Crime, illegal waste disposal, and pluvial flooding: Three challenges to the sustainability of a tropical conurbation

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Abstract

Rapid urbanization in Latin America and the Caribbean has led to considerable social, economic and environmental problems. This thesis aims to provide a better understanding of the links between natural and social factors in informing the development of urban policy strategies that can steer cities in Latin America and the Caribbean towards a more sustainable future. This thesis focuses on three issues that have emerged as key challenges for the implementation of policies that promote more socially inclusive and environmentally sustainable urban development in the region: growing socio-economic inequality; the limitations of solid waste collection and its processing systems; and increasing pressures on infrastructure caused by natural hazards. The thesis explores Barranquilla, Colombia, as a case study of a Latin American urban zone. First, the thesis explores the role of socio-economic factors as determinants of criminal activity in a context of increasing climate stress. Second, it considers the scope for public intervention aimed at eradicating all open-air dumps in Barranquilla, using a contingent valuation study to explain the degree to which households are willing to participate and pay for such intervention. This work applied a two-step regression model to a sample of 815 households within the urban territory to assess the socioeconomic factors that determine the households' preferences. Finally, the determinants of households' preferences for implementing a sustainable urban drainage system to cope with the phenomenon of flash-floods formation is investigated. A discrete choice experiment was applied to estimate households' willingness to pay for three attributes of a SuDS: 1. Reducing the number of fatalities; 2. Improving vehicular mobility; and 3. Improving pedestrian mobility. A basic mixed logit model and an extended mixed logit were used to determine households' preferences for each attribute. From a policy-making perspective, this research reveals new evidence that can provide insights into the types of policy approaches that are needed to enhance the sustainability of Barranquilla. It shows the need for a new, more integrative approach to policy, to consider climate and environmental factors alongside structural and socio-economic ones, such as high levels of income inequality and low levels of educational attainment in the poorest areas of the city. It also highlights the importance of improving trust between communities and authorities in order to implement these policies effectively, so that real progress can be made towards more sustainable futures for Barranquilla and similar cities in the Latin American region.

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Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this or any other university. All sources are acknowledged in the thesis as references.

Chapters 2, 3 and 4 have been written as scientific articles. As such, all copyrights will be transferred to the corresponding publishers.

Chapter 1: Crime, illegal waste disposal, and pluvial flooding: Three challenges to the sustainability of a tropical conurbation

1.1 Introduction

The motivation for this research stems from the urban sustainability literature, in particular in the context of the Latin America and the Caribbean region. This chapter explores the complexity of managing environmental challenges associated with the rapid increase of urban development evidenced in these countries, and how this affects the design of this research.

While urban areas cover about 0.4-0.9% of the global land surface, half of the population lives in cities, and the United Nations projected to further increase to 68% by 2050 (UNDESA, 2019). This high population density may offer some environmental, economic, and social advantages, but it can impose a wide range of sustainability challenges to global human-natural systems related to energy, food, human health, biodiversity, water, and climate (Daily & Ehrlich, 1992; Dye, 2008; Hodson, 2016). Making cities more inclusive, safe, resilience and sustainable is a global priority, which is highlighted by 'Sustainable Cities and Communities' being listed as Goal 11 of the Sustainable Development Goals (SDG) adopted by United Nations Member States in 2015 (United Nations [UN], 2015). Moreover, the sustainable development of cities is recognized as key to successfully implementing the whole SDG agenda (UN, 2017), given the cross-cutting nature of urban issues. For example, solid waste management affects living conditions, sanitation, inequalities, marine and terrestrial ecosystems, public health and access to decent jobs, therefore having close links at least 12 of the SDG (Rodic-Wiersma & Wilson, 2017). SDG 6 seeks 'to ensure the availability and sustainable management of water and sanitation for all', which is a daunting task in urban water systems due to the growing scarcity of this resource, growing variation on weather and climate conditions, increasing demand, pollution, and technical, financial and governance limitations in managing infrastructure, among others (Polonenko et al., 2020). Similarly, the link between urban governance and climate change is now firmly established. Cities produce 80% of the GDP of countries (Sassen, 2018; Zhang, 2016) and generate 75% of energy-related CO2 emissions (Intergovernmental Panel on Climate Change [IPCC], 2014). Here the issues explored in the literature include the construction

and operation of buildings (i.e., cities' built environment), housing affordability, urban transport, traffic congestion, air quality, energy systems (e.g., Croce et al., 2019; Heidrich et al., 2016; Mendizabal et al., 2018). This suggests the enormous breadth of the literature on urban sustainability challenges. There is an increasing interest in the understanding of the interlinkages among the interconnected factors of sustainability as a crucial knowledge to avoid trade-offs and conflicts that may undermine the effectiveness of urban policy efforts. In a recent analysis, del Mar Martínez-Bravo et al. (2019), in a study involving European residents in multiple cities, found a positive association between economic sustainability and city liveability linked to the effect of social sustainability, which they show compensate for the effect that greater economic activity has on pollution. Du and Zhang (2020) and Du et al. (2020) documented the trade-offs of local interventions towards either improving job access or the number of and accessibility to green spaces, because of their effects on urban housing affordability, which impacts more on disadvantaged populations, undermining social equity. In a more technical study, Zhang et al. (2019) show the conflict between urban policies toward improving clear water and sanitation and the impacts that these may have on greenhouse emissions, and consequently on addressing climate change mitigation.

In this thesis, I examine the urban development challenges as barriers to the realization of more safe, clean and liveable environment in Latin America region, taken as case study the tropical mid-city of Barranquilla, Colombia. On doing this, my dissertation as a whole recognises the interconnections of the three dimensions of sustainability, social, environmental and economic, when planning to address urban risks. I explore the risks of experiencing crime, of being exposed to uncontrolled solid waste, and natural hazards. Throughout the chapters, a nexus is created by examining the linkages that these urban risks created between a social sustainability perspective (addressing poverty, inequality, and the opportunities that building social cohesion and trust can generate), an economic perspective (recognising urban land as an important finite resource, and looking at alternatives forms of funding for public services attending to conditions of affordability and willingness to pay), and an environmental perspective (suggesting the potential for win-win options in terms of safety, health and wellbeing through green-blue infrastructure in vacant plots). This is because illegal dumping often occurs in vacant plots, posing health risk to residents, increasing opportunities for crime, and clogging drains, which exacerbates floods and

their impacts. Overall, this thesis contributes to the literature by exploring the link between urban planning policies that can generate win-win outcomes in the three challenges explored – crime, illegal dumping and the hazard of flash-floods.

