders in water resources management was assessed. This followed a demonstration of the method during the training session.

The evaluation was carried out by discussions with participants during and after the training, and using questionnaires (see Appendix J) distributed to participants at the end of the training session. The data from the evaluation questionnaires were compiled and analysed using IBM SPSS Statistic. The participants' perspective of the system is presented in the following sub-section.

5.3.1 Participants Perspective of the Mobile Data Collection System

Following the demonstration of the data collection system participants discussed possible uses of such a system in the catchment. Participants were particularly impressed by its ability to transmit images and GPS positions. Because of this they felt that the system could be used as a tool for monitoring and reporting activities that affect the environment. They cited activities such as encroachment on wetlands, felling of trees, bush burning and poor farming practices among others.

Participants also felt that the system could help in mapping out what they called the environmental “hot spots” in the catchment. These were areas where there was severe degradation of the environment. They felt that the images could serve as photographic evidence which could be preserved for future reference, especially when assessing improvements where interventions have been implemented or further deterioration where no action taken has been.

Participants also felt that the system could provide a convenient way of sharing information with relevant government institutions in times of emergencies, such as during times of flooding, extreme drought or disease outbreak. They felt this could ensure that all institutions have the same version of events on the ground and enable coordinated and timely response by the responsible authorities.

Some participants, however, expressed reservations about the system. They had three points of concern. First participants felt that the costs of the devices that were required to use the system were prohibitively high. They said most of the affordable devices available on the local market were of low specifications and therefore unlikely to cope with the requirements of the system. This was in reference to the processor speed of the devices, which appears to have been the problem with most of the participants devices. This had made it difficult for them to download the ODK Collect app. This problem was compounded by availability of many counterfeit devices on the local market.

The second concern was the poor internet connectivity and mobile network coverage. The Mobile network coverage was so poor, especially in the rural and peri-urban areas. This is an issue that was experienced first-hand during the conduct of this study whereby it was not possible to upload any data collected while out in the field. Most rural locations had no mobile network coverage. Even in some urban areas mobile network coverage was poor. These challenges made it difficult to accomplish tasks such as downloading or uploading data. Sometimes it would require several attempts before such tasks were completed. This limited the ability of most people to use internet services especially where transfer of large amounts of data was involved.

The third concern was the cost of data for internet connection. Participants felt that the cost of internet data bundles was quite high, especially for the ordinary person. These concerns constitute major obstacles to the potential adoption and use of mobile data collection as a method of involving the local community in water resources management efforts.

5.4 Chapter Summary

The study set out to investigate the feasibility of mobile data collection as a method of involving stakeholders in the management of water resources. To that end a web-based mobile data collection system was developed and tested. Participants were recruited and trained to use the system for field trials of mobile data collection.

However, there were challenges of poor internet connectivity, and low specifications of participants devices in terms of processor speed. These challenges prevented participants from taking part in the field trials. The evaluation was therefore carried out based on the participants theoretical perspective of the system.

Participants were generally happy with the mobile data collection system. They rated it highly and felt that it could have been a useful method for monitoring various activities affecting the environment, and mapping out what they called environmental “hot spots”.

Chapter 6

Enabling Environment for Water Resources Management

6.1 Introduction

As water resources challenges continue to mount, the concept of IWRM continues to be widely promoted and adopted as an approach for ensuring sustainable development and management of available water resources (UN-Water, 2015). Implementation of IWRM however is both politically and technically challenging. The overlap between political administrative boundaries and the catchment within which IWRM is to be implemented presents challenges of power struggle in decision making as well as selection of those to participate (Blomquist and Schlager, 2005). This is further complicated by multiple and often conflicting interests in the water resources within a catchment and the scale of coordination required among the relevant sectors.

Successful implementation of IWRM, however, entails bridging the gap between the theoretical principles on which the concept is based and their practical implementation (Rahaman, 2009; Wilkinson et al., 2016). One of the key principles that underpin IWRM is the need for participatory involvement in the management of water resources. However, efforts to involve stakeholders in water resources management have often registered little success (Agyenim and Gupta, 2012; Irvine and O'Brien, 2009; Jingling et al., 2010; Teodosiu et al., 2013; De Stefano, 2010).

Realising stakeholder involvement requires that the prevailing governance arrangements support participation. To that end the GWP suggests putting in place a framework for water resources management with clearly defined institutional roles and practical management instruments (GWP, 2004). This framework is expected create an enabling environment that supports implementation of IWRM principles. Countries such as South Africa, Tanzania, Mexico, Ghana, Uganda and India, that have attempted to implement the concept of IWRM, have followed this route and instituted policy and institutional reforms to create an enabling framework to support implementation of the IWRM principles (Agyenim and Gupta, 2012; Petit and Baron, 2009; Rahaman, 2009; UNEP, 2012). However, few studies have attempted to assess the extent to which creating an enabling framework for water resources management does in fact result in implementation of the IWRM principles (Agyenim and Gupta, 2012; Gupta, 2010; Ioris, 2008). It is within this context that this study assessed the extent to which the water resources management framework in Uganda provides an enabling environment that supports stakeholder participation.

The study was conducted in Uganda; which is one of the countries that is implementing IWRM as a means of improving the management of its water resources. In order to achieve the goal of the study the water resources management framework of Uganda was examined. Document review method was used to identify key policy and legislative instruments that govern the development, management and use of water resources in Uganda.

IWRM requires a coordinated participatory approach to water resources management. In order to realise participatory involvement appropriate governance arrangements are necessary (GWP, 2017). The evaluation criteria where identified based on the governance arrangements needed to support participation and the extent to which these were reflected in the policy and legislative instruments as well as in the management arrangements. The key governance arrangements include incentive to promote stakeholder participation, financial resources and human capacity needed to support implementation of the participatory process and enforcement of policies, as well as coordination among sectors (GWP, 2017). The analysis involved examining statements in the documents that relate to aspects of involvement in water resources management as well as provisions made for financial resources and human capacity to implement activities related to water resources management. The findings are presented in the sections that follow.

6.2 Uganda's Water Resources

Uganda is a landlocked country located in Eastern Africa, with an estimated population of 34.6 million people and an annual population growth rate of about 3% (UBOS 2016). Uganda is endowed with several freshwater resources including Lake Victoria, which is one of the largest freshwater lakes in the world. Uganda lies in the

Nile basin with most of the country lying in the upper Nile. The four major lakes in the country are Lake Victoria, Lake Kyoga, Lake George and Lake Albert, while the major rivers include the River Nile, River Mpologoma, River Katonga, River Rwizi, River Kafu and River Aswa. Apart from these there are over 160 other minor water bodies scattered across the country. There are also dams and valley tanks most of which are used for livestock watering and aquaculture. Surface water is the major source of water for various activities such as domestic use, agriculture, industry, power generation, transport and recreation. Groundwater is also available but mainly used in rural areas for domestic purposes and livestock watering. Groundwater though exhibits seasonal variations in yield (DWRM, 2011c; UN-Water, 2006).

The country's total annual renewable water resource (TARWR) base is estimated to be 43.3×10^9 m^3/year, with a dependency ratio of 69% (DWRM, 2011c). This translates to internal renewable water resources (IRWR) of 13.6×10^9 m^3/year. By 2010 the rate of water withdrawal was estimated to be 2.8% of the internal renewable water resources (DWRM, 2011c). However there is a remarkable uneven spatial distribution and seasonal variability of water resources across the country. The drier regions of the north-east and parts of the south-west (see Figure 6.1 below), are experiencing water scarcity. These areas are locally referred to as the cattle corridors because cattle keeping is the traditional source of livelihood for most people and cattle are considered a sign of prestige. Incidents of conflict have been reported in these areas as pastoralists move with their animals from place to place in search of water and pasture (UN-Water, 2006). Pastoralists' animals often wander into people's gardens and destroy crops and this often leads to confrontation between pastoralists and the local communities. The nomadic behaviour among pastoralists not only poses a security risk but also poses a potential health hazard as cattle diseases could be transferred from one part of the country to another.

At current population estimates the average annual per capita water availability is about 1,240m^3, based on the TARWR and 390m^3 based on the IRWR. These figures could be much lower in the drier regions of the country. These figures paint a gloomy picture of the water resources situation in the country. According to UNEP (2008), water stress is experienced when the annual per capita water availability falls between 1,000m^3 – 1,700m^3 and water scarcity is experienced when availability fall below 1,000m^3.

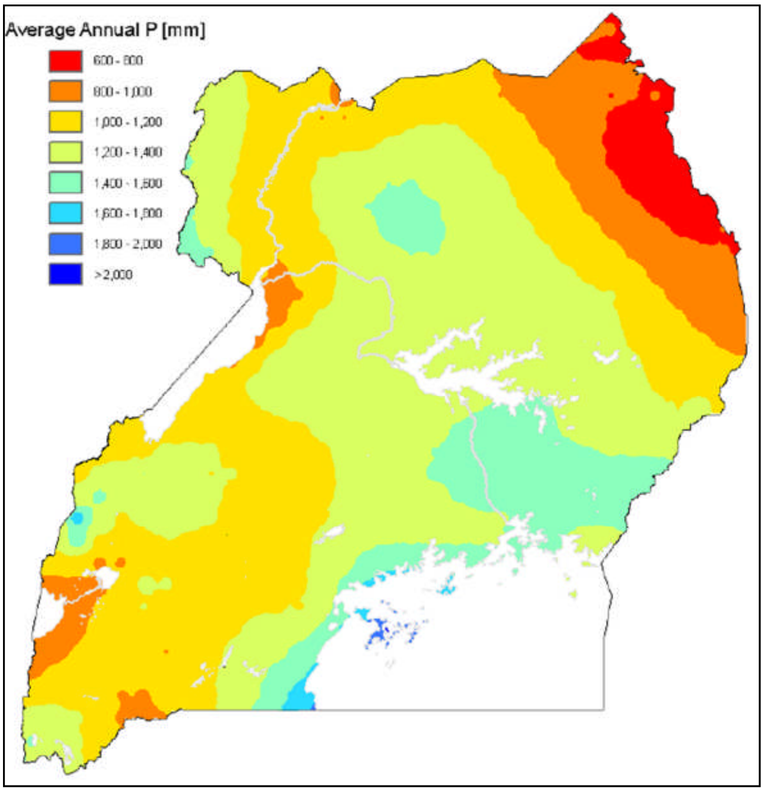


Figure 6.1: Average annual rainfall in Uganda

Source: DWRM (2011c)

To compound the problem of uneven spatial and seasonal distribution of water resources in Uganda, the country is faced with a threat of diminishing water resources. Several water sources in the country have been reported to show a declining trend both in quantity and quality (DWRM, 2011a). These include the River Rwizi, Lake Wamala, the Lake Victoria catchments and several ground water sources. The drop in Lake Victoria's water levels in 2004 – 2005 greatly affected NWSC, a water supply company, forcing the company to extend some of their raw water abstraction structures in the towns of Entebbe, Kampala and Jinja further into the lake (NWSC, 2007; NWSC, 2010).

These water resources challenges are aggravated by rapid population growth, currently estimated at 3% per annum, deforestation, increased agricultural production to support the growing population, urbanization, industrialization and climate change, all of which are exerting pressure on the environment leading to rapid depletion and degradation of available water resources (GIZ, 2014; Rubarenzya, 2008). These issues form a formidable challenge to the management of the countries water resources.

6.2.1 Importance of Uganda's Water Resources

Uganda's water resources play an important role in the economic and social development of the country by supporting key sectors such as agriculture and industry that are the mainstay of the economy. The country also depends on its water resources for hydroelectricity generation, fisheries and aquaculture, tourism and recreational activities, and transport.

Uganda is predominantly an agricultural country with most people depending on the agricultural sector for their livelihood. The local industries are mainly agro-based and they too depend on the agricultural sector for most of their raw materials. Agriculture plays a vital role in the country's economy accounting for over 70% of the countries workforce (UBOS, 2016). In the last decade, however, the country has experienced a continuous decline in the agricultural sector. This is evident from the decline in the average annual growth of the sector and the decline of the sectors' contribution to the overall GDP of the country (see Table 6.1 below), from over 50 % in the 1990s (World Bank, 2014), to 23.6% in the 2015/16 financial year (UBOS, 2016). Consequently the percentage of export earnings from agriculture have also declined from over 85% in the 1990s to 40% in 2012 (UBOS, 2013).

Water is a very vital input in agriculture without which the survival of the agricultural sector could be threatened. This could have a knock-on effect on the local industry, the development of the country and the livelihood of the people.

Table 6.1: Uganda's GDP Statistics

	1992	2002	2011	2012	2013	2014	2015	2016
(% GDP)								
Agriculture	51.1	24.9	24.7	25.9	22.5	22.2	23.8	23.6
Industry	13.2	24.4	27.5	28.6	26.3	26.3	19.7	19.8
Services	35.7	50.7	47.8	45.5	45.1	45.4	48.6	48.7
Taxes							7.9	7.9
(Average annual growth)	**1992/ 2002**	**2002/ 2012**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Agriculture	3.8	1.5	1.2	0.8	1.3	1.5	-	3.2
Industry	11.4	8.9	7.9	2.5	6.8	5.6	7.8	4.0
Services	8.0	8.0	7.4	4.3	6.5	5.6	4.8	6.5
Taxes							9.5	0.9

Source: World Bank (2014), UBOS (2014b), and UBOS (2016)

Over 85% of the Uganda's electricity is derived from hydropower (UBOS, 2016). The energy sector plays a key role in fostering growth and economic development of the country by powering the industrial and other sectors. The country's water resources are therefore very important in this respect.

6.3 Water Resources Management Framework

Water resources management in Uganda is underpinned by a comprehensive policy, legal and institutional framework. The approach adopted in the framework to manage the country's water resources is based on the concept of IWRM where water resources are developed and managed with the participation of stakeholders. The existing framework is partly a result of the water sector reform that was carried out to address the water resources challenges in the country.

6.3.1 Policy and Legislative Framework

The water resources in Uganda are vested in the state by the constitution. The key policy and legislative instruments that govern the development, management and use of water resources in Uganda are shown in Table 6.2. These instruments form the basis of the analysis in the subsequent sections.