This chapter presents the rationale and background for the thesis. Section 1.2 explains the empirical contextual issues that motivate the need for this research in the context of the Latin America region; and justifies in line with the literature the focus on the thesis in three social and environmental concerns that threaten the sustainability of most cities in this region: growing crime rates (Ceccato, 2011; Zmerli & Castillo, 2015); the limitations of solid waste collection and its processing systems (Aparcana, 2017; Koop & van Leeuwen, 2017); and increasing pressures on infrastructure caused by natural hazards (Güneralp et al., 2015). Section 1.4 reviews the contextual background of the city of Barranquilla. In section 1.5, the objectives, research gap, approach taken, and main contributions of each chapter are outlined.

1.2 Urbanisation in Latin America and the Caribbean

Latin America and the Caribbean is recognised as the most densely urbanized developing region in the world. In this subcontinent, some countries have undergone an advanced process of consolidation of large conurbations and human settlements in relation to the rest of the continent (Inter-American Development Bank [IADB], 2011). In a historical context, the urbanization process in Latin America and the Caribbean has been closely linked to the massive industrialization that arose after World War II. This encouraged the demographic transition from the rural domain to urban settlement, consolidating a structural process that now places urban conglomerates as the most important areas of Latin American economies (Economic Commission for Latin America and the Caribbean [ECLAC], 2017). Latin American cities, by hosting greater economic opportunities, therefore provide the epicentres of social, economic and environmental changes that will determine the sustainability of national economies.

Even though the progressive urban development evidenced in the countries of Latin America and the Caribbean in the last 60 years has generated internal political problems, mainly due to population growth and lack of planning, there are sustainable development indicators that also

show the positive side of the urbanization process. For example, there is a positive correlation between GDP and the human development index (HDI), which is particularly visible in large urban centres (Hou et al., 2015; Lamb & Rao, 2015). In general, the economies of the big cities are characterised by high levels of competitiveness, easy access to the factors of production, and the generation of knowledge and innovation as a consequence of productive specialization, as well as benefitting from good access to the global market (Pred, 2017). Thus, it is in these territorial urban spaces where human capital is combined with technological capacity in a dynamic process that leads to high levels of productivity and capacity to assimilate technology transfers that strengthen the innovative capacity of countries. However, it is evident that the urbanization process has also led to a range of inequalities as a consequence of the uneven distribution in factors of production and consumption and are visibly manifested in an increase in urban poverty (Smith, 2019; Wei & Ewing, 2018).

Indeed, despite the strong social welfare policies that exist in Latin America and the Caribbean (Cruz-Martinez, 2017), poverty and economic inequality in cities persists, and is characterised by limited access to essential public services and high socioeconomic segregation rates among households (Musterd et al., 2017; Schafer & Vargas, 2016). The lack of coverage in the basic needs of a large part of the population, often located in the periphery of the cities, leads to violence, poor disposal of solid waste and the invasion of public land prone to natural disasters, among key challenges to urban sustainability within the region. The visible contrast in standard of living between social classes at the level of the urban territory reinforces the vulnerability of the most disadvantaged households, which generates a spiral of exclusion that contributes to the high levels of criminality observed in most urban conglomerates of Latin America (Moncada, 2016; Rivera, 2016; Román et al., 2019). Similarly, the disorderly urbanization process has also led to a series of environmental disparities that in turn constitute a serious degradation threat to air and water sources. Therefore, growing environmental injustice (Asilsoy & Oktay, 2018; Lome-Hurtado et al., 2019) is an urgent challenge, alongside socio-economic inequality, in the increasingly difficult task of implementing sustainable development strategies in a context of rapid urbanisation (Jarvis et al., 2016; Nijkamp & Perrels, 2018; Zoomers et al., 2017).

Incidence of urban violence in Latin America and the Caribbean is among the highest worldwide. According to the Mexico Citizens' Council for Public Security, in 2016 more than 80% of the 50 most violent cities in the world were in Latin America (Brazil, Colombia, Mexico, and Venezuela; see Consejo Ciudadano para la Seguridad Pública y la Justicia Penal [CCSPJP], 2016). Although there are a few successful cases of tackling urban violence in Latin America, the problem has persisted in urban settlements in Brazil, Colombia, Mexico, and Venezuela.[1] Current evidence points to three factors that must be considered in order to mitigate the spiral of crime often affecting the most vulnerable neighbourhoods: (i) socioeconomic factors, especially income inequality and lack of education (Jaitman & Guerrero Compeán, 2015; Vakis et al., 2016); (ii) law enforcement (Stockholm International Peace Research Institute [SIPRI], 2017); and (iii) adaptive capacity to climate change (Mares & Moffett, 2016). While socio-economic and law enforcement factors have been widely analysed in the crime literature, particularly in the Latin American context (Cotte-Poveda, 2011; Heinemann & Verner, 2006; Moncada, 2016; Rivera, 2016), little is known about the influence of the stress caused by high temperatures in cities on the frequency of occurrence of crimes.

The persistent existence of illegal dumpsites in areas within metropolitan perimeters of developing countries is another sustainability challenge addressed in this thesis. Even though the literature emphasizes the advantages and disadvantages of different urban waste management systems (Dyson & Chang, 2005; Hoornweg & Bhada-Tata, 2012; Wilson et al., 2006), the causes of the emergence of illegal dumpsites in Latin American districts over the last three decades have not been sufficiently analysed. Problems arising from these illegal uses of public land include respiratory diseases in children and adults, civilian risks associated with security, and damages to the urban landscape (Hardoy et al., 2013; Sarkar et al., 2014; Zohoori & Ghani, 2017). Some sources suggest socioeconomic factors such as income inequality and low levels of education as factors underlying illegal waste disposal (Banzhaf et al., 2019; Ma & Hipel, 2016). Others point to the problem of accessibility to the official waste disposal sites (Aparcana, 2017). Lastly, there is some evidence in the literature suggesting that the lack of certain kinds of social capital like community participation and social trust lead to people's continued use of illegal dumpsites

[1] For instance, despite the initial attainments in social interaction of deprived neighbourhoods in Rio de Janeiro, violence has been persistent in the latest years partly due to the power of drug gangs settled in the favelas (Rodgers & Baird, 2016).

(Nyarai et al., 2016; Zhang & Zhao, 2019). To counter such actions effectively, urban sustainability policies recognise the necessity of establishing consensual agreements, built through mutual trust and alliances between citizens and local authorities.

An increase in the risk posed by natural hazards is the third threat to sustainability that the thesis considers. Susceptibility to the risk of flooding particularly needs addressing urgently, both technically and economically, to resolve the threats posed by natural disasters (Haddow et al., 2017; Montz et al., 2017). Here again local governments have a critical role in resolving local environmental risks (Gilbert et al., 2013), because the sustainability of urban areas depends largely on the efficiency in the provision of utilities. There needs to be more attention to the use of green and grey infrastructure to face the challenges of increasing flood risk in the context of climate change (Hurlimann & Wilson, 2018; Matthews et al., 2015).

Next, I examine in detail the motivation for the study of these three urban sustainability challenges in Latin America, and the background literature on these subjects.

1.2.1 First challenge: Determinants of violent crime

Given the dual nature of cities in terms of offering opportunities, and also threats, evidence of a link between urbanization and violence is inconsistent. According to Buhaug and Urdal (2013) changes in the level of common and organized violence have not been on a par with the growth of urban centres globally, and, for that reason, the relationship between urban growth and violence is not clear. Urban areas are not necessarily more violent than rural areas, and neither are larger cities necessarily more violent than smaller cities (Brennan-Galvin, 2002). Eizenberg and Jabareen (2017) argue that cities which lack clear sustainability policies, that include the promotion of a sense of community, safety, and health, are more at risk of political instability, making their residents' lives insecure through crime and violence in all its forms. An aggravating factor in this situation is that the proximity of dissimilar ethnic, religious, and economic groups has exacerbated social divisions. In such a context, insurgent groups take advantage of social inequity to foster social unrest and expand violence at all social levels (Davis, 2013). A latent danger is that the poorer and more violent areas of cities in developing countries can become safe

havens for criminal networks or subversive groups, which take advantage of disaffected local youth to insert them into their ranks and increase their urban dominance (Kilcullen, 2015).

In short, it is likely that many types of violence persist or even increase in cities that develop rapidly and are institutionally weak in relation to crime (LaFree, 2018). Hence, the structural factors that underlie violence must be identified to mitigate violent crime. This dissertation expands the literature on the linkages between social, economic and environmental determinants of urban crime, offering new insights of the interactions among them. Evidence provided by ECLAC (2017), IADB (2011), and SIPRI (2017) focuses on three factors which can contribute to urban security, and with it, urban sustainability and quality of life: (*i*) socio-economic conditions; (*ii*) rule of law at the urban level; and (*iii*) disaster risk reduction. There is also strong evidence that urbanization has been a key factor in boosting GDP growth (Bertinelli & Black, 2004; Chen et al., 2014; Glaeser & Henderson, 2017). As has been argued, cities are conglomerates that offer opportunities to essentially all segments of society. However, cities can also create elements of social exclusion. Income inequality in urban areas is much greater than in rural areas (ECLAC, 2017) with a contrasting incidence at the urban level, commonly visible in the metropolis of developing countries. There are, on the one hand, high levels of wealth and modern infrastructure; and, on the other hand, urban areas characterized by severe deficiencies and lack of basic public services, creating a deep distancing between "haves" and "have-nots" which in turn intensifies the social exclusion of the latter. The rapidity of the urbanization process is also an essential factor in understanding the exclusion of large areas of the urban population from basic services (IADB, 2011), as rapid urban growth may mean that the provision of infrastructure and economic opportunities do not grow at the same pace. All of this implies that socioeconomic factors are key in the understanding of the link between urbanization and concomitant violence. In fact, the empirical evidence corroborates that high levels of income inequality, also affected by the lack of inclusion in urban policies, and unemployment, especially of young people, are driving violence (Enamorado et al., 2016; Salahub et al., 2019). Education also has an impact on of the level of violence (Oosterveld et al., 2018). For example, Lochner and Moretti (2004) explored the association between crime and changes in compulsory school attendance laws by state over time in the United States (changes believed not to be produced by increases in crime) and found that an additional year of high school attendance significantly reduces the likelihood

of arrest and imprisonment. In addition, these authors found that a 1 percent increase in the high school graduation rate for men leads to estimated savings of US $ 1.4 billion per year in relation to the social costs of crime. Similar results were obtained by studying changes in the compulsory school attendance laws in the United Kingdom (Machin et al., 2011, 2012). However, not only does the higher level of education seem relevant, but also the quality of education received. Deming (2011) estimates the impact of going to different types of schools (assigned by a lottery) on crime in the Charlotte-Mecklenburg school district (USA). Seven years after the raffle, the beneficiaries assigned to the best schools were arrested less frequently and for fewer days. The effect is greater in the most at-risk youth, who committed 50 percent fewer crimes compared to those not benefited by the lottery. Studies also found that school can also produce a disabling effect. That is, by keeping the youth off the street and busy during the day, school attendance can have an effect on criminal participation. Jacob and Lefgren (2003) find evidence in this regard for property crimes by comparing days of school attendance with the crime rate when the school does not open its doors (for teacher training, vacations or holidays).