Table 6.2: Policy and legislative instruments governing water resources management in Uganda

	Description	Year
Policy	The National Water Policy	1999
	The National Environment Management Policy	2014
	The National Agriculture Policy	2013
	The Uganda National Land Policy	2013
	National Policy for the Conservation and Management of Wetland Resources	1995
Supporting Laws	The Constitution of the Republic of Uganda	1995
	The Water Act, Cap. 152	1995
	The National Environment Act, Cap. 153	1995
	The National Water and Sewerage Corporation Act, Cap. 317	2000
	The Rivers Act, Cap. 357	1907
	The Local Governments Act, Cap. 243	1997
	The National Forestry and Tree Planting Act	2003
	The Land Act, Cap. 227	1998
Supporting Regulations	The Water Resources Regulations	1998
	Water Supply Regulations	1999
	The Sewerage Regulations	1999
	The Water (Waste Discharge) Regulations	1998
	The Environmental Impact Assessment Regulations	1998
	The Waste Management Regulations	1999
	The National Environment (Wetlands, River Banks And Lake Shores Management) Regulations	2000
	The National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations	1999

Source: Personal compilation from review of document

6.3.1.1 Policy Framework

The National Water Policy

Following the water sector reform of 1998, a National Water Policy (NWP) was formulated and adopted in 1999. The NWP is based on the concept of IWRM and promotes stakeholder participation in the management of water resources and development of basic water and sanitation services. The overall policy objective of the NWP for water resources management is “to manage, and develop the water resources of Uganda in an integrated and sustainable manner, so as to secure and provide water of adequate quantity and quality for all social and economic needs of the present and, future generations with the full participation of all stakeholders” (MWE, 1999).

The National Water Policy was developed under two distinct categories: (i) water resources management. This covers the policy objectives and strategies for protecting, monitoring, allocating and assessing the water resources in the country. (ii) Water development and use. This covers the policy objectives and strategies for the development and use of water in the country. It covers aspects of domestic water supply, water for agricultural production and other water uses such as recreation and industry.

The government of Uganda has endorsed international declarations, resolutions and guidelines, emanating from international forums on water resources management. Notable among which is Agenda 21’s, Chapter 18 on freshwater resources which resulted from the United Nations Conference on the Environment and Development held in Rio de Janeiro in 1992. This chapter is concerned with the “protection of the quality and supply of freshwater resources through application of integrated approaches to the development, management and use of water resources” (UN, 1992). These declarations, resolutions and guidelines have been embraced by the NWP to improve the management of water resources in the country.

The NWP aims to ensure uniformity and adoption of a common approach to the management of the country’s water resources. To that end Section 8.4.3 of the NWP provides for development of sectoral water use and management policies and plans that are consistent and compatible with the national water policy. This is consistent with the requirements in Section 18.12 of Agenda 21 (UN, 1992), to improve integrated water resources management.

In order to support implementation of the NWP financial resources are required. To that end Section 5.4.2 of the NWP provides for financing for domestic water supply while Section 6.4.3 provides for financing for water for agricultural production. In line with this government has allocated resources in the national budget to support implementation of these activities as shown in Table 6.3. This is consistent with the requirements of Section 18.22 of Agenda 21 (UN, 1992), which lays the responsibility of mobilising financial resources needed for water resources management activities on governments. However, the NWP does not mention financing for water resources management although financial resources for this purpose are allocated in the national budget.

Table 6.3: Proposed Budget Allocations for 2016/17 and the Medium Term

		2015/16		Medium Term Projections		
	2014/15 Outturn	Approved Budget	Spent by End Sept	2016/17	2017/18	2018/19
Vote: 019 Ministry of Water and Environment						
0901 Rural Water Supply and Sanitation	23.974	64.644	8.935	85.766	50.084	60.084
0902 Urban Water Supply and Sanitation	50.479	213.006	64.768	194.575	71.571	70.970
0903 Water for Production	19.481	42.170	7.172	42.242	52.777	61.634
0904 Water Resources Management	5.884	41.539	2.370	37.587	7.713	17.713
0905 Natural Resources Management	21.304	24.876	6.600	26.381	24.963	24.963
0906 Weather, Climate and Climate Change	4.496	14.684	2.976	14.684	3.966	3.966
0949 Policy, Planning and Support Services	14.020	26.041	3.760	33.940	26.871	19.703
Total for Vote:	**139.639**	**426.959**	**96.581**	**435.174**	**237.945**	**259.032**
Vote: 122 Kampala Capital City Authority						
0908 Sanitation and Environmental Services	0.009	13.588	0.000	13.588	16.195	0.013
Total for Vote:	**0.009**	**13.588**	**0.000**	**13.588**	**16.195**	**0.013**
Vote: 150 National Environment Management Authority						
0951 Environmental Management	7.647	9.046	1.788	9.046	10.247	11.539
Total for Vote:	**7.647**	**9.046**	**1.788**	**9.046**	**10.247**	**11.539**
Vote: 157 National Forestry Authority						
0952 Forestry Management	11.286	23.099	5.331	26.279	28.639	30.975
Total for Vote:	**11.286**	**23.099**	**5.331**	**26.279**	**28.639**	**30.975**
Vote: 500 501-850 Local Governments						
0981 Rural Water Supply and Sanitation	62.372	62.372	12.574	62.372	77.613	89.480
0982 Urban Water Supply and Sanitation	1.504	2.504	0.626	2.504	2.629	3.629
0983 Natural Resources Management	2.853	3.353	0.838	3.353	4.872	5.152
Total for Vote:	**66.729**	**68.230**	**14.039**	**68.230**	**85.114**	**98.261**
Total for Sector:	**225.311**	**540.922**	**117.739**	**552.317**	**378.140**	**399.820**

Source: MFPED (2015). Amounts are in billions of UGX.

In order to protect its interest in the shared water resources in the region the government of Uganda needs to play a role in the management of these water resources. Accordingly, Section 4.4 (i) of the NWP provides for development of a strategy of dealing with the shared international water resources. This is in line with the requirement of Section 18.10 of Agenda 21 (UN, 1992), regarding the management of transboundary water resources.

Implementing the provisions of the NWP requires adequate human capacity at all levels. Development of such capacity is therefore necessary. Accordingly, Section 4.4 (viii) of the NWP provides for capacity building to ensure sustainable management of water resources. Section 5.4.3 (i) provides for capacity building to strengthen management and sustainability aspects for domestic water supply, while Section 6.4.5 provides for capacity building to strengthen management and sustainability aspects for water for agricultural production. These provisions are consistent with the requirements of Section 18.20 of Agenda 21 (UN, 1992), regarding the need for adequate human capacity to implement the principles of integrated water resources management.

To ensure consistency in policies and approaches to water resources management in the country Section 5.4.5 of the NWP provides for cross-sectoral coordination and collaboration among all stakeholders in the water sector. Accordingly, Section 8.5 of the NWP vests the responsibility of monitoring the implementation of the provisions of the national water policy in the Directorate of Water Development (DWD), in the MWE. Monitoring implementation is meant to ensure that the goals that have been set are met and that challenges as well as areas for improvement are identified. DWD organises a Joint Sector Review (JSR) annually in September/October to review and assess the performance of the water sector. This forum enables stakeholders to discuss developments in the sector and plan for the subsequent years. However, the JSR is not a decision making body. Any undertakings made during the JSR are subject to approval by the Water & Environment Sector Working Group, a decision support mechanism in the MWE. These provisions are consistent with the requirements of Section 18.12 of Agenda 21 (UN, 1992), regarding the need to strengthen cooperation and associated mechanisms, so as to improve integrated water resources management.

The NWP is currently undergoing review to make it responsive to emerging issues and challenges such as climate change, increased urbanization and industrialization, and rapid population growth.

The Uganda National Land Policy

The Uganda National Land Policy, 2013 provides for natural resources and environmental management in Chapter 6.7 of the policy. In Section 140 (d) the Uganda National Land Policy provides for the protection of water resources through promotion of good land use practices in conformity to sound environmental management principals. In Section 142 (ii) the government shows a commitment to restore polluted watercourses and in Section 142 (iii) the government shows commitment to provide special protection to water catchment areas. In section 142 (iv) & (v) the government is committed to ensuring that designated wetlands, river banks, lake shores and water catchment areas are not tampered with. However the policy does not mention how these activities will be funded neither is there a provision in the national budget, under the ministry responsible for land, for funds to support implementation of water related activities. Without the necessary financial support it is unlikely that these commitments will be fulfilled.

The policy recognises land as a cross-sectoral resource that plays a central role in sectors such as agriculture, forestry, water, wildlife and human settlement. To that end section 129 of the policy provides for cross-sectoral integration in land management so as to support development in other sectors. As one of the strategies for enhancing natural resources and environmental management section 141 (iv) of the policy provides for strengthening the capacity for enforcement of natural resources regulations, environmental planning and monitoring.

National Policy for the Conservation and Management of Wetland Resources

The National Policy for the Conservation and Management of Wetland Resources, 1994 recognises the important role that wetlands play in water resources management, especially their filtration capacity that is vital for wastewater treatment. The policy also recognises that wetlands are sources of water supply in addition to the other numerous services they provide. For that matter the policy aims to promote the conservation of the country’s wetlands in order to sustain their beneficial functions for the wellbeing of the people of Uganda.

The policy recognises the limited human capacity in wetland management which has consequently led to unabated degradation of wetlands in the country. To that end

Section 7.11 of the policy provides for development of more human capacity in the area of wetland management.

In order to realise the policy objectives financial resources are needed to support implementation of activities for conservation and management of wetland resources. Unfortunately the policy does not mention how these activities will be funded. However, provision has been made in the national budget under natural resources management in the MWE.

The policy recognises the importance of cross-sectoral collaboration in promoting conservation of the country's wetland resources. To that end Section 5 (5) of the policy provides for management of wetlands in collaboration with other sectors by integrating wetland issues in their planning and decision making processes.

The National Environment Management Policy

The National Environment Management Policy, 2014 on its part provides for water resources management in Section 3.5 of the policy. The policy aims to ensure that the water resources in the country are managed "in a wise, integrated, sustainable and coordinated manner". The proposed strategies for achieving this policy objective include:

i) "Strengthen and develop national, regional and international partnerships and networks to enhance management and equitable utilisation of shared water resources;
ii) Promote catchment based integrated water resources planning, management and development;
iii) Promote stakeholders participation in water resources management and development;
iv) Promote an integrated approach to planning and implementation of water and related activities;
v) Promote creation of synergy and efficient use of resources;
vi) Develop local capacity for community management and maintenance of water catchment areas and water source points;
vii) Strengthen the capacity to measure and to continuously assess and monitor the quality and quantity of water resources"

The NEMP recognises that environmental concerns are cross-sectoral and therefore require a multi-sectoral management approach. Accordingly, Section 5.2 provides for enhancing linkages and synergies among sectors, while annex 2 of the policy provides for costs of integrating environmental concerns into all development policies, plans and budgets at national, district and local levels. Other implementation costs are to be covered under individual sector budgets.

The NEMP recognises the importance of enforcing environmentally related laws in order to ensure sustainable management of the environment and natural resources. Accordingly, Section 3.17, provides for human resource development covering aspects of enforcement.

The National Agriculture Policy

The National Agriculture Policy, 2013, was developed under the Ministry of Agriculture Animal Industry and Fisheries (MAAIF). Section 28 of the policy recognises that achievement of the policy objectives depends on “complementary policies and actions by other supporting sectors”. It therefore provides for collaboration with the relevant sectors. To that end Chapter 4.4 of the policy provides for joint planning between MAAIF and MWE in the provision of water for agricultural production. It also provides for collaboration between the relevant ministries in the development of interventions to mitigate the impacts of extreme weather events on agriculture.

As a strategy to boost agricultural production Section 26 (vii) of the policy undertakes to develop capacity in rain water harvesting and utilisation, while Section 23 (xiii) undertakes to support sustainable management and use of water resources. Accordingly, Section 33 provides for increased investment in areas of water for agricultural production. To that end the government has allocated funds in the national budget to support activities related to water for agricultural production.

The Energy Policy for Uganda

Electricity production in Uganda is one of the largest water user in the country, with over 85% of the country’s electricity being derived from hydropower (UBOS, 2016). The energy sector is, therefore, a significant stakeholder in the water sector. However, from the documents available, there is no indication that the energy sector is involved in water resources management. Neither the Energy Policy for Uganda, 2002, nor the Renewable Energy Policy, 2007 make any provision for water resources management.

6.3.1.2 Legal and Regulatory Framework

The government of Uganda is committed to ensuring proper management of its water resources for the benefit of its citizens. This is evident from the provisions in the constitution and other related legislative instruments. Some of the policy statements in the Constitution of the Republic of Uganda, 1995 related to water resources management are stated under the “National Objectives and Directive Principles of State Policy”. For example, Objective XIII (Protection of natural resources) states that “the state shall protect important natural resources, including land, water, wetlands, minerals, oil, fauna and flora on behalf of the people of Uganda”. This is in line with the state’s role of protecting and promoting the fundamental and other human rights and freedoms of its people. As part of the objectives to promote social welfare and economic development in the country, Objective XXI (Clean and safe water) states that “the state shall take all practical measures to promote a good water management system at all levels”. As part of the objectives for environmental management, Objective XXVII (The environment) states that “the state shall promote sustainable development and public awareness of the need to manage land, air and water resources in a balanced and sustainable manner for the present and future generations”.

Realising these objectives requires resources to support implementation of various activities. To that end Chapter 9 of the constitution provides for financing arrangements, while Chapter 10 provides for human resources under the public service.

The legislation that give effect to the National Water Policy is comprised of seven Acts. These are:

1) *The Water Act, Cap. 152, 1995*. This provides the legal framework for the development, management and use of water resources and for water

supply. The Water Act is the principal law from which all aspects of water resources management in the country derive. The Act provides for creation of institutions to manage water and sewerage services. The main regulations that give effect to the Water Act are: (i) the Water Resources Regulations, 1998; (ii) the Water Supply Regulations, 1999; (iii) the Water (Waste Discharge) Regulations, 1998; and (iv) the Sewerage Regulations, 1999.

2) *The National Environment Act, Cap. 153, 1995*. This provides the framework for coordinated and sustainable management of the environment in the country. It also provides for the establishment of National Environment Management Authority, an organisation that is responsible for management of the environment. The main regulations that give effect to the National Environment Act are: (i) the Environmental Impact Assessment Regulations, 1998; (ii) the National Environment (Wetlands, River Banks And Lake Shores Management) Regulations, 2000; (iii) the National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations, 1999; and (iv) the Waste Management Regulations, 1999.

3) *The National Water and Sewerage Corporation Act, Cap. 317, 1995*. This provides for the establishment of National Water and Sewerage Corporation, an organisation responsible for the provision of water and sewerage services in urban centres in the country as entrusted to it under the Water Act, 1995. Section 4 (2) of the Act provides for management of the water resources; from which the Corporation gets all the water it supplies. Part VI covers the financing arrangements of the corporation.

4) *The Rivers Act, Cap. 357, 1907*. This Act provides for control of certain activities in rivers in the country. These activities include dredging and use of steam vessels. These activities are regulated and require a license from the responsible authorities.

5) *The Local Governments Act, Cap. 243, 1997*. This defines the roles and responsibilities of different levels of Local Government in the provision of water services and management of water resources in liaison with the MWE.

6) *The Land Act, Cap 227, 1998*. This provides for the protection of environmentally sensitive areas, such as water resources, for the common good of the citizens of the country.
7) *The National Forestry and Tree Planting Act, 2003*. This provides for the development and management of forests so as to conserve the water, soil and air quality. This is meant to ensure conservation of the country's natural resources. This Act also provides for the establishment of National Forestry Authority, an organisation responsible for the management of forests in the country.