A second key factor related to urban crime is the lack of governance and low levels of law enforcement, which have been identified as key reasons for the persistence of levels of violence in urban areas (Oosterveld et al., 2018). Good security governance implies much more than just patrolling the streets and having squadrons of police officers available. The evidence suggests that a police strategy aimed only at repression produces poor results (Holland, 2015). For this reason, the discussion in the literature on the role of urban governance to reduce violence revolves mainly around discussing the merits of decentralization. Some works argue that decentralization promotes prevention, which requires closeness to social actors so that it can be implemented considering the needs of the most vulnerable population (González, 2019; Román et al., 2019). However, decentralization can also lead to opportunities for corruption at the local level, which explains why governance is sometimes placed under the direct control of the national government (González, 2019).

Lastly, there is increasing evidence that relates weather and human behaviour, and in particular, the association between warmer weather and the prevalence of violence (Butke & Sheridan, 2010; Cohn, 1990; Cohn & Rotton, 2000; Field, 1992; Harries & Stadler, 1983; Harries et al.,

1984; Horrocks & Menclova, 2011; Ranson, 2014). Extreme heat makes people irritable, agitated or apathetic (Anderson, 2001). Hsiang et al. (2013) find that extreme heat increases aggression and violence, with a standard deviation of the increase in temperature and rainfall being associated with a 4% increase in interpersonal violence and a 14% increase in intergroup violence. The increase in heat also contributes to insomnia and is exacerbated by increases in humidity (Okamoto-Mizuno & Mizuno, 2012). Moreover, extreme heat is now considered to be the leading cause of weather-related death, surpassing hurricanes, lightning, tornadoes, floods and earthquakes combined. The Center for Disease Control and Prevention (2019) reports 7,800 deaths attributable to extreme heat between 1999 and 2009, and forecasts more frequent and extreme heat. Concurrent factors such as poverty, poor housing and lack of access to cool environments can contribute to this greater vulnerability. The most protective tool against heat stress is the availability of air conditioners in operation. Unfortunately, these types of cooling systems are beyond the reach of many people who live outside society, especially in tropical urban areas of the developing world.

1.2.2 Second challenge: The illegal disposal of solid waste

The 20th century saw rapid growth of industrial production, as well as an increase in the global population; together, these have caused massive proliferation of waste (Ziadat & Mott, 2005). Inadequate management of household waste can contribute significantly to environmental degradation in urban areas and causes irreversible damage to the environment. An example of this is the improper disposal of household solid waste in urban open-air dumps with significant environmental consequences such as burning waste, explosions, emission of irritating odours, and air pollution, putting the health of millions of people at risk (Al-Khatib et al., 2015; Coolidge et al., 1993; Mavropoulos & Newman, 2015; Medina, 2000).

Medina (2010) suggests that public management capacity and financial restrictions affect the ability of municipal governments to improve solid waste management. This is consistent with Ichinose and Yamamoto (2010), who argue that the absence of adequate waste facilities is the main factor that incentivizes creation of open-air dumps. Thus, illegal dumping occurs more frequently in cities in developing countries due to the institutional, financial and technical

limitations of local authorities (D-Waste, 2014). Fullerton and Kinnaman (1995) also argue that the lack of proper treatment facilities increases household costs resulting from controlling waste and creates the incentive to burn or dispose of waste in illegal sites to avoid these expenses. Most research on illegal dumping comes from Africa, focusing on themes including household risk perception, institutional issues, health threats, and social capital. For example, Henry et al. (2006) points out the risks to urban communities in Kenya posed by open-air dumps, with a particular focus on population exposure to toxic chemicals. Based on the results from a survey of 591 households, Ogu (2000) finds that three-fifths of the urban population in Benin City, Nigeria have no solid waste collection service. Consequently, residents resort to illegal dumping to dispose of their households' solid waste. The author argues that private schemes to handle excess waste are needed, with these schemes being tailored to each neighbourhood's own circumstances. Wahab (2012) researches the role of trust, cultural norms and social networks within the solid waste management initiatives in Ibadan, Nigeria. Using a sample of 385 households, Wahab presents the positive impact of these measures of social capital on collective solid waste management strategies. Similar works also exist in other countries. Pokhrel and Viraraghavan (2005) describe the environmental and public health problems caused by illegal waste disposal that continuously lies on the riverbanks of the Kathmandu Valley in Nepal. The authors suggest that implementing source-separated recycling would reduce the costs of waste treatment. Seng and Kaneko (2010) analysed solid waste management in Phnom Penh, Cambodia, where illegal garbage dumps result from inconsistency in garbage collection times – a situation rooted in irregular garbage truck schedules, low levels of environmental awareness held by residents, and weak disposal regulations.

Despite the prevalence of illegal dumping, there are few studies that address its determinants in Latin American cities, most likely due to the difficulty researchers may encounter in obtaining information directly from households (Kinnaman & Fullerton, 1996, p. 978). One exception is the analysis conducted by Yousif and Scott (2007) on the waste management system in Mazatenango, Guatemala. According to this work, the increase in illegal dumping occurs because half the residents do not utilize the official waste disposal system, either because they cannot afford it or because they are dissatisfied with inefficiencies in the solid waste collection system such as inadequate collection (e.g., some residences are inaccessible for garbage trucks

due to the spontaneous development of neighbourhoods), poor disposal or the lack of a sanitary landfill in the city. Moreover, the issue of illegal dumping in Latin American cities has focused on people who are financially dependent on informal collection of solid waste. Many refer to the latter as the so-called "waste pickers". For example, Zapata-Campos and Zapata (2013) examine the social impact of a cooperative of waste pickers in Managua, Nicaragua, illustrating the relevance of the role performed by waste pickers in tackling illegal dumping in Central American urban settlements. Similarly, Fergutz et al. (2011) highlight the activities waste pickers perform in Brazilian cities and argue in favour of cooperatives to enhance their living standards. This research expands on this existing literature on the Latin America context by focusing on urban residents' perceptions of illegal dumping, in particular their social preferences towards supporting local policy initiatives.