As with the respective policies, all the Acts promote cross-sectoral collaboration in enforcing implementation of the respective policies.

6.3.2 Institutional Framework

In order to develop and manage water resources in sustainable manner the right institutions, with clearly stipulated responsibilities, need to be in place (GWP, 2017). Uganda has a comprehensive institutional framework for the development and management of its water resources. The existing institutional framework operates at three levels namely the national level, sub-national/regional level and district/local level (see Figure 6.2 below). This is all geared towards achieving the national water policy objective of ensuring sustainable water resources management in the country.

6.3.2.1 National Level

The principal ministry mandated with the overall responsibility for water resources management in the country is the Ministry of Water and Environment (MWE). In carrying out its responsibilities the MWE works in collaboration with other line ministries and development partners (DPs). The other line ministries that facilitate and implement the NWP measures include the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Ministry of Local Government (MLG), Ministry of Lands, Housing and Urban Development (MLHUD), and Ministry of Finance, Planning and Economic Development (MFPED). The MFPED facilitates the implementation of the policy measures by mobilising and allocating the financial resources required to carry out various activities. The MAAIF provides technical support in the development of infrastructure and use of water for agricultural production. The MLG facilitates the District Local Governments in delivering services at district and community level. The MLHUD is responsible for the management of land affairs in the country and ensures that water resources are protected. The DPs provide technical and financial assistance to support water resources management activities.

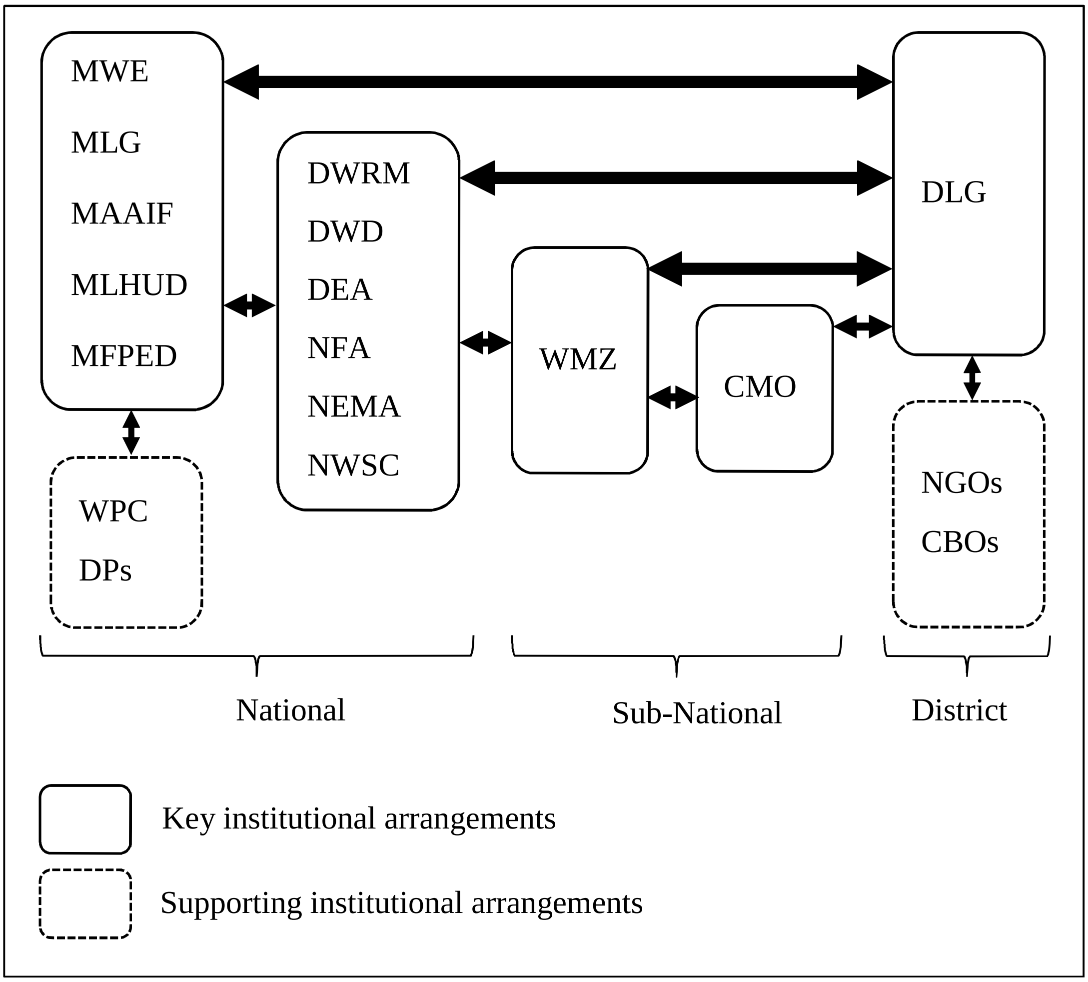


Figure 6.2: Institutional arrangement for water resources management in Uganda

The principal agencies of the MWE responsible for carrying out the mandate of the ministry are the Directorate of Water Resources Management (DWRM), Directorate of Water Development (DWD), Directorate of Environmental Affairs (DEA), National Water and Sewerage Corporation (NWSC), National Environment Management Authority (NEMA), and National Forestry Authority (NFA). There is also a Water Policy Committee (WPC). In carrying out their functions these agencies work in collaboration with each other, as well as the WMZs and the DLGs.

The Water Policy Committee

As part of the institutional framework, Section 9 of the Water Act provides for the establishment of a Water Policy Committee (WPC) whose role is to coordinate formulation and revision of water resources management policies and act as a principal advisory organ to the Minister responsible for water on all policy matters. Membership of the WPC is provided for in Section 4.5 (i) of the NWP and stipulated in Section 9 of the Water Act, 1995. It includes the following members:

a) "the Permanent Secretary in the Ministry responsible for water resources;
b) the executive director National Environment Management Authority;
c) the director responsible for irrigation;
d) the director responsible for animal industry and fisheries;
e) the commissioner responsible for industry;
f) the commissioner responsible for hydropower;
g) one district council chairperson;
h) one chief administrative officer;
i) the managing director, National Water and Sewerage Corporation;
j) two persons having special qualifications or experience relevant to the functions of the Water Policy Committee; and
k) the director of water development."

In addition, Section 14 (1) of the Water Resources Regulations, 1998 provides for appointment of a sub-committee to advise the WPC on technical matters. In Section 14 (3) these regulations seek to ensure that in appointing members to the sub-committee, "all relevant stakeholders have an opportunity to contribute to significant decisions relating to water policy". The range of sectors from which relevant stakeholders may be selected is specified in Section 14 (4) of the regulations and includes the following:

a) “local government;
b) foreign affairs;
c) health;
d) works and transport;
e) meteorology;
f) geological survey and mines;
g) hydropower;
h) veterinary services;
i) forestry
j) NGOs
k) Any other interest group”

The membership of the sub-committee depends on the issues on which guidance or technical advice is required.

The Directorate of Water Resources Management

The DWRM is the lead agency for water resources management in the country. It is responsible for:

a) “Formulating and maintaining water policies, laws and regulations
b) managing, monitoring and regulating the use of water resources through issuance of water use, abstraction and wastewater discharge permits
c) implementing integrated water resources management activities
d) coordinating Uganda's participation in the joint management of transboundary water resources and peaceful cooperation with Nile Basin riparian countries”

The DWRM is comprised of four departments, these are:

i) Water Resources Monitoring and Assessment
ii) Water Resources Planning and Regulation

iii) Water Quality Management
iv) International and Transboundary Water Resources Affairs

The Directorate of Water Development

The DWD is responsible for the development and use of water in the country, covering aspects of domestic water supply, water for agricultural production and other water uses such as recreation and industry. The DWD is comprised of four departments, these are:

i) Urban Water Supply
ii) Water for Production
iii) Rural Water Supply
iv) Urban Water Supply Regulation

The Directorate of Environmental Affairs

The DEA is responsible for:

a) Inspection and monitoring of the environment and all natural resources in the country
b) Restoration of degraded ecosystems
c) Coordination and supervision of activities aimed at mitigating and adapting to climate change.

In carrying out its functions the DEA works in collaboration with NEMA and the National Forestry Authority (NFA). The DEA is comprised of four departments, these are:

i) Environment Support Services
ii) Forest Sector Support
iii) Meteorology
iv) Wetlands Management

The National Water and Sewerage Corporation

NWSC is a government owned parastatal organisation that is responsible for the provision of water and sewerage services in all the major urban centres in the country. However there are some urban centres where NWSC does not operate. In these centres water and sanitation services are provided by the respective local governments in liaison with DWD. In carrying out its functions NWSC collaborates with all the other agencies in the water sector.

The National Environment Management Authority

NEMA is responsible for coordinating, monitoring and supervision of all the regulatory functions and activities related to environmental management in the country. NEMA works in collaboration with DEA and NFA.

The National Forestry Authority

NFA is a semi-autonomous organisation under the MWE that is responsible for the management of forest reserves in the country. It is also responsible for providing technical support to stakeholders in the forestry sub-sector.

Transboundary Institutions

The water resources that are shared with other countries are managed through the transboundary institutions. These institutions include the Lake Victoria Basin Commission (LVBC) and the Nile Basin Initiative (NBI).

6.3.2.2 Sub-National Level

To facilitate development and management of water resources at sub-national level the country has been divided into four water management zones (WMZs), namely Victoria, Albert, Kyoga and Upper Nile as shown in Figure 6.3 below. WMZ offices have been opened in each of the zones. Some of the functions formerly performed at central level by DWRM, such as water quality monitoring, have been devolved to the WMZs. The main purpose of the WMZs is facilitate implementation of catchment-based water resources management by taking activities closer to where they are needed so as to be able to mobilise and involve the local stakeholders. The WMZs are supervised by the DWRM. In carrying out their functions the WMZs work in collaboration with other ministry agencies, the CMOs and the District Local Governments (DLGs).

The WMZs have been demarcated into catchments and catchment management organisations (CMOs) have been established to promote coordinated planning and management of water and related resources in the catchment. The CMO provides a platform through which the stakeholders meet and discuss water resources issues in the catchment. The CMO is managed by a catchment management committee (CMC) which represents key stakeholders in the catchment.

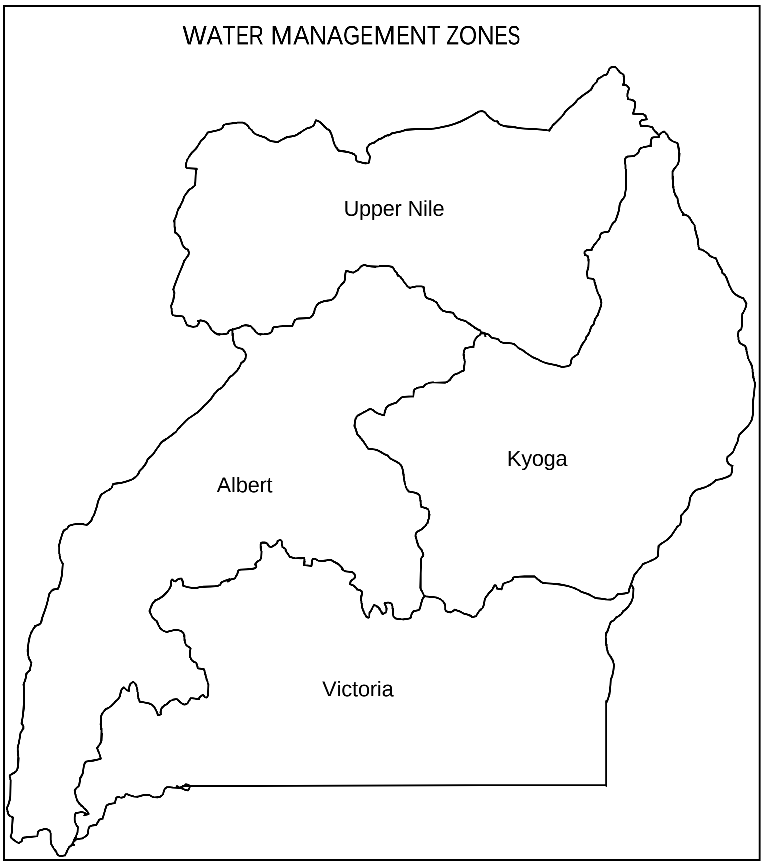


Figure 6.3: Map of Uganda showing the water management zones

6.3.2.3 District Level

At district and community level the District Local Governments, in liaison with MWE, are responsible for management of water resources. The Water Act, 1995 also provides for the establishment of Water User Groups, Water and Sanitation Committees, and Water User Associations at community level to ensure proper operation, maintenance and management of point water supply sources and sanitation facilities. This is the level at which the DLGs work with NGOs and CBOs to deliver services to the communities. The DLGs also work in collaboration with other water sector agencies including the WMZs and CMOs.

Allied Sector Agencies

Public sector efforts in water resources management are supplemented by non-governmental organisations (NGOs), community based organisations (CBOs), and the private sector. These agencies provide technical and financial support for water resources management activities.

6.4 Stakeholder Participation and the Water Resources Management Framework

It is clear that considerable effort has been put to developing the water resources management framework in Uganda. The NWP has to a large extent been developed based on Agenda 21's Chapter 18 which is concerned with "application of integrated approaches to the development, management and use of water resources". The NWP embodies provisions for stakeholder participation in the management of water resources at national, sub-national and district/local levels. Consistent with Chapter 18.9 of Agenda 21 concerning the need for multi-sectoral approaches for the development, management and use of water resources, the requirement for participatory involvement has also been provided in all other sectoral policies that include elements of water resources management. These provisions have also been integrated in the respective legislation that give effect to those policies.

The NWP attaches importance to sustainability aspects. Accordingly Section 5.4.3 (ii) of the NWP provides for creation of Water Source Committees at village level for the operation and maintenance of water sources. In line with the fourth principle of IWRM that seeks to recognise the role of women in the management of water resources, the NWP emphasises that at least 50% of the Water Source Committee members should be women. This promotes empowerment of women and gender balance in water resources management.

The NWP recognises the role of NGOs, CBOs and the private sector in the management of water resources. The NGOs and CBOs involved in the water and environment sector have come together and formed an umbrella organisation called the Uganda Water and Sanitation Network (UWASNET). UWASNET coordinates the activities of NGOs and CBOs involved in the water and environment sector. It also acts as a platform for sharing experiences among its members and for engagement with government, the private sector, and development partners in the water sector.