1.2.3 Third challenge: Reducing the risk of pluvial flooding

Natural hazard events have been increasing in intensity and frequency (Reguero et al., 2015; Reyer et al., 2017) and human settlements in urban areas must adapt to the effects that climate change brings (Allen et al., 2016; European Environment Agency [EEA], 2016). According to UN-Habitat (2018), over the last decade, natural disasters affected more than 220 million people and caused economic damage of USD $100 billion per year and 42% of economic losses in housing are due to floods. By 2030, this report concludes that without significant investment to make cities more resilient, natural disasters may cost cities worldwide $314 billion each year and climate change may push as many as 77 million more urban residents into poverty.

Climate change and natural disasters are not isolated challenges for cities but interact with socioeconomic factors including economic growth or recession, demographic change, urban sprawl, technological developments and social conflicts, and can exacerbate inequalities (World Bank and Social Survey, 2013; EEA, 2016). They can therefore change the vulnerabilities of cities. For example, an ageing population is one that is more vulnerable to extreme events, and rapid population expansion in informal settlements in areas exposed to natural hazards can increase vulnerability (Pelling, 2010). There is also evidence that progress in socio-economic conditions can strengthen local capacity and improve civic resilience to disasters through

appropriate housing, disaster-preparedness, education, and the cooperation and trust between public and private sectors and between local and national government (EEA, 2016; Mguni et al., 2014, 2016; Pelling, 2010).

Nevertheless, globally, extreme heat events have led to particularly high rates of mortality and morbidity in cities as urban populations are pushed beyond their adaptive capacities (Norton et al., 2015). Extreme heat events are expected to increase in cities in developing countries as a result of climate change (World Economic and Social Survey, 2013), and the phenomenon known as the heat island effect will be more intense, with serious consequences in terms of mortality and morbidity (Agarwal et al., 2018). Rapid urbanization in many cities in developing countries has increased the paving of urban areas to the detriment of vegetated areas, causing increases in solar radiation during the day (Riffat et al., 2016; Sun et al., 2019). Moreover, in tropical areas, surface waterproofing increases relative humidity levels when it rains, increasing the thermal sensation and the appearance of disease transmission vectors, such as dengue and diphtheria. The impacts of climate variability are also aggravated when cities do not have adequate stormwater drainage, because runoff increases, and flash floods are therefore more common. Sustainable drainage systems have been one of the hydrological solutions to the problems of urban storm floods in developed countries (Butler et al., 2018). These systems combine green infrastructure and grey infrastructure strategies.[2] In fact, green infrastructure is an alternative to address the problems of climate change related to both floods (Hoang & Fenner, 2016) and the heat island effect (Lehmann, 2014). The concept of urban green infrastructure is related to planned and unplanned green spaces, which cover both private and public areas, which can also provide socio-environmental benefits (Lovell & Taylor, 2013; Norton et al., 2015). Interestingly, the greening of abandoned areas such as illegal garbage dumps or vacant lots is also positively correlated with crime reduction (Branas et al., 2018). Table 1.1 illustrates how green infrastructure as part of a sustainable drainage system may include retaining native vegetation, parks, street trees and more technical options, such as green roofs and rain gardens.

[2] Grey infrastructure involves everything related to civil works such as buildings, roads and storm drainage systems, among others. By contrast, green infrastructure includes everything related to vegetation such as trees, green areas, rain gardens, etc. On the other hand, blue infrastructure refers to everything related to water, such as rivers, wetlands, floodplains, water treatment areas, etc. For more details on these concepts, see Depietri and McPhearson (2017).

Table 1.1 Existing grey and green infrastructure as part of the process of implementing sustainable drainage systems to reduce the risk of flash-floods

Green infrastructure	Grey infrastructure
Irrigated and non-irrigated green spaces	Channelization
Green roofs	Porous pavement
Rain gardens	Rainwater tanks

Source: Norton et al. (2015)

1.3 Barranquilla as a study-case

The District of Barranquilla, Colombia, is located between the two tropics at a latitude of 10°58′06″ N, a longitude of 74°46′52″ W and an average elevation of 24 metres above sea level (Fig. 1.1). It is Colombia's fourth most populous city, with 1,897,734 inhabitants (Departamento Administrativo Nacional de Estadística [DANE], 2016). It also acts as the Colombian Caribbean region's predominant economic and financial centre. Official data show that approximately 21.7% of Barranquilla's population live in poverty and 2.8% in extreme poverty (DANE, 2018). However, Cepeda (2011) estimated that 40.7% of Barranquilla's population lives under the poverty line, placing it third of all Colombian cities in terms of the percentage of people living in poverty. An earlier study by Pérez and Salazar (2007) ranked Barranquilla as having the highest poverty rates in Colombia.

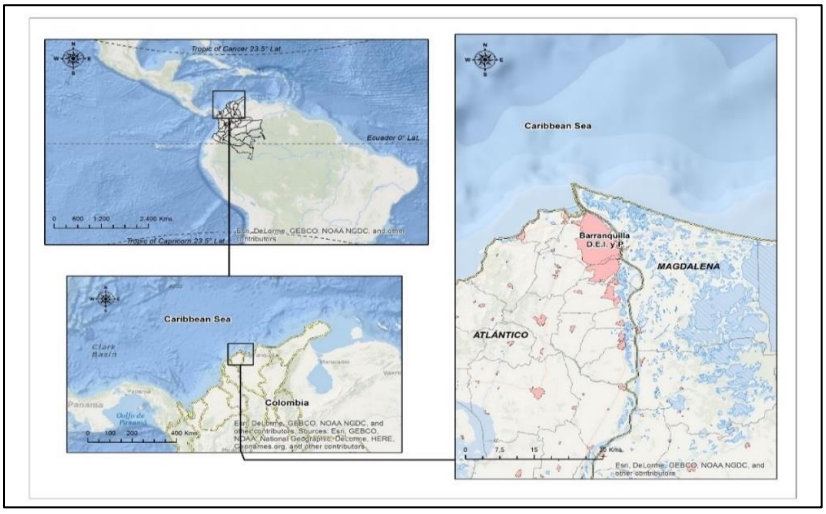

Figure 1.1 Barranquilla. Geographic location
Source: The Colombian Geographical Institute Agustin Codazzi

The choice of Barranquilla as a case study can be justified because of its challenging problems in the area of violence and crime, illegal disposal of solid waste and storm floods. In terms of violence, Barranquilla's homicide rate is higher than Bogotá's and in 2014 the murder rate overtook that of Medellin to secure the status of the second highest homicide rate in the nation, behind Cali (Fig. 1.2). In terms of non-lethal violence, Bogotá exhibits the highest daily rate of interpersonal violence, despite the significant efforts the Colombian government has invested in making it a safer place to live (Fig. 1.3). However, Barranquilla shows levels of interpersonal violence similar to the much larger and more historically crime-ridden cities of Medellin and Cali. At a global level, in 2011 and 2012 Barranquilla ranked 42nd and 50th respectively among the most violent cities in the world according to the Mexico's Citizens' Council for Public Security's annual ranking (CCSPJP, 2016).

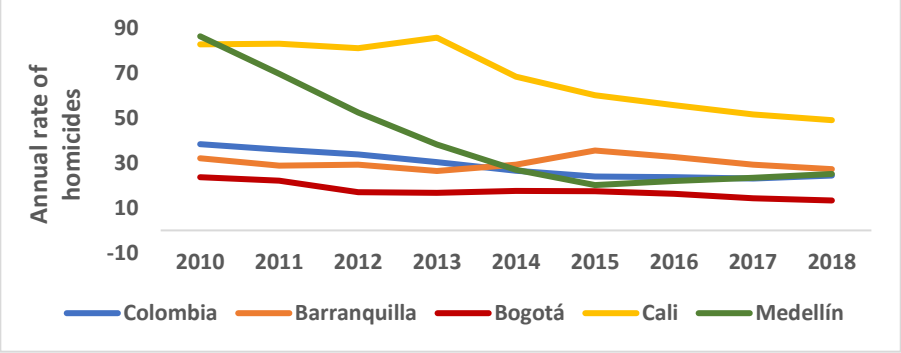

Figure 1.2 Evolution of homicides in major Colombian cities
(Rate per 100,000 inhabitants)
Source: The Colombian Institute of Legal Medicine and Forensic Sciences

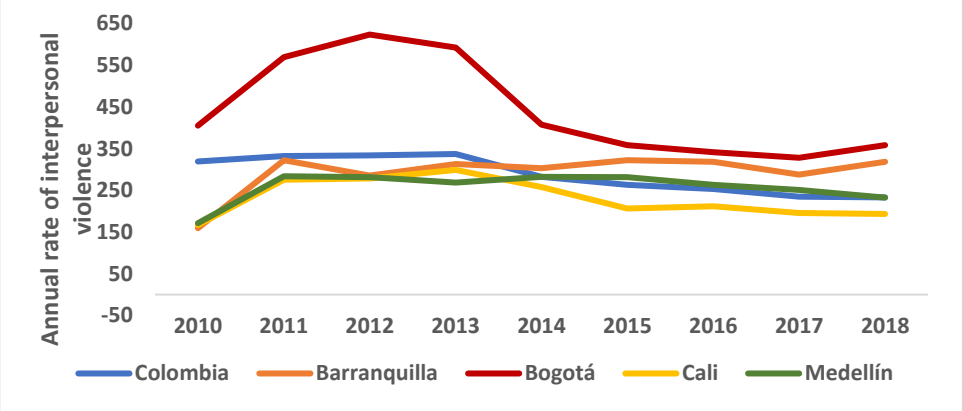

Figure 1.3 Evolution of interpersonal violence in major Colombian cities
(Rate per 100,000 inhabitants)
Source: The Colombian Institute of Legal Medicine and Forensic Sciences

Barranquilla has one of the most modern sanitary landfills in the country, run by the Triple A company. However, about 800 tons per day of garbage remain outside it, since they are deposited in the 166 illegal garbage dumps in the city. Animal traction vehicles, homeless people and common people litter different sectors and neighbourhoods of Barranquilla with garbage, household goods that are no longer of use or dead animals. Given this, the local sanitation provider Triple A, responsible for the collection of rubbish in the city, detected during the first quarter of 2018, 30 critical points, according to the daily report of collection of its vehicles and operators (El Tiempo, 2019). These open-air dumps have become a public health problem for residents (Armenta et al., 2018). Moreover, in the absence of a formal rainwater drainage system, the streets in Barranquilla fulfil the function of surface storm sewer and, in times of rain, strong water currents, called in Spanish *arroyos*, are formed. As a result, the city has the exceptional condition of having no less than 67 kilometres of flash-floods (channelized and non-channelized), which drag solid wastes and turn the streets into open-air dumps after each downpour (Rodríguez et al., 2014).

The Mayor's Office of Barranquilla is currently investing COP $700 billion in the channelization of 16 kilometres of 8 dangerous flash-floods, which cross several points of the city (El Tiempo, 2019). Some of these sections have already been delivered. However, the functionality of these channels is sometimes reduced by the large quantity of plastic sheets and materials that end up covering the grilles where the rainwater enters to continue on its way to the underground box culverts and from there to the Magdalena river (Ayala et al., 2017).

Lastly, the geographical location of Barranquilla, with an ocean and river on its borders, makes it prone to flooding. Economic losses due to pluvial flash-floods have been estimated to affect 20% of the city's GDP annually (Hidroestudios & ConCEP, 1997, p. 9-1). Since 1933, according to the records of Colegio Marco Fidel Suarez (2018), 94 deaths have occurred due to flash-floods. Future projections warn about the increase of extreme weather events in the context of climate warming (Cai et al., 2015). For instance, in 2010, the city was affected by an abnormal intensity of precipitation because of the *La Niña* phenomenon (Hoyos et al., 2013). In November 2010,

rains in Barranquilla increased by 200 percent more than the average for that month in previous years (Semana, 2010).