Uganda lies in the upper Nile basin and by virtue of this location the country shares most of its water resources with other riparian countries in the Nile basin. These countries include: Rwanda, Burundi, Tanzania, Kenya, the Democratic Republic of Congo (DRC), South Sudan, Sudan and Egypt. Uganda therefore ought to adhere to international laws on the use of shared water resources such as UNECE (2013). This is recognized in Section 3.2 of the NWP and taken into account in the legal and regulatory framework for water resources management. To that end Uganda participates in regional efforts to manage the shared water resources in the region. These include the Nile Basin Initiative and the Lake Victoria Basin Commission. This is aimed at safeguarding the country’s interests in the shared water resources. This is consistent with Chapter 18.10 of Agenda 21 that requires riparian states to formulate strategies for managing shared water resources.

The current water resources management framework in Uganda is, to a large extent, consistent with the governance requirements needed to support stakeholder participation in water resources (GWP, 2017). However some implementation issues have been observed. For example, whereas the policy objective for water resources management is to manage and develop the water resources of the country “*with the full participation of all stakeholders*”, it has been observed that not all stakeholders are involved in the management of the country's water resources. From the documents available the energy sector was identified as a major stakeholder that was not involved in water resources management.

Where stakeholder participation in the management of water resources has been attempted, for example in the River Rwizi catchment, reasonably good progress has been made in mobilising stakeholders. However, it has been observed that the composition of the stakeholder groups is not adequately constituted. During the stakeholders' forum meeting held in Mbarara in May 2015, it was observed that the meeting comprised mainly of political leaders and government officials. There were over 60 participants in attendance however hardly any local stakeholders on the ground were present. With such a composition it is likely that issues that affect the ordinary people on the ground could easily be missed during discussions.

During the same meeting it was also observed that formulation of action points was not systematically done and there was no clear method of prioritising action points or associating them with specific issues to be addressed. Action points were suggested by individual participants by show of hands. Sufficient time was not given to discuss issues and proposed action points. This was partly due to the method of engagement which did allow interactive discussion among participants. Time was also not adequately allocated to items on the agenda and the facilitator seemed to rush through the items. Figure 6.4 shows participants at the stakeholders' forum meeting.

Figure 6.4 Participants at the Rwizi catchment stakeholders' forum meeting

A participant interviewed after the meeting expressed a sense of dissatisfaction with the mode and venue of the meeting. He felt that the meeting should have been held at the local level with the people on the ground and not at regional level because *"people who come for these regional workshops do not put into practice what they learn"*. Referring to lack of action by those responsible, he said *"people are sleeping!"*. He added that it was *"better to go on the ground and have small meetings so that people can understand totally"* why and how to manage water resources.

The other implementation issues observed relate to financial and human resources. Limitations in funding and human resources capacity especially in terms of numbers, skills, knowledge and experiences have been reported (Rubarenzya, 2008; MWE, 2013; MWE, 2014) as some of the factors affecting proper functioning of the water sector in Uganda.

These findings suggest that there is still need for improvement in the area of stakeholder participation in the water sector. Specifically there is need adopt methods and tools that support active stakeholder involvement. These could involve methods for selecting those to be involved, methods of engagement with those selected, and tools to facilitate the engagement process. Findings from Chapter four of this report suggest that participatory modelling, coupled with a Bayesian networks model, could offer the support necessary.

6.5 Chapter Summary

This chapter has analysed the framework for water resources management in Uganda, covering the National Water Policy (NWP) as well as the legislative and institutional frameworks. This is summarised in Table 6.4 below. The findings show that Uganda has a comprehensive framework for water resources management. Water resources management functions exist at three levels namely the national level, sub-national level and at district/local level. However, despite this the country's water resources continue to show a declining trend.

The NWP is based on the concept of IWRM and embraces declarations, resolutions and guidelines emanating from international forums on water resources management to improve the management of water resources in the country. To that end the NWP promotes stakeholder participation in water resources management. However, there is still need for improvement in the area of stakeholder participation in the water sector, specifically aided by methods and tools that support active stakeholder involvement.

By virtue of its location in the Nile basin Uganda shares most of its water resources with its neighbours. Uganda actively participates in regional efforts aimed at managing these water resources. This is aimed at protecting her interests in the shared water resources.

Uganda is predominantly an agricultural country with agriculture accounting for over 70% of the country's workforce (UBOS, 2016). The country's water resources play a vital role in supporting the agricultural sector and the overall development of the country.

Table 6.4: Summary of evaluation of the water resources management framework in Uganda

	Incentives	Financial Resources	Human Capacity	Coordination
Policy				
The National Water Policy	Clear statements in the policy objectives and strategies for management of water resources	Provides for allocation of public funds to support implementation of strategies	Provides for capacity building to strengthen water resources management aspects	Yes
The National Environment Management Policy	Clear statements in the policy objective and strategies for management of water resources	Provides for government funding to cater for natural resource management and environmental protection	Provides for capacity development to strengthen management and maintenance of water catchment areas and water source points	Yes
The National Agriculture Policy	Statements in the strategies to achieve policy objectives of boosting agricultural production	Provided by government through the ministry responsible for water	Provides for development of capacity for rain water harvesting and use	Yes
The Uganda Land Policy	Clear statements in the policy objectives and strategies for natural resources and environmental management, and in the implementation framework	There is no mention of how water related activities are to be funded, neither is there provision in the national budget	Provides for strengthening the capacity for enforcement of natural resources regulations, environmental planning and monitoring	Yes
National Policy for the Conservation and Management of Wetland Resources	Clear statements in the policy principles and strategies for management of wetland resources	Provided in the national budget under natural resources management in the MWE	Provides for development of human capacity in wetland management	Yes

	Incentives	Financial Resources	Human Capacity	Coordination
Legal Framework				
The Constitution of the Republic of Uganda	Clear provisions and statements in the constitution under the National Objectives and Directive Principles of State Policy	Catered for under finance	Catered for under public service	Yes
The Water Act, Cap. 152	Clear statements in the objectives of the Act	Provided for in the national budget	Provides for creation of institutions, water user groups and associations to manage water and sewerage services	Yes
The National Environment Act, Cap. 153	Clear statements in the principles of environmental management	Provides for funding of activities related to natural resources management	Creates NEMA that is responsible for environmental management	Yes
The National Water and Sewerage Corporation Act, Cap. 317	Mainly focused on water supply and sewerage services	No clear provision for water resources management activities	Creates the NWSC that is responsible for water and sewerage service in urban centres	Yes
The Local Government Act, Cap. 243	Clear statements in the objectives of the Act, and in the functions and services for which district councils are responsible	Catered for under the financial provision of the Act	Covered under the district public service	Yes
The National Forestry and Tree Planting Act, 2003	Statements in the purpose of the Act, and in the objectives for management of forest reserves	Makes provision for funding of NFA activities	Provides for the establishment of NFA to manage forests in the country	Yes

	Incentives	**Financial Resources**	**Human Capacity**	**Coordination**
The Land Act, Cap. 227	Statements in the control of land use	There is no provision related to water resources management activities	Provides to establishment of institutions for land management	Yes
Institutional Framework				
National Level	Statements in the policy and legislative instruments	Provided for in the national budget	Provided for in the respective institutional arrangements	Yes
Sub-National Level	Statements in the policy and legislative instruments	Provided for in the national budget	Provided for through the CMO	Yes
District Level	Statements in the policy and legislative instruments	Provided for in the national budget	Provided for in district local government management arrangements	Yes

Key:

(green)	Positive: Criteria have been met
(purple)	Neutral: Not clear if criteria have been met or not
(orange)	Negative: Criteria have not been met

Chapter 7

Discussion

7.1 Introduction

The current water resources challenges call for a concerted effort involving various sectors, disciplines and experiences. To that end IWRM has been widely promoted as a means of realising sustainable management and use of available water resources. A key requirement of IWRM is the involvement of stakeholders in the management of water resources. However efforts involve stakeholders in water resources management have often registered little success.

This study set out to investigate means through which stakeholder participation in water resources management could be improved so as to enhance implementation of IWRM. To that end the following were investigated:

1. The potential of participatory modelling as a means of involving stakeholders in water resources management
2. The extent to which participatory modelling can deliver benefits for water resources management
3. The extent to which the water resources management framework in Uganda provides an enabling environment that supports stakeholder participation
4. Feasibility of mobile data collection as a means of involving stakeholders in water resources management

The key findings of this study are presented in Chapters 4, 5 & 6 above. Those findings are discussed in this chapter.

7.2 The Potential for Participatory Modelling to Support Stakeholder Participation in Water Resources Management

A participatory modelling exercise was designed and implemented with a select group of participants in the River Rwizi catchment in western Uganda. The exercise provided participants with an opportunity and a common ground to explore and reconcile different perspectives to the water resources issues in the catchment. The approach adopted in this study was designed to facilitate direct and interactive participation of all participants in a model building exercise. Overall evaluation shows that the modelling exercise achieved the objectives for which it was set up. To that end participants identified the main water resources problem in the catchment as well as possible intervention strategies for addressing it. The effects of the different intervention strategies, and combinations thereof, were also analysed and interventions prioritised.

The key stages of the participatory modelling exercise that ensured active and direct stakeholder participation were (i) the problem identification stage, (ii) the model quantification stage, (iii) the interventions identification stage, and (iv) the scenario analysis stage. The problem and interventions identification stages enabled participants to explore the water challenges in the catchment in more detail. Identifying the problem at the beginning of the modelling exercise ensured that the exercise was clearly focussed from the outset. It also enabled participants to embrace a clear direction and focus from the outset. A clear direction and focus, coupled with a clearly identified problem facilitated identification of interventions for addressing the problem. This demonstrated the importance of involving stakeholders right from the outset of a participatory process. The aspect of early involvement of stakeholders has also been acknowledged by other authors (Carmona et al., 2013; Castelletti and Soncini-Sessa, 2007; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010), as a prerequisite for participatory processes.

By identifying the water problem and possible interventions, and considering the possible effects of the interventions, the participatory modelling exercise essentially constitutes a decisional process. Involvement of stakeholders in the modelling exercise ensures that they are part of the decisional process. This suggests that a participatory modelling exercise can support stakeholder participation in water resources management by involving them in decision making.

Analysis of the participatory modelling process provides valuable insights of how and when the modelling objectives were realised as well as the factors that influenced the process. This is important for improving the guidance available for stakeholder participation which could subsequently increase the chances of successful stakeholder involvement in water resources management.

The process analysis revealed three main factors that influenced the participatory modelling process and had a direct bearing on the process outcomes. These factors are: (i) the stakeholders selected to take part in the modelling exercise, (ii) the modelling tool used, and (iii) the model building exercise. These factors are discussed below.

Stakeholder Selection

It was found that the participants were essentially the ones driving the modelling exercise by providing all the necessary input. It was therefore important that the participants that took part in the study were carefully selected so as to benefit from a broad range of views, knowledge and experiences of water resources issues across the catchment. This was important for ensuring that the water resources problem as well as appropriate intervention strategies were clearly identified.

Because of the need to select "information-rich" stakeholders to take part in the modelling exercise, the selection process focussed on ensuring that the group of participants selected had views, knowledge and experiences of issues under consideration, that were representative of those of the wider stakeholder community. As a consequence the participants selected were not a representation of the various stakeholder groups in the wider community. This means that the group selected does not necessarily have to be a representation of the stakeholders in the community, however, the groups' views, knowledge and experiences of issues under consideration need to be representative of those of the wider stakeholder community (Reed et al., 2009).

Such representativeness can be achieved by drawing out a checklist of the knowledge and experiences that are required of the stakeholder group (Chevalier and Buckles, 2008). The use of checklists ensures that key participants are not unintentionally excluded and helps avoid bias that could arise from the social networks of the individuals involved in the selection exercise. This is important for addressing the recognised challenge of selecting relevant stakeholders to be involved in a participatory process (Blomquist and Schlager, 2005; Sgobbi and Giupponi, 2007; Kessler, 2004).

If the method of selecting participants had sought to ensure representation of the stakeholders rather than representativeness of their views, knowledge and experiences, the outcome could probably have been different. Stakeholders in a given catchment can be placed in many different types of groups/categories. If each of the groups/categories were to be represented it could result in a large number of participants. A large group can make the process cumbersome and it can be difficult to combine divergent perspectives into meaningful outcomes (Chan et al., 2010).

A large group can also limit meaningful engagement. There are people who are not used to talking in front of a large group of people and therefore involving such people in a large group could limit their ability to participate effectively. It is also likely that there could be several participants with similar experiences. Once one of them has shared those experiences this could render the rest of the participants with similar experiences redundant; as repeating the same issues would be a waste of time. On the other hand there could be some participants with no knowledge or experience of issues under consideration and therefore have no contribution to make. Such participants could end up as “free-riders”, which is not the purpose of participation.

This study found that it is more practical to work with a small number of participants. Discussions were more orderly and focused, and it allowed direct interaction among participants. This finding is consistent with findings report by other authors (Bromley et al., 2005; Chan et al., 2010; Zorrilla et al., 2010), in previous studies involving participatory processes. It may be expected that the bigger the number of participants the better for generating ideas and representing the community in the participatory process. However, some studies suggest that the gains in terms of additional useful contributions in a large group may be minimal compared to the cost of organising a large group (Krueger et al., 2012).

Choice of Modelling Tool

The Bayesian networks model used in the modelling exercise exhibited unique characteristics, that include: flexibility; use of networks to represent relationships; use of probability theory; a graphical display; ability to perform scenario analysis; and ability to consider both qualitative and quantitative data. These characteristics played a key role in facilitating active involvement of all participants as shown in Section 4.4.2 above. Because of their ability to facilitate participation, these characteristics were found to be important requirements for a modelling tool that is to be used in a participatory process. These findings are consistent with those reported by other authors (Carmona et al., 2013; Castelletti and Soncini-Sessa, 2007; Ticehurst et al., 2007; Zorrilla et al., 2010), that have used Bayesian networks models in a participatory process. These characteristics make Bayesian networks models suitable for engagement with stakeholders in a participatory framework.

The flexibility of the Bayesian networks model enables changes in circumstances and requirements to be taken into account during the modelling process by adjusting the model accordingly. This characteristic is important as it ensures that decisions made are based on information that is up-to-date, and that the decisions are relevant to the prevailing circumstance. Use of a Bayesian networks model in a participatory process enables the process to be adaptive and therefore suitable for adaptive decision making and management (Henriksen and Barlebo, 2008; Pahl-Wostl, 2006).

The use of networks to represent relationships between variables allows Bayesian networks to accommodate a wide range of issues. This is particularly important when dealing with a group of stakeholders with different interests and perspectives because it enables their concerns, interest and ideas to be taken into account when decisions are made. The challenge, however, is that Bayesian networks models can easily grow in size and complexity as variables are added. This has to be controlled so that the model doesn't become too complex for participants to understand and therefore lose transparency and confidence among them (Gaddis et al., 2010; Mendoza and Prabhu, 2006; Voinov and Bousquet, 2010).