1.4 Thesis aims and structure

The overarching goal of this thesis is to offer a better understanding of the social, economic and environmental interconnections between the three issues on urban risks that have emerged as key sustainability challenges for cities in the Latin American region: growing crime rates; illegal dumping; and flooding. The thesis focuses on Barranquilla as a case study.

Based on an understanding that the development of effective policies for improving the liveability of this city requires the establishment of agreements between authorities and citizens, and that underlying social and economic conditions are likely to affect both the scale of the problems and potential policy responses, the thesis addresses the following specific research questions:

(i) What is the role of socio-economic factors as determinants of lethal and non-lethal crimes in a context of increasing climate stress?

(ii) What are urban households willing to pay towards public efforts towards eradicating open-air dumps?

(iii) What are urban households' preferences for reducing flooding risk and impacts regarding human health and mobility across the city?

Chapter 2 explores the determinants of crime in Barranquilla, focusing on the role of climate alongside socio-economic factors. This analysis considers the associations between weekly patterns of two indicators of criminal activity –homicides and interpersonal violence – and socio-economic and environmental factors such as income, education, law enforcement, the presence of vacant lots, and an indicator of thermal stress. The results suggest that, in general, poverty and low levels of education influence the likelihood of both types of crimes in this area; the

proximity to a local police station is a deterrent of perpetrating both homicides and interpersonal violence. Conversely, the proximity to a vacant lot increases the likelihood of both types of crime. On the other hand, thermal stress is an important predictor of interpersonal violence, but it has no influence on the likelihood of committing homicides. These findings draw attention to the importance for decision-makers to consider climate and environmental factors alongside structural and socio-economic determinants of crime, when designing long-term urban security policies in Barranquilla or other tropical conurbations in Latin America.

Chapter 3 considers the socio-demographic factors that explain the degree to which households are willing to participate and pay for a public intervention aimed at eradicating all open-air dumps in Barranquilla. To this end, I applied probit and tobit models to a sample of 815 households within the urban territory. The results reveal that factors such as institutional trust and the level of income are important predictors for both the willingness to join and the willingness to pay for the public intervention. Nonetheless, many factors related to community involvement are weak. Community members lack trust in the government's initiatives, so their personal level of involvement remains low. To begin an initiative that will be successful, these factors must change. Once there has been improvement in these areas, it will be possible to begin an initiative to end open-air dumping in this city.

The fourth chapter considers the determinants of households' preferences for implementing a sustainable urban drainage system (hereinafter, SuDS) to cope with the phenomenon of flash-floods formation. According to Hallegatte et al. (2013), because of climate change, through 2050, Barranquilla ranks as the second most at-risk city in the world in terms of material losses due to rainfall floods. In an effort to overcome this risk, I perform a discrete choice experiment to estimate households' willingness to pay (WTP) for SuDS. I estimated a basic mixed logit model as well as an extended mixed logit to determine the WTP values for each attribute. The results reveal a positive association between head of household's socio-demographic factors and their WTP towards a combination of grey infrastructure (channelization, rainwater harvesting, and porous pavement) with green infrastructure strategies (green zones, green roofs, rain gardens, and green pavement). In addition, results show a positive relationship between perceived risk and risk communication and the utility households derive from the

implementation of SuDS. I found that WTP values varied largely because of the heterogeneity of households' preferences. Moreover, this study provides evidence that it is important to enhance the risk communication between local authorities and households so as to raise awareness about how to prevent the consequences of flash-floods.

The final chapter provides an overall discussion of the main findings, policy implications and pathways for future research. The evidence found in this thesis provides key policy recommendations for improving Barranquilla's social and environmental sustainability.

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Chapter 2: A time-series analysis of the factors associated with crime in Barranquilla, Colombia

2.1 Abstract

Designing long-term urban security policies in Latin America, the world's most violent region, requires an understanding of the factors influencing the occurrence of crime. In studying the causes of crime, most of the literature has focused on socio-demographic variables. However, there is increasing evidence that weather conditions may also have an effect on urban crime. This study brings together different theoretical backgrounds to examine the effects of education of the offender, the social context of the neighbourhood where crime occurred (socio-income status, police presence and presence of vacant lots), and weather conditions (heat stress) on various types of crimes, mainly homicides and interpersonal violence. A count data approach is used to model the weekly-recorded crimes in the city of Barranquilla, Colombia. Thus, in contrast with more commonly studied temperate zones, this study offers new insights to this literature in the context of a developing-country tropical urban setting, characterised by hot and humid weather conditions all year-round. Poverty has a positive influence on the likelihood of homicides in this city, but it has no statistical association with interpersonal violence cases, even though levels of both crimes are increased by low levels of education in more deprived neighbourhood, proximity to vacant lots and areas where there is less local policy presence. Heat stress is an important predictor for interpersonal violence but has no influence on homicides. The results highlight that improvements in urban planning, addressing the presence of vacant lots, and in urban socioeconomic conditions, need to go hand-in-hand with local actions to address crime.

Keywords: crime; violence; poverty; education; law enforcement; heat stress; Latin America

2.2 Introduction

The growing urbanization in Latin America imposes serious challenges on local governments for the sustainability of their population settlements. Eight out of 10 Latin Americans live in cities and 70% of the low-income citizens are located in urban areas (Economic Commission for Latin America and the Caribbean [ECLAC], 2012). One of the key challenges associated with

urbanization in Latin America subcontinent is crime, as evidenced by the fact that Latin America is the most violent region in the world. Eight of the ten countries with the most homicides in the world are in Latin America (United Nations Office on Drugs and Crime [UNODC], 2013), as well as 47 of the 50 most violent cities (Consejo Ciudadano para la Seguridad Pública y la Justicia Penal [CCSPJP], 2016). One in three Latin American adults considers crime and violence as the highest priority issue (Jaitman et al., 2015). The consequences of crime are long lasting, since the fear of crime affects people's behaviour, and high levels of crime constrain investments and erode trust in institutions and social capital (Malone, 2010). Figures of this magnitude, and the societal, human and physical impacts of crime, highlight the need to reduce the occurrence of crime as an issue of major public concern, and justify targeted local management strategies aimed at the underlying social, economic and environmental drivers.

Given the high levels of crime and violence in Latin America, local governments in the region face urgent challenges to establish effective public policies aimed at both preventing and curbing current crime in urban communities. Crime is generally seen as the result of the interaction of factors inherent to the individual as well as the social and environmental conditions in which they live (Wikström, 2017). In the urban context, factors influencing crime include socio-economic conditions such as income inequality and low levels of schooling (Bell et al., 2016; Hjalmarsson et al., 2015; Jonck et al., 2015), social phenomena such as the presence of blighted vacant lots (Branas et al., 2018; Kondo et al., 2015), and weak security governance at the urban level (Davis, 2013; Stockholm International Peace Research Institute, [SIPRI], 2017; UNODC, 2016). More recently, the influence of changing climate has become a serious concern among researchers and practitioners, in response to increasing evidence of the consequences of extreme weather conditions for emotional stress and crime (Hu et al., 2017; Schinasi & Hamra, 2017). The literature about urban crime in Latin America has focused extensively on issues related to organized crime, drug trafficking, police corruption, and the widespread activity of gangs from civil conflict's reinserted members (Cotte-Poveda, 2011; Fajnzylber et al., 1998; Heinemann & Verner, 2006; Imbusch et al., 2011; Moncada, 2013; Rivera, 2016), however there is a dearth of studies that identify and/or analyse broader socio-economic and climatic features as driving factors of crime. Yet, understanding the influence of these underlying factors holds the key to identifying additional potential policy levers that can enhance policy responses to crime in the

region. The primary objective of this study is to fill this gap in providing evidence in a Latin America city, Barranquilla (Colombia), focusing on the effects of indicators of income, urban abandonment and police enforcement efforts in the neighbourhood on the probability of occurrence of crime. In addition, to better guide policy interventions, this work also includes the analysis of the effect that changing weather conditions has on weekly crime counts.

Within the Colombian domestic context, Barranquilla is a city where a large part of its population lives in poverty.[3] The rapid demographic changes seen in the city during the last decade as well as the boost in public investment have been accompanied by higher homicide rates (Aldana-Domínguez et al., 2018). Indeed, Barranquilla's homicide rate is higher than Bogotá's and has been steadily rising, recently overtaking Medellin to secure the status of the second highest homicide rate in the nation. In terms of non-lethal violence, Barranquilla shows similar levels of interpersonal violence as the much larger and more historically crime-ridden cities of Medellin and Cali. While Barranquilla has not always been historically considered an unsafe place, it has already featured twice in the world's most violent cities' ranking.[4] The current poverty levels in combination with the violent background justify the use of Barranquilla as an interesting case study when it comes to identifying the demographic, societal, economic and climatic factors that are associated with crime and violence, and could therefore provide opportunities for policy interventions to develop efficient government responses to crime.

The study uses as a departing point a set of factors established in the literature, which have been identified as the most influential in the explanation of urban crime. These factors extend through a range of individual characteristics, neighbourhood characteristics, and weather-related factors. In identifying the role of this factors in urban crime for Barranquilla, my contribution to the literature is twofold. First, I contribute to the empirical literature on urban crime by exploring the combined effect of socio-economic, socio-environmental, police presence, and weather factors on lethal and non-lethal crimes. Second, although the relationship between weather variation and

[3] Official data indicate that 21.7% of Barranquilla's population live in poverty and 2.8% in extreme poverty (Departamento Administrativo Nacional de Estadística [DANE], 2017). However, previous studies had shown a dramatic scenario in terms of poverty. Cepeda (2011) estimated that 40.7% of Barranquilla's population lives under the poverty line, placing it as the third Colombian city with the highest percentage of poverty. In turn, Pérez and Salazar (2007) ranked Barranquilla as having the highest poverty rates in Colombia.

[4] In 2011 and 2012 Barranquilla ranked 42nd and 50th respectively among the 50 world's most violent cities according to the annual ranking published by the Mexican Citizens' Council for Public Security (see CCSPJP, 2016).

crime has been extensively investigated, the impact of weather has not yet been examined in an urban context characterised by tropical climate, as it occurs in the study area of Barranquilla, with high temperatures and high humidity throughout the year. Moreover, the social-cultural and institutional settings of Colombia differ greatly from Western Europe and North-America, where these issues have been more investigated.

2.3 Theoretical framework

Cities are territorial spaces that enable economic development, innovation and social interaction (World Economic and Social Survey, 2013). In criminology, crime can be understood as the result of the interaction between a motivated offender and a criminal opportunity, where the physical environment settings create opportunities that facilitate the interactions between offenders and potential targets (Felson & Clarke, 1998). In this crime opportunity framework, the Routine Activity Theory (RAT), proposed by Cohen and Felson (1979), focuses on explaining the process of an offender‘s decision–making. According to the RAT for a crime to occur, there must be a potential criminal, who acts according to costs and benefits, an attractive target or an appropriate victim, and the absence of police presence. This theory recognizes the opportunity as a condition for the prevalence of crime and does not include the influence of factors such economic inequality on criminal activity.

The RAT postulates three conditions necessary for a crime to be carried out, widely described by Felson (2013). The first is a motivated individual, who observes the opportunities for crime and determines the best way to do it. The second condition is that the individual acts in a zone that is familiar to him, since, although there are more lucrative territories if they are unknown by the offender, the probabilities that they proceed in them are reduced. Finally, the third condition is that in order for the crime to occur, a triggering event must appear. For instance, the individual may hear a conversation about a large sum of cash in a private home or may be aware that a family is on vacation or may see a house that draws attention for its luxury, or even an open window. In this sense, routine activities form a space of activity (both in time and in physical space), and from that space of activity people develop a repetitive pattern that sometimes turns them into the targets of criminals (Clarke & Felson, 1993; Felson, 2017).

However, the