Bayesian networks model can take into account uncertainty in the information used during the modelling exercise. Uncertainty is taken care of and built into the model through the conditional probability tables. This finding is consistent with what other authors have reported (Cain, 2001; Carmona et al., 2013; Henriksen et al., 2007; Henriksen and Barlebo, 2008; Zorrilla et al., 2010). This is particular important where data for planning is either lacking or inadequate and has to be filled in by information gathered from local “experts” and other stakeholders. Such information can be fraught with uncertainty and this has to be taken into account.

The Model Building Exercise

This study found that the model building exercise was the most important aspect of the participatory process. The model building exercise provided participants with a common ground for discussions and enabled them to jointly identify and assess water resources issues in the catchment. The steps taken to construct the model encouraged discussions among participants and provided a structured and systematic framework through which active participation of all involved was realised. The graphical display of the model played a crucial role as a visualisation aid and enabled participants to understand and follow the discussions accordingly. The crucial role the graphical display of the model plays in a participatory modelling exercise has also been recognised by other authors (Carmona et al., 2013; Sgobbi and Giupponi, 2007; Voinov and Bousquet, 2010).

This study also found that the strength of participatory modelling lies in the model building exercise. Unlike approaches such as information and consultations meetings that limit active participation (Arnstein, 1969; Butterworth et al., 2010; Jingling et al., 2010; Luyet et al., 2012; Perkins, 2011), participatory modelling enables active stakeholder participation through the model building exercise. The steps taken to construct a model constitute a real decision making process where participants are directly and actively involved. This means that it is through the model building exercise that active stakeholder participation in water resources management can be realised.

Models have often been developed by modelling experts in isolation; without the involvement of non-experts in modelling. Because of this models have often been seen as “black boxes” whose internal working cannot be understood by non-experts in modelling. This has sometimes led to loss of trust in model outputs (Prell et al., 2007; Stringer et al., 2014; Voinov and Bousquet, 2010). However, involving non-experts in a model building exercise helps to open the “black box”, especially when participants are involved in all stages of the exercise as was the case during this study. This level of transparency helps to build stakeholder trust and confidence in the model outputs.

Water resources management requires good knowledge and understanding of the interactions between people and the natural environment (Carmona et al., 2013; Pahl-Wostl, 2006; Simonovic, 2002; Videira et al., 2010). This enables water resources managers to assess resource use options, including their impacts on both people and the environment (Hong et al., 2012; Jakeman and Letcher, 2003; Liu et al., 2008; Pahl-Wostl et al., 2007). However, the complexity of these systems and their relationships often poses a challenge for water resources managers. This challenges could be addressed by harnessing the capabilities of participatory modelling. By constructing a model of the interactions between people and the natural environment, water resources managers could be able to identify issues of concern and formulate appropriate strategies to address them.

The factors discussed above are very crucial for a participatory modelling process and can determine the success or failure of the process. Careful attention therefore needs to be given to each of them during the planning and implementation stages of the process in order to achieve meaningful outcomes. Selecting participants that do not have the necessary knowledge and experiences, for example, could lead to inaccurate framing of the problem to be addressed. This could in turn lead to identification of inappropriate interventions. On the other hand choosing a modelling tool that does not interactively involve participants and integrate their concerns, knowledge and experiences could limit stakeholder participation. This could defeat the purpose of the process and leave participants dissatisfied. The process analysis therefore provides valuable insights for improving the guidance available for stakeholder participation.

7.3 Benefits of Participatory Modelling

The process analysis revealed some benefits of participatory modelling (see Section 4.5 above). These are important for (i) promoting participatory modelling as a means through which meaningful stakeholder participation can be achieved, and

(ii) supporting the case for stakeholder participation in water resources management. The key outcomes are discussed below.

Platform for Dialogue

The participatory modelling exercise provided a platform that enabled participants to come together to discuss water resources issues in the catchment and to come up with possible intervention strategies. This kind of forum is important for addressing the current water resources challenges that require a concerted effort from various experiences and disciplines for planning and decision making (Bielsa and Cazcarro, 2014), as it enables people to come together to share a wide range of knowledge and experiences.

The dialogue among participants also enhanced their social network and relationships as they got to know each other better. This was clear from interactions among participants, which become more free towards the end of the workshop sessions compared to those at the start. Prior to the workshops most participants had not interacted closely despite coming from the same catchment. The social relations among stakeholders is important for ensuring meaningful engagement because it determines their ability to constructively interact (Voinov and Bousquet, 2010).

Support to Decision Making

The model building exercise essentially constituted a four stage decisional process. The first stage involved identifying the problem that needed to be addressed. The second stage involved identifying possible intervention options to address the problem. The third stage involved predicting the possible outcomes of the individual interventions and combinations thereof. The fourth stage involved selecting the intervention option that provided the best possible outcome.

In most cases this approach to decision making is carried out informally. However, participatory modelling provides a systematic and structured way of formalising this approach. The model building exercise provided an objective and transparent way of integrating participants knowledge, views and experiences, by enabling them to contribute to the different stages in the decision making process. This is important because it enables stakeholders to actively participate in decision making.

Involvement in decision making is one way through which real stakeholder participation can be realised (Desai, 2002; Agarwal et al., 2000).

In water resources management it is often the people on the ground who bear the burden of any water related issues. The exact problems they face can, therefore, be clearly identified and defined if they are involved. A clearly identified problem ensures that appropriate interventions are identified. Identifying the wrong problem could lead to formulating inappropriate interventions.

The use of a Bayesian networks model with a "what if" analytical capability eases the task of predicting possible outcomes of the different interventions and enables participants to appreciate the possible effects of any proposed interventions. This enables them to make informed decisions based on a shared understanding of the issues and to prioritise the interventions based on a consideration of their individual and combined effects. This is particularly useful in water resources management where large volumes of information have to be processed when dealing with complex linkages between different elements in a catchment and the water system. This information is dynamic and keeps changing in relation to social and economic pressures put on the natural system. Water resources managers, therefore, need to have the capacity to effectively identify and assess a range of issues affecting the water resources and evaluate the impact of any proposed management actions on the state of the water resources.

Social Learning

The model building exercise enabled participants to learn from each other and improve their knowledge and understanding of issues around them. It also helped participants to share and appreciate each other's concerns about the water situation in the catchment. The model building exercise therefore served as a platform for sharing knowledge and information, in addition to promoting dialogue. The educational potential of participatory modelling has been recognised by other authors (Carmona et al., 2013; Gaddis et al., 2010; Voinov and Gaddis, 2008; Voinov and Bousquet, 2010; Zorrilla et al., 2010; Chan et al., 2010), who found that it shaped participants' perspectives and understanding of issues under consideration. Improvement in knowledge and understanding is important as it empowers stakeholders to make informed decisions (Brody et al., 2003), This is good for water resources management because an informed and knowledgeable community can be instrumental in addressing their water resources challenges (Kessler, 2004; Carmona et al., 2013).

The educational potential of the model building exercise could be harnessed to mobilise the community to join water resources management efforts by creating awareness of water resources issues in the community. The conceptual modelling task, for example, could be used in educating communities about the relationships between activities taking place in the catchment, the quality of water at the source and the health of the community (Chan et al., 2010). The conceptual model diagram, or parts of it, could also be converted to posters and used for educational purposes.

Enhancing Participants' Trust

The approach adopted in this study was to involve participants in all stages of the modelling exercise. This ensured that participants knew how all the decisions were arrived at. This level of transparency was helpful in fostering participants' trust and confidence in the process outputs. Stakeholder trust is important for ensuring their support and increases the chances for successful implementation of decisions (Carr et al., 2012; Nare et al., 2011; Voinov and Bousquet, 2010).

Flexibility

The Bayesian networks model used as a tool to facilitate the participatory modelling process enabled the process to be flexible. This allowed new ideas to be accommodated and adjustments to be made in response to the changes in participants' knowledge and requirements. This is an important characteristic for ensuring that all participants' ideas and concerns are taken into account. This characteristic also makes the process adaptive and therefore responsive to the requirements of the stakeholders hence making it suitable for adaptive management (Henriksen and Barlebo, 2008; Pahl-Wostl, 2006).

Whereas the participatory modelling process delivered some benefits, in the context of water resources management a key benefit often sought from a participatory process is to ensure an improvement in the state of water resources (Loucks and Beek, 2005). This was not assessed because such improvements do not often appear in the short term. They tend to appear in the medium to long term, which was way after the modelling period. The challenge such assessment could encounter is that over the medium to long term periods, some changes that could affect the state of the water resources in a catchment could occur; for example change in weather pattern, rainfall regime or development plans. This could make it difficult to directly link any improvement registered in the state of water resources to the participatory process implemented (Carr et al., 2012). Any assessment over such periods need to take this into account.

7.4 Weaknesses Observed with Participatory Modelling

Although participatory modelling has shown potential as a method for involving stakeholders in water resources management, some weaknesses have been observed with this approach. These are discussed below.

The model developed has the potential to be biased towards the participants' world view and understanding of the system it describes. This is because the model was developed based on participants knowledge and experiences of water resources issues in the catchment. This knowledge and experiences are finite and therefore may not adequately represent a complete understanding of the complex linkages in the water system and the human environment. However, the bias was minimised by validating the model using data obtained from the documents reviewed.

Whereas participatory modelling enables stakeholders to participate in decision making, there is no assurance that the decisions made during the process will be implemented. This is because the final decisions are often made elsewhere "outside the room" where the participants in the modelling process may have no say. Participatory modelling therefore doesn't fully empower stakeholders to make decision. It does, however, offer a better chance of stakeholders' views being heard, compared to other approaches such as information and consultation meetings that limit active involvement of stakeholders (Arnstein, 1969; Butterworth et al., 2010; Jingling et al., 2010; Luyet et al., 2012; Perkins, 2011). In relation to the levels of participation shown in Table 2.1 above, participatory modelling sits at level 4 in the table.

A participatory modelling exercise is difficult organise, especially when it comes to mobilising participants. It was also observed that participants' attendance was influenced by their interest in issues being addressed. All participants were affected by the water resources issues in the catchment in some way and therefore their interest in these issues was bound to be high. This observation is consistent with that reported by Videira et al. (2009), where the participation rate between the first and the third/final workshops fell drastically (by more than 50%) because participants where not interested in the issues being addressed. It is therefore important to take into account interest in the issues being addressed when the potential participants are being identified so as to increase the chance of good attendance and also ensure meaningful engagement.

Participatory modelling is time consuming and therefore requires commitment on the part of the stakeholders to set aside time to attend. Time can be of essence to some stakeholders and can determine whether they attend the modelling workshops or not. Getting a day and time that is convenient for all participants can also be a challenge and because of this attendance rate fluctuates between modelling workshops. This findings are consistent with what other authors have reported (Krueger et al., 2012; Videira et al., 2009; Voinov and Bousquet, 2010). It is therefore important to take into account stakeholders' time and availability during the planning phase. This involves finding out from the stakeholders themselves, for example during the preliminary consultation meetings, if they are available and if so when and for how long in each session.

Participatory modelling is costly in terms of logistical requirements needed to organise and conduct the modelling workshops. These include costs for hiring a venue for the workshops, hiring equipment such as overhead projectors, buying stationary items and providing refreshments to participants. Participants may also have to be paid reimbursement for their transport costs. In addition there is the cost of the modelling software. Participatory modelling also requires a competent facilitator and this may call for facilitator training or hire where necessary.

Participatory modelling involves only a small group of people at a time. It therefore runs a risk of leaving out some stakeholders and this could lead to unintended negative consequences such as legitimisation of decisions favoured by few individuals (Carr et al., 2012; Sgobbi and Giupponi, 2007). Given the challenges of organising a participatory modelling exercise and the time constraints on many people there is a real risk that not all stakeholders that are identified and invited will be able to attend. This was the case during this study where some stakeholders who had been identified and invited could not attend due to other commitments. However follow up discussions were held with some of them to get their views on the issues discussed with the other participants.

Unlike public hearings, participatory modelling requires careful selection of participants. It aims to bring about change through the strategic intervention of a few individuals (Voinov and Bousquet, 2010). By involving only a select group of people participatory modelling does not promote democracy as is expected from participation (Fiorino, 1990).

Participatory modelling does not necessarily empower the marginalised groups in society as suggested by some participation literature (Anokye, 2013; Kessler, 2004). Because of the need to select "information-rich" participants to take part, the marginalised groups could still be left out unless they satisfy the selection criteria.

7.5 The Potential of an Enabling Environment for Water Resources Management to Ensure Stakeholder Participation

Water resources management in Uganda is underpinned by comprehensive policy, legal and institutional frameworks. A NWP was formulated and adopted in 1999 following reforms in the water sector. The NWP is based on the concept of IWRM and embraces declarations, resolutions and guidelines emanating from international forums on water resources management, to improve the management of water resources in the country. Analysis of the water resources management framework in Uganda shows that an enabling environment that supports stakeholder participation in water resources management has been created. This shows that Uganda has met at least one of the key requirements for implementation of IWRM (GWP, 2004; GWP, 2017).

In line with the objective of ensuring that the country's water resources are managed with the *"full participation of all stakeholders"* the NWP makes provisions for stakeholder involvement in water resources management. This is addressed through the various sector policies and legislation that provide for water resources management. However, based on the information available during this analysis, there was no indication that the energy sector, which is one of the key stakeholders in the water sector, was involved in water resources management. Neither the Energy Policy for Uganda, 2002 nor the Renewable Energy Policy, 2007 makes any provision for water resources management. This indicates a failure to achieve the objective of ensuring *"full participation of all stakeholders"* in the management of the country's water resources.

The energy sector is a major stakeholder in the water sector given that over 85% of the electricity produced in the country is derived from hydropower. Absence of the energy sector from the water resources management table indicates issues with oversight and coordination mechanisms for water resources management in the country. The fact that a large stakeholder such as the energy sector can be left out means that more smaller stakeholders could as well have been left out.

Hydropower development presents a significant opportunity for the country to use its water resources to foster growth and economic development. It is, therefore, important for the energy sector to play a role in the management of water resources in order to protects its interest and ensure uninterrupted operations that could occur if the water it relies on is diverted for other purposes such as agricultural production. This could have serious knock-on effects on other sectors that rely on hydropower and in the development of the country in general.

Given the water resources management framework in place in Uganda, the water resources in the country would be expected to be well managed. However, available reports indicate that the country's water resources continue to show a declining trend mainly due to poor land use practices (DWRM, 2011b). This is happening despite existence of policies and legislation aimed at promoting good land use practices so as to protect the water resources.

Discussion with some participants during the study revealed that there was a general problem with law enforcement in the country. Participants felt that there was political interference in the enforcement of the laws and as a consequence some of the laws were being selectively applied. It was also apparent from the documents reviewed (MWE, 2013; MWE, 2014), that there were challenges of low staffing levels in various departments, especially at district level, making it difficult for them to perform their duties as expected. Despite existence of a comprehensive legal framework, inadequate enforcement of relevant provisions of the law is a major obstacle to management of water resources in Uganda. This finding is consistent with that reported by Rwakakamba (2009), who found that there was a gap between the existing environmental laws in the country and their actual implementation.

These findings suggest that creating an enabling environment for water resources management does not necessarily ensure stakeholder participation, nor does it bring about better management of water resources. An enabling environment may need to be supported by additional measures that ensure that (i) all key stakeholders are identified and involved, and (ii) relevant laws are adequately enforced. The monitoring and coordination strategies of the DWD may need to include such measures so as to ensure that the provisions of the NWP are appropriately implemented. On the other hand high level political support and oversight may be necessary to minimise the challenges arising from political patronage in enforcing the law. Adequate staffing will also be necessary to ensure that the established institutional arrangements work as intended.

7.6 Feasibility of Mobile Data Collection as a Method for Stakeholder Participation in Water Resources Management

Mobile data collection is an approach that appears attractive as a means of involving stakeholders in the management of water resources by way of collecting and transmitting information that could be used for planning and management purposes. However, an evaluation of a web-based mobile data collection system developed for this study reveals that that potential may be difficult to realise, especially in a developing country context. Three main reasons for this have been identified and these are discussed below.

Poor Internet Connectivity

A web-based mobile data collection system requires an internet connection for someone to be able to transmit the data collected, and view the data transmitted on a web server. Poor internet connectivity was found to be a major obstacle to the use of a web-based data collection system. This was a general problem in many parts of the country. Most mobile phone network operators used mainly the 2nd generation (2G) network outside the major urban centres. 2G network could not allow connection to the internet. The 3rd generation (3G) network, that could allow connection to the internet, was only available in some urban centres. The 4th generation (4G) network was only available in a few major towns and required a 4G capable device.

The issues of network coverage and internet connectivity pose a significant challenge to the development and use of a web-based mobile data collection system such as the one developed and used in this study. The group of stakeholders targeted to be involved are those who live in or close to sites from where data is required. These sites often happen to be in rural areas where mobile network coverage is often poor or non-existent. In such circumstances it is very unlikely that such stakeholders can be involved in mobile data collection using a web-based system.

Device Specifications

A web-based mobile data collection system requires devices with a web-browser and good processor speed to be able to access the internet to download and upload data. It was observed that a majority of the target group of stakeholders had ordinary GSM mobile phones without web browsers. Where the phones had web browsers that functionality was mostly underutilised. This was because these stakeholders mainly use their phones for making calls, sending text messages (SMS) and for mobile money transactions. These are services that do not require an internet connection. It is therefore unlikely that the target group of stakeholder will have devices that will measure up to the requirement of a web-based system. This limits the possibility of involving such stakeholders using a web-based system.

The challenges highlighted above bring forth the fact that whereas there is widespread availability and use of mobile phones in most developing countries such as Uganda, their functionality remains greatly underutilised and restricted to basic services that do not require internet connectivity.

Expenses Involved

The main costs associated with a web-based system are the cost of devices and the cost of internet connection. Devices that meet the requirements of a web-based system are often expensive for most people to afford compared to the ordinary phones. In addition such devices need to be charged regularly, almost on a daily basis, unlike the ordinary phones. This can be a problem in areas without power supply, as is often the case in most rural areas in developing countries such as Uganda. This would necessitate taking the device to a place where it can be charged. Such places often charge a fee for charging devices. In addition it is time consuming and encroaches on stakeholders valuable time that could otherwise be used to fend for their families. The additional expense and inconvenience could be disincentives for stakeholders especially when they do not see any immediate direct benefit for them (Jensen and Meckling, 1994; Ostrom et al., 1993).

Internet connection, where it is available, is still expensive and most people cannot afford. For the majority of rural stakeholders who live “hand-to-mouth” and depend on subsistence agriculture for their livelihood, this could be an additional financial burden.

Whereas mobile data collection raised a lot of interest among participants and appeared to have promise as a method of involving stakeholders in water resources management, the aforementioned challenges pose significant obstacles to its possible adoption and use. This means that a web-based mobile data collection system may not be a viable method of involving stakeholders in water resources management, especially in developing countries. An alternative method that does not require an internet connection, and can use an ordinary GSM phone with a 2G network, may be required.

Chapter 8

Conclusions and Recommendations

8.1 Introduction

The growing global problem of freshwater scarcity has led to the promotion and adoption of IWRM as a means to achieve sustainable development and management of available freshwater resources. However, despite decades of popularity IWRM has registered dismal performance on the implementation front (Biswas, 2008; Blomquist and Schlager, 2005; Bunclark et al., 2011; Jeffrey and Gearey, 2006; Medema et al., 2008; Rahaman, 2009). One of the main problems relates to the challenge of involving stakeholders in the management of water resources (Butterworth et al., 2010; Sgobbi and Giupponi, 2007).

Successful implementation of IWRM involves closing the gap between the theoretical principles on which the concept is based and their practical implementation (Rahaman, 2009; Wilkinson et al., 2016). One of the key principles that underpin IWRM is the requirement for participatory involvement in water resources management. However, efforts to involve stakeholders in the management of water resources has often registered little success (Agyenim and Gupta, 2012; Irvine and O'Brien, 2009; Jingling et al., 2010; Teodosiu et al., 2013; De Stefano, 2010). It is against this background that this study set out to investigate means through which stakeholder involvement in water resources management could be improved so as to enhance implementation of IWRM. This study had the following objectives:

1) To investigate the potential of participatory modelling as a means of involving stakeholders in water resources management
2) To assess the extent to which participatory modelling can deliver benefits for water resources management
3) To investigate the feasibility of mobile data collection as a means of involving stakeholders in water resources management

4) To assess the extent to which the water resources management framework in Uganda provides an enabling environment that supports stakeholder participation

In order to achieve the first and second objectives a participatory modelling exercise was designed and implemented with a select group of stakeholders and the process evaluated. In order to achieve the third objective, a mobile data collection system was developed, tested and evaluated. In order to achieve the fourth objective a framework for water resources management in Uganda was examined.

The main findings of the study are presented in Chapters 4, 5 and 6, and discussed in Chapter 7. This chapter draws on those findings to make conclusions.

The rest of this chapter presents a summary of the key findings of the study, the conclusions drawn from those findings, implications of the findings for practice and policy, and recommendations for further study.

8.2 Summary of Key Findings

Participatory Modelling

The first objective of the study was to investigate the potential of participatory modelling as a means of involving stakeholders in water resources management. The study found that participatory modelling is a suitable means of involving stakeholders in water resources management. The study identified four main stages of the modelling exercise through which this can be achieved. These are:

i) The problem identification stage – this allows participants to jointly explore the water challenges in the area and identify the main issues of concern
ii) The model quantification stage – this enables participants' knowledge, experiences and expertise to be built into the model in form of conditional probabilities and used in decision making. The outputs of the model are calculated based on the conditional probabilities and therefore they reflect the knowledge and experiences of participants

iii) The interventions identification stage – this enables participants to identify interventions that are relevant to their concerns

iv) The scenario analysis stage – this enables participants to select and prioritise appropriate interventions for implementation

Three key factors that influence a participatory modelling exercise, and have a direct bearing on the process outcomes, were also identified. These are:

i) The stakeholders selected to take part in the modelling exercise – they are essentially the ones driving the process by providing all the necessary input. They need to be carefully selected so as to benefit from a broad range of views, knowledge and experiences of water resources issues across the catchment

ii) The modelling tool used – this needs to have characteristics that facilitate participation for it to be suitable for engagement with stakeholders in a participatory process. Characteristics such as flexibility, ability to perform scenario analysis, ability to consider qualitative and quantitative data, and ability to consider uncertainty were found to be important in this respect. To that end the study revealed the effectiveness of a Bayesian networks model as a tool for facilitating engagement with stakeholders in a participatory framework

iii) The model building exercise – this provided participants with a common ground for discussions and enabled them to jointly identify and assess water resources issues in the catchment. The steps taken to construct the model provided a structured and systematic framework through which active participation of all involved was realised

The second objective of the study was to assess the extent to which participatory modelling can deliver benefits for water resources management. The study identified some benefits of participatory modelling that were found to be important for supporting stakeholder participation in water resources management. These include:

i) It provides a platform for dialogue. This enables stakeholders to come together to discuss issues of concern and come up with possible intervention strategies
ii) It provides a means through which stakeholders can be involved in decision making
iii) The model building exercise provides opportunity for social learning where participants learn from each other thereby improving their knowledge and understanding of issues around them. This enables them to objectively analyse and discuss issues of concern from an informed point of view
iv) It enhances participants' trust and confidence in the process outputs especially when participants are involved in all stages of the modelling process
v) Use of a modelling tool such as a Bayesian networks model makes the process flexible and suitable for adaptive management

However, some weaknesses with participatory modelling were also observed. These include:

i) The model developed has the potential to be biased towards the participants' world view and understanding of the system it describes because it is based on participants knowledge and experiences of the system.
ii) There is no assurance that the decisions made during the participatory modelling process will be implemented because the final decisions are often made elsewhere where the participants in the modelling process may have no say
iii) It is time consuming and therefore requires commitment on the part of the stakeholders to set aside time to attend
iv) It is difficult to organise, especially in relation to mobilising participants and finding a competent facilitator
v) It is costly in terms of logistical requirements needed to organise and conduct the modelling workshops
vi) Participatory modelling involves a small group of people at a time. It therefore runs a risk of leaving out some stakeholders which could lead to

unintended negative consequences, such as legitimisation of decisions favoured by few individuals

vii) It doesn't promote democracy as expected from participation because only a select group of people are involved.

Mobile Data Collection

The third objective of the study was to investigate the feasibility of mobile data collection as a method of involving stakeholders in the management of water resources. The study found that a web-based mobile data collection system is not viable as a method of involving local stakeholders in water resources management, especially in a developing country context. Three main reasons for this were identified. These are:

i) Poor internet connectivity and mobile network coverage. This affects the participants' ability to use the system since an internet connection is required.
ii) A majority of the target group of stakeholders were found to have ordinary GSM mobile phones without web browsers. This affects their ability to use a web-based mobile data collection system.
iii) The cost of a suitable device and data bundles for internet connection were found to be high for the target group of stakeholders. This makes the whole system expensive for the target group.

An Enabling Environment for Water Resources Management

The fourth objective of the study was to assess the extent to which the water resources management framework in Uganda provides an enabling environment that supports stakeholder participation. The study found that the existing water resources management framework in Uganda supports stakeholders participation in water resources management.

However, the study also found that creating an enabling environment does not necessarily ensure stakeholder participation, neither does it ensure better management of water resources. It was found that although the existing water resources management framework in Uganda provides an enabling environment for stakeholder participation, not all key stakeholders in the water sector were involved in water resources management. It was also found that despite existence of such a comprehensive framework, the water resources in Uganda were continuing to deteriorate. Some implementation issues were also observed with the water resources management framework.

8.3 Conclusions

The conclusions drawn from this study are in the area of practical applications to advance the practice of IWRM and participatory modelling. From the findings of the study the following conclusions have been drawn.

1. Participatory modelling can enhance implementation of IWRM by supporting stakeholder participation in the management of water resources
2. A Bayesian networks model is an effective tool for facilitating engagement with stakeholders in a participatory framework
3. An enabling environment for water resources management on its own is not sufficient to enhance implementation of IWRM
4. A web-based mobile data collection system cannot enhance implementation of IWRM because it cannot support stakeholder involvement in water resources management

8.4 Implications for Policy and Practice

While stakeholder participation in the management of water resources is a key requirement in the implementation of IWRM, its realisation in practice has largely taken the form of informing and consulting stakeholders with minimal real input from stakeholders. This has largely been attributed to inadequate guidance of how actual stakeholder participation can be achieved in practice (Biswas, 2008; Medema et al., 2008; Sgobbi and Giupponi, 2007).

As the responsibilities of managing water resources are increasingly being decentralised, for example through catchment-based water resources management

(DWRM, 2010; DWRM, 2014a), with more emphasis being placed on stakeholder participation, mechanisms for effectively involving stakeholders are required. This study makes an attempt to improve the guidance available on how to constructively involve stakeholders in water resources management by demonstrating how participatory modelling, using a Bayesian networks model, can support scoping water resources management issues with stakeholders. Methodologically, participatory modelling offers guidance on how to constructively engage stakeholders, and the Bayesian networks model offers an effective tool for facilitating the engagement process.

Improving stakeholder participation in water resources management is essential for fulfilling the requirement of IWRM regarding participatory involvement and is therefore a step towards enhancing implementation of IWRM. Enhancing implementation of IWRM is important for realising target 6.5 of the SDGs, which seeks to ensure implementation of IWRM at all levels.

Participatory modelling is costly and time consuming to implement. Ability to apply participatory modelling could, therefore, be influenced by availability of necessary resources. This could pose significant constraints to the use of participatory modelling in a participatory framework, especially in developing countries were financial resources are likely to be scarce.

Currently there is no standardised method of conducting participatory modelling. Insights from this study can contribute to the state of knowledge and improvements in participatory modelling practice and in raising awareness of its potential benefits for water resources management. This is useful for advancing and ensuring a more meaningful and practical future for participatory modelling.

Very few studies that have used participatory modelling have evaluated the process leading to the development of the model. In light of this, insights from this study could contribute to the state of knowledge in the area of evaluation of participatory modelling processes.

8.5 Recommendations

Recommendations for Policy and Practice

The conclusions from this study suggest that adoption of participatory modelling could enhance implementation of IWRM. In this regard it is recommended that participatory modelling could be made an integral part of the IWRM implementation process, especially at the stage of scoping water resources issues in the catchment. In so doing, account must be taken of the resources needed to implement participatory modelling, specifically financial and human resources. These resources could be major limiting factors and therefore mobilising financial resources and developing human capacity may be necessary.

The conclusions also suggest that an enabling environment for water resources management on its own is not sufficient to enhance implementation of IWRM. In this regard it is recommended that in creating such an environment consideration must be taken to include supporting measures that ensure that (i) all key stakeholders are identified and involved, and (ii) relevant laws are adequately enforced.

Recommendations for Further Research

This study looked at the issues affecting a whole catchment in general. Similar studies could be carried out at different locations within the same catchment, say upstream and downstream, to determine if there are different issues and priorities in different locations and how the management options identified compare.

In water resources management a key benefit often sought from participation is to ensure an improvement in the state of water resource. An investigation could be carried out to determine whether stakeholder participation does actually lead to better water resources management. Given that changes in the state of water resources often appear in the medium to long term, any changes taking place in the catchment during such a period that could affect the state of water resources need to be taken into account, e.g. change in weather or development plans.

Other means of improving stakeholder participation in water resources management could be investigated.

This study has assessed the water resources management framework in Uganda with respect to its capacity to support stakeholder participation. Following on from the findings of this study there is need to determine the extent to which the framework is translated into practice.

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Appendix A: Ethical Approval Letter

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UNIVERSITY OF LEEDS

Charles Ekure
School of Civil Engineering
University of Leeds
Leeds, LS2 9JT

MaPS and Engineering joint Faculty Research Ethics Committee (MEEC FREC)
University of Leeds

20 February 2015

Dear Charles

Title of study **Identifying the potential to enhance implementation of IWRM by using participatory modelling and participatory data collection as methods for stakeholder engagement**

Ethics reference **MEEC 14-015**

I am pleased to inform you that the application listed above has been reviewed by the MaPS and Engineering joint Faculty Research Ethics Committee (MEEC FREC) and following receipt of your response to the Committee's initial comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	*Version*	*Date*
MEEC 14-015 Ethical Review Application Form for Charles Ekure.pdf	2	09/02/15
MEEC 14-015 Fieldwork Risk Assessment Form for Charles Ekure.pdf	2	09/02/15
MEEC 14-015 Mobile Data Collection system evaluation questionnaire.pdf	2	09/02/15
MEEC 14-015 Participants Information Sheet and Consent form.pdf	2	09/02/15
MEEC 14-015 Workshop Evaluation Questionnaire.pdf	2	09/02/15
MEEC 14-015 Response to Ethics Committee.pdf	1	09/02/15

Committee members made the following comments

- You have stated on the participant information form that permission will be sought if identifiable information is going to be made public (also stated in Section C19). The Committee advises adding a statement added to the consent form, giving people the option to opt in or out of being identified so that you have written consent for this as well.

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator, Research & Innovation Service
On behalf of Professor Gary Williamson, Chair, MEEC FREC

CC: Student's supervisor(s)

Appendix B: Research Approval Letter

Uganda National Council for Science and Technology
(Established by Act of Parliament of the Republic of Uganda)

UNCST

06/08/2015

Our Ref: **SIR 142**

Charles Ekure
National Water and Sewerage Corporation
Kampala

Re: Research Approval: **Identifying the potential to enhance implementation of IWRM by using participatory modeling and participatory data collection as methods for stakeholder engagement**

I am pleased to inform you that on **03/03/2015**, the Uganda National Council for Science and Technology (UNCST) approved the above referenced research project. The Approval of the research project is for the period of **03/03/2015** to **03/08/2015.**

Your research registration number with the UNCST is **SIR 142.** Please, cite this number in all your future correspondences with UNCST in respect of the above research project.

As Principal Investigator of the research project, you are responsible for fulfilling the following requirements of approval:

1. All co-investigators must be kept informed of the status of the research.
2. Changes, amendments, and addenda to the research protocol or the consent form (where applicable) must be submitted to the designated local Institutional Review Committee (IRC) or Lead Agency for re-review and approval **prior** to the activation of the changes. UNCST must be notified of the approved changes within five working days.
3. For clinical trials, all serious adverse events must be reported promptly to the designated local IRC for review with copies to the National Drug Authority.
4. Unanticipated problems involving risks to research subjects/participants or other must be reported promptly to the UNCST. New information that becomes available which could change the risk/benefit ratio must be submitted promptly for UNCST review.
5. Only approved study procedures are to be implemented. The UNCST may conduct impromptu audits of all study records.
6. A progress report must be submitted electronically to UNCST within four weeks after every 12 months. Failure to do so may result in termination of the research project.

Below is a list of documents approved with this application:

	Document Title	Language	Version	Version Date
1.	Research Proposal	English	N/A	N/A
2.	Questionnaire	English	N/A	N/A

Yours sincerely,

Hellen N. Opolot
for: Executive Secretary
UGANDA NATIONAL COUNCIL FOR SCIENCE AND TECHNOLOGY

LOCATION/CORRESPONDENCE

Plot 6 Kimera Road, Ntinda
P. O. Box 6884
KAMPALA, UGANDA

COMMUNICATION

TEL: (256) 414 705500
FAX: (256) 414-234579
EMAIL: info@uncst.go.ug
WEBSITE: http://www.uncst.go.ug

Appendix C: Workshop Programs

Program for Workshop 1

Date: 30th April 2015. Time: 10:00 – 12:00

Venue: Agip Motel – Mbarara

Focus: Stakeholder Participation in Water Resources Management

#	Task	By	Time
1	Brief introduction and background	Facilitator	10:00 – 10:20
2	Discussion and identification of resources at stake in the catchment	Participants	10:20 – 10:40
3	Identification of the issue and variables (*causes, effects)*, and identify management objective	Participants	10:40 – 11:00
TEA BREAK			**11:00 – 11:20**
4	Development of conceptual model of the issue	Participants	11:20 – 12:00
END			**12:00**

Program for Workshop 2

Date: 14th May 2015. Time: 10:00 – 12:00

Venue: Agip Motel – Mbarara

Focus: Stakeholder Participation in Water Resources Management

#	Task	By	Time
1	Recap of Workshop 1	Facilitator	10:00 – 10:10
2	Finalise the conceptual model and check that it is arranged in a logical order	Participants	10:10 – 10:30
3	Define the states of the variables in the model	Participants	10:30 – 11:00
TEA BREAK			**11:00 – 11:20**
4	Introduce the method of Mobile Data Collection and design a form for data collection	Facilitator/Participants	11:20 – 11:40
5	Demonstrate method of mobile data collection	Facilitator/Participants	11:40 – 12:00
END			**12:00**

Program for Workshop 3

Date: 9th July 2015. Time: 10:00 – 12:00

Venue: Agip Motel – Mbarara

Focus: Stakeholder Participation in Water Resources Management

#	Task	By	Time
1	Recap of Workshop 2	Facilitator	10:00 – 10:10
2	Validation of the model network, inputs and output	Participants	10:10 – 10:30
3	Identification of management options (interventions) and possible future scenarios	Participants	10:30 – 10:50
TEA BREAK			**10:50 – 11:10**
4	Scenario analysis and discussion of outputs	Facilitator/Participants	11:10 – 11:40
5	Discussion of the mobile data collection systems field trials	Participants	11:40 – 12:00
6	Filling the questionnaire	Participants	12:00
END			

Appendix D: Workshop Scripts

Script for Workshop 1

The first workshop will begin by clarifying the aim of the study, how the workshops will be run and the ground rules that will govern the conduct of participants. This will be followed by a brief introduction of IWRM and the role of stakeholders. Thereafter the participants will perform a number of tasks as below.

Task 1.1

Participants to consider the resources at stake in the catchment prioritise them and select one of major concern. (*The study to focus on a single issue in order to fit within the limited time available*)

Task 1.2

Participants to identify specific issue with the resource and identify the problem variables (causes and effects). Participants to identify management objective.

Task 1.3

Participants to organise the variables into a network in the form of a cause-and-effect relationship to develop a conceptual model of the problem.

(The process to be based on the Driving Force-Pressure-State-Impact-Response (DPSIR) framework)

This and all other stages to be keenly observed for any possible insights from the interaction that takes place including the non-verbal communication

Script for Workshop 2

Task 2.1

Recap activities of workshop 1 and discussion of any issues that arose therein.

Task 2.2

Participants to finalise development of the conceptual model and check that the network is arranged in a way that makes logical sense. This is to make sure that all variables of interest have been identified. (*Any other unfinished tasks from the previous workshop to be handled in this workshop)*

Task 2.3

Participants to choose and quantify the states of each of the variables by assigning respective probabilities. (*The state of a variable is quantified by specifying a conditional probability table that expresses the probability of the variable being in a particular state given the state of the variables that influence it)*.

Task 2.4

Introduce and demonstrate the method of mobile data collection

Script for Workshop 3

Task 3.1

Recap activities of workshop 2 and discussion of any issues that arose therein

Task 3.2

Participants to validate the model network and inputs by assessing the relationships expressed in the model and model output by comparing the results of selected variables with their past/current status.

Task 3.3

Participants to identify management options (interventions) and possible future scenarios.

Task 3.4

Carryout scenario analysis by running the model for different management options under different future scenarios. Participants to examine the outputs and identify optimal intervention options that are more likely to be realised under each scenario.

Task 3.5

Present and discuss results from the mobile data collection field trials.

Task 3.6

Administer the questionnaire

Appendix E: Observation guide

General

Sources of drinking water; water supply facilities; rivers, lake and streams; major industries,

Specific

1. Workshops
    - Categories of participants, participation rate, contribution in discussions, stages of workshop generating lots of discussion and issues discussed
2. Field visits
    - Sources of water pollution – solid and liquid waste collection points, points of environmental damage, threats to the water source
3. CMC meeting
    - Categories of participants (stakeholders), chairperson, issues discussed and how decisions are arrived
4. Stakeholders Forum meeting
    - Categories of participants (stakeholders), language used, issues discussed and how decisions are arrived

Appendix F: Interview Guide

General Text

I am carrying out a study on stakeholder participation in water resources management. I believe your experience with water resources issues in the Rwizi catchment makes you the ideal person to help us with this study.

I have just a few questions I need to ask you regarding water issues in the catchment.

1. What do you consider as the major water resources issues in the river Rwizi catchment? *(e.g. water quantity, water quality etc.)*
2. Which of these do you consider the most important and why? *(one that needs immediate attention)*
3. What do you think are the causes of this issue?
4. How is this affecting communities in the catchment generally and you in particular?
5. What do you think could be done to address this issue?
6. As a key stakeholder in the catchment what are you doing or willing to do to address this issue? *e.g. Restoration of degraded land and wetlands, collecting/sharing information for management purposes, proper management and disposal of waste etc.*
7. Is there anything else you want to tell me about the water issues in the catchment?

That is all for now. Thank you so much for your time. I may get back to you if I require more information from you.

Thank you

Appendix G: Workshop Evaluation Questionnaire

Workshop Name: Participatory Modelling for Water Resources Management

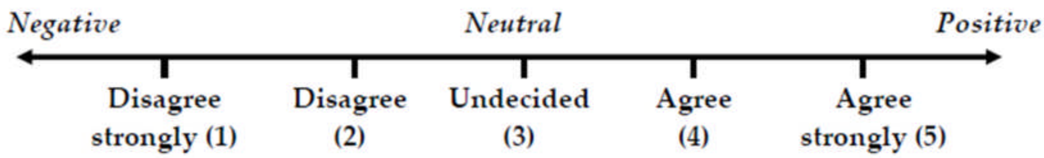
Location: Mbarara, Uganda

Date: _______________

Participant Ref No: 09072015____

INSTRUCTIONS

Please tick/circle the number that represents the extent to which you disagree or agree with the following statements according to the scale below.



Your feedback is much appreciated. Thank you

A: PARTICIPATORY MODELLING PROCESS

1.	The main objective for water resources management in the area has been identified	1	2	3	4	5
2.	The process enabled sharing of knowledge and information among participants	1	2	3	4	5
3.	The process provides opportunity for participation in water resources management	1	2	3	4	5
4.	The process enabled me understand the interrelationships of water resources issues	1	2	3	4	5
5.	The solutions identified are acceptable	1	2	3	4	5

B: MODEL DEVELOPMENT

6.	I was involved in building the model	1	2	3	4	5
7.	The process of model building encouraged discussion among participants	1	2	3	4	5
8.	The model helped to focus discussions	1	2	3	4	5
9.	The model building process improved my understanding of water issues in the area	1	2	3	4	5
10.	My ideas/opinions/concerns have been included in the model	1	2	3	4	5

In section C below please tick/circle the number that represents the extent to which you disagree or agree with the statements as of ***NOW*** *(at the end of the workshops) and also* ***BEFORE*** *the workshops.*

C: GENERAL KNOWLEDGE OF WATER RESOURCES ISSUES

11.	I know the causes of water resources problems in the area	**NOW**	**1**	**2**	**3**	**4**	**5**
		BEFORE	1	2	3	4	5
12.	I know the effects of water resources problems in the area	**NOW**	**1**	**2**	**3**	**4**	**5**
		BEFORE	1	2	3	4	5
13.	There are strategies in place to address the water problems in the area	**NOW**	**1**	**2**	**3**	**4**	**5**
		BEFORE	1	2	3	4	5
14.	I have opportunity to participate in water resources management in my area	**NOW**	**1**	**2**	**3**	**4**	**5**
		BEFORE	1	2	3	4	5
15.	I know what can be done to improve the water situation in the area	**NOW**	**1**	**2**	**3**	**4**	**5**
		BEFORE	1	2	3	4	5

D: METHOD OF PARTICIPATION

Please feel free to use the backside of this paper if you need more space to write your response.

16. What are your thoughts on the method of participation overall?

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17. What did you like/dislike about the method?

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18. How do you think the method could be improved?

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Appendix H: Participant Invitation, Information Sheet & Consent Form

Participants Invitation

Date:_______________

____

____

____

Invitation to Participate in a Research Workshop

You are invited to take part in a research. However, before you decide it is important that you understand why the research is being done and what will be involved. Please take time to read the attached information carefully. You may discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information. You may take your time to decide whether or not you wish to take part. Thank you for your time.

Charles Ekure

Participants Information Sheet

Research Title

Identifying the potential to enhance implementation of integrated water resources management by using participatory modelling and mobile data collection as methods for stakeholder engagement

What is the purpose of this research?

There is a pressing global problem of increasing freshwater scarcity. This is mainly due to increasing demand for water from the growing population and effects of climate change among others. This has forced many countries to reconsider their options regarding management of their water resources. In this regard integrated water resources management (IWRM) has been promoted and adopted by many countries as the most appropriate concept to address the current water related challenges in a sustainable and cost-effective manner. IWRM is basically an approach of coordinating the way water is used and managed by taking into consideration all sectors, water types and categories of use and incorporating good governance. This needs direct and active involvement of stakeholders. Stakeholders in this case are people or sectors that are affected by or that can affect the state of water resources in the area.

The purpose of this research is to identify the possibility of improving implementation of integrated water resources management through stakeholder involvement.

The research will involve engaging selected participants in identifying water resources issues and possible solutions through workshops, interviews and in mobile data collection using mobile phones or other similar portable devices. These activities will be spread out over a period of five months.

Why you have been chosen

The research is about the role that stakeholders can play in ensuring better management of water resources. We believe your experience with water resources issues in the area makes you ideally suited to help us with this research. You could also help by proposing suitable ways in which these issues may be solved. About 15 participants are expected to attend the workshops and about 15 will attend the interviews.

Do I have to take part?

Taking part is entirely voluntary. Also if you change your mind you can withdraw from the research at any time without it affecting you in any way. You do not have to give a reason for withdrawing.

How can I take part?

There are two ways you can take part.

1. You can take part in workshops in which water resources issues in the area will be discussed and their representation developed in form of a model. **No specific educational background is required for this activity**. Each workshop will last about two hours. Local travel expenses to and from the venue of the workshops will be reimbursed.
2. You can talk to me in an interview session about these issues. This will take about 30 minutes.

What are the possible benefits of taking part?

There are no immediate benefits for the people participating in the research, however it is anticipated that this work will contribute to formulation of appropriate strategies and interventions for managing water resources in the area.

If I decide to take part, what will happen to my responses?

With your permission our discussions will be recorded on an audio/video recorder. This is because all that you say is important to the research and I do not want to miss out anything. Recording also means I won't be distracted by trying to write down what is being discussed. I will keep the recording private and use it only to help me to write up what we discuss.

The findings from this study will be published so that other people can learn from it but no names will be used.

Confidentiality and Anonymity

All data and information collected from you will be treated in a confidential manner and used solely for study purposes. Data and information collected will be used in such a way that it will not be possible to link it to you. However where it becomes necessary to make public some information that might reveal who you are, permission will first be sought from you. In this case you have the option to refuse to be identified.

Illegal activity

The research will take place in an urbanising catchment. There are a number of ongoing activities within the catchment such as farming, brick making etc. as well as a number of industries. Some of these activities have potential to directly affect the state of the water resources while industries may produce waste and other by-products that could affect the state of the water resources if not treated as required. If during the course of this study we come across an individual or organisation whose activity is affecting the state of water resources in the area, such organisation or individual will be reported to the National Environment Management Authority as required by law.

What do I have to do now?

Check that you fully understand the information on this sheet and ask me anything you are not clear about. If you agree to take part, then please read and sign the consent form below.

Contact for further information

Name: Charles Ekure
Address: School of Civil Engineering
University of Leeds
Leeds, LS2 9JT
United Kingdom
Tel: +447440434081/+256772685314
Email: cen9c2e@leeds.ac.uk

Name: Prof Nigel Wright
Address: School of Civil Engineering
University of Leeds
Leeds, LS2 9JT
United Kingdom
Tel: +441133430350
Email: n.g.wright@leeds.ac.uk

Thank you for taking your time to read this information sheet

Participant Consent Form

Research Title:
Identifying the potential to enhance implementation of integrated water resources management by using participatory modelling and mobile data collection as methods for stakeholder engagement

Tick the box if you agree with the statement

1	I confirm that I have read and understand the information sheet explaining the above research and I have had the opportunity to ask questions about the research.	☐
2	I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.	☐
3	I agree for the data collected from me to be stored in an anonymised form and used for relevant future research	☐
4	I agree to take part in the above research and will inform the principal investigator should my contact details change.	☐
5	I understand that the information I give will be kept confidential and anonymous. However where need be I accept to be identified with this information	☐

Name of Participant: __________________. Signature and Date ______________

Name of Researcher: _________________. Signature and Date ______________

Appendix I: Conditional Probability Tables

CPT for Population

Population	
Low	High
0.50	0.50

CPT for Restoration

Restoration	
No	Yes
0.50	0.50

CPT for Law Enforcement

Law Enforcement	
No	Yes
0.50	0.50

CPT for Demand

Population	Demand	
	Low	High
Low	0.90	0.10
High	0.10	0.90

CPT for Socioeconomic Development

Demand	Socioeconomic Development	
	Low	High
Low	0.95	0.05
High	0.05	0.95

CPT for Land Use

Human Activities	Land Use	
	Low	High
Low	0.90	0.10
High	0.10	0.90

CPT for Climate Change

Human Activities	Climate Change	
	Moderate	Significant
Low	0.60	0.40
High	0.40	0.60

CPT for Rainfall

Climate Change	Rainfall	
	Normal	High
Moderate	0.50	0.50
Significant	0.40	0.60

CPT for Human Activities

Socioeconomic Development	Demand	Human Activities	
		Low	High
Low	Low	0.95	0.05
Low	High	0.10	0.90
High	Low	0.10	0.90
High	High	0.05	0.95

CPT for Runoff

Restoration	Rainfall	Land Use	Runoff	
			Low	High
No	Normal	Low	0.40	0.60
No	Normal	High	0.30	0.70
No	High	Low	0.30	0.70
No	High	High	0.05	0.95
Yes	Normal	Low	0.80	0.20
Yes	Normal	High	0.60	0.40
Yes	High	Low	0.80	0.20
Yes	High	High	0.50	0.50

CPT for Waste

Law Enforcement	Land Use	Waste	
		Low	High
No	Low	0.95	0.05
No	High	0.05	0.95
Yes	Low	0.98	0.02
Yes	High	0.60	0.40

CPT for Water Quality

Waste	Runoff	Water Quality	
		Poor	Good
Low	Low	0.20	0.80
Low	High	0.60	0.40
High	Low	0.60	0.40
High	High	0.95	0.05

Appendix J: Mobile Data Collection Evaluation Questionnaire

Name: Mobile Data Collection System

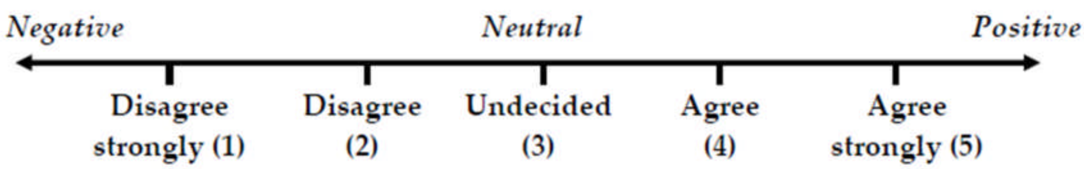
Location: Mbarara, Uganda

Date: _______________

Participant Ref No.: 09072015____

INSTRUCTIONS

Please tick/circle the number that represents the extent to which you disagree or agree with the following statements according to the scale below.



Your feedback is much appreciated. Thank you

A: Mobile Data Collection

1.	I'm concerned about the water resources situation in my area	1	2	3	4	5
2.	Mobile data collection can enable me to participate in managing water resources in my area	1	2	3	4	5
3.	The mobile data collection system is helpful for monitoring activities that affect water resources	1	2	3	4	5
4.	I'm interested in participating in collecting data using this system	1	2	3	4	5

5. The mobile data collection system is easy to understand 1 2 3 4 5

B: SYSTEM OF DATA COLLECTION

Please feel free to use the backside of this paper if you need more space to write your response.

6. What are your thoughts on this system of data collection overall?

____

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7. What did you like/dislike about the system?

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8. How do you think the system could be improved?

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Appendix K: Step for Developing a Mobile Data Collection System

1. Setup a Google account so as to be able to access and use Google's infrastructure for developing the system.
2. Create a data collection form (see Figure 8.1 below) using the ODK Build module of the ODK tool kit. Once logged into the ODK Build module (http://build.opendatakit.org), a blank untitled form appears. Creating a new data collection form involves adding questions to the blank untitled form. The type of questions to be added (e.g. Text, date) can be selected from the bottom of the page. The pane on the right hand side of the form allows text to be entered when adding the questions and also allows various properties for the form to be set.
3. Create an App Engine. This is a platform that allows building and hosting of applications on Google's infrastructure.
4. Create an application and assign it an identifier. The identifier assigned to the application created was "cen9c2e.appspot.com". This also became part of the URL for the App Engine.
5. Set up an online server (see Figure 8.2 below) using the App Engine's setup and the ODK Aggregate module of the ODK tool kit. This is where data collected from the field is uploaded. An online server was used because the service was free up to 1 GB of storage, which was adequate for the purpose of the study. This helped save costs of purchasing a local server. It was also more convenient and helped avoid the risks of theft and hardware failure from power interruptions and fluctuations that were common in the study area.
6. Set access restrictions to the server as shown in Figure 8.3 below. This gives restrictions to the people who have permission to submit data collected in the field, view the data submitted and edit the data.

7. Upload the data collection form to the App Engine. This allows anyone who has the ODK Collect app installed, and appropriately configured in their mobile device, to download and use the form for collecting data. Once the form is successfully uploaded it will appear in the App Engine, ready for download as shown in Figure 8.4 below.

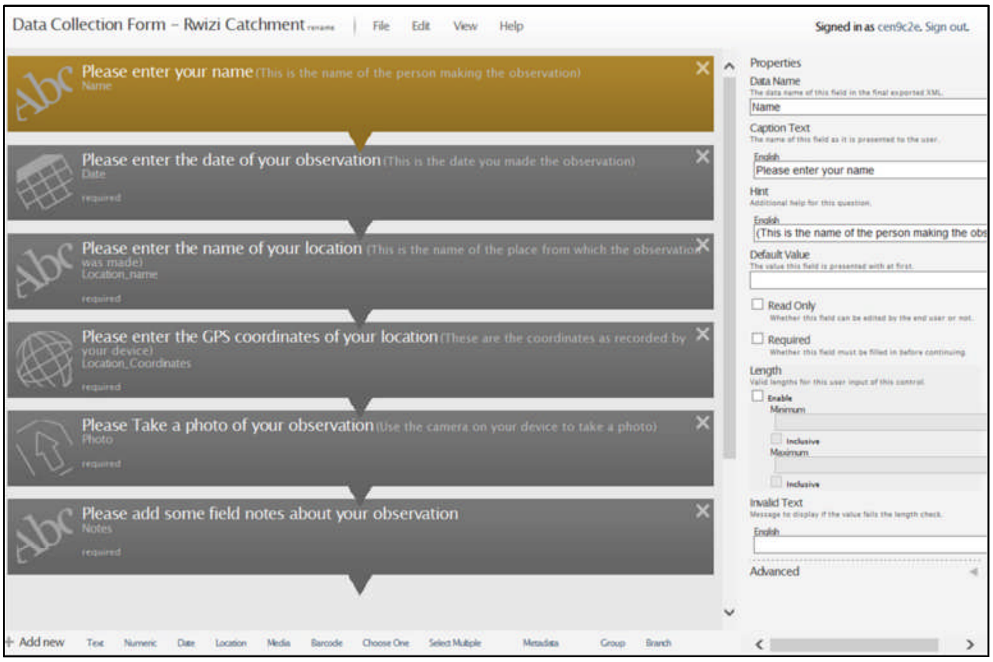

Figure 8.1: A screenshot of a data collection form created using the ODK Build module

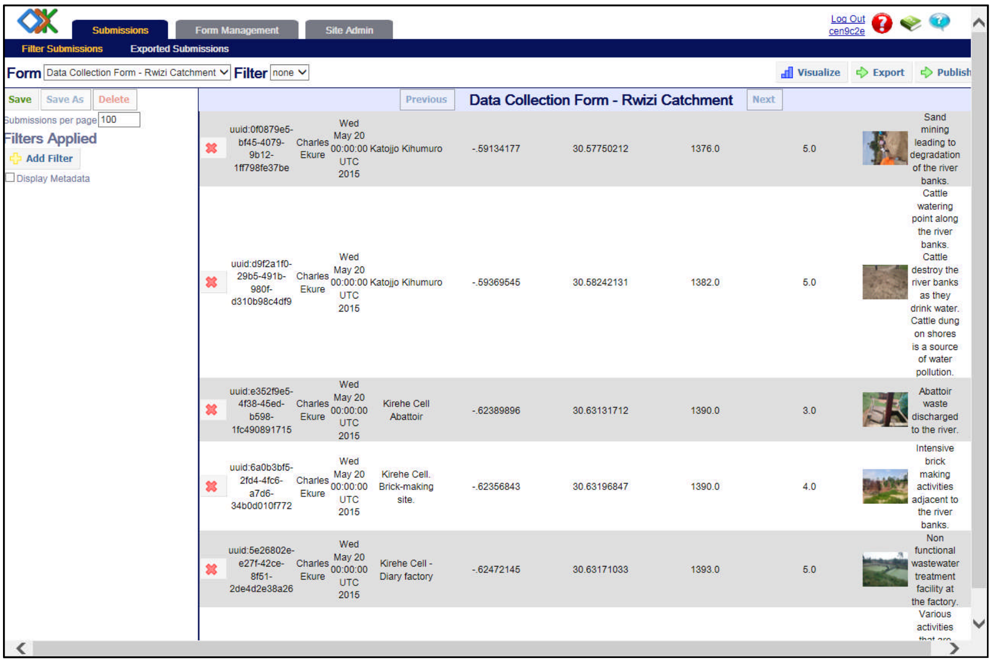

Figure 8.2: A screenshot of the online server with data forms uploaded

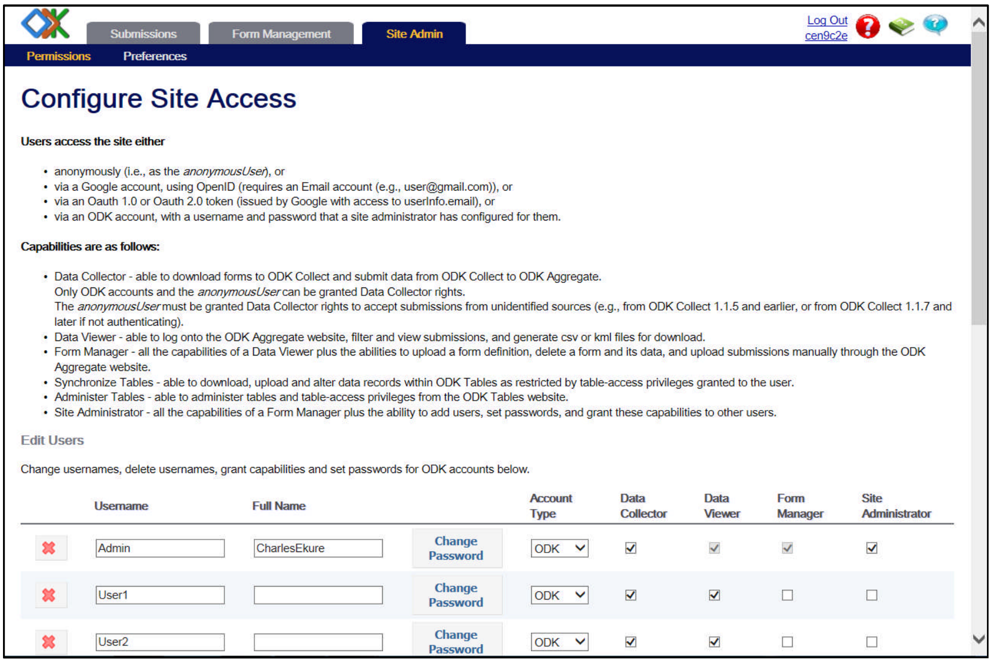

Figure 8.3: A screenshot of server access restriction settings

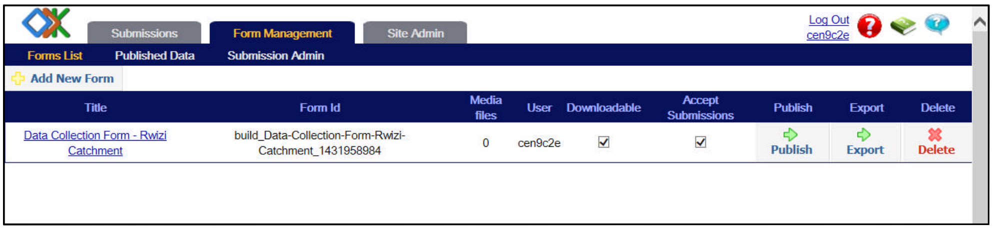

Figure 8.4: A screenshot of the online server with a blank data collection form ready for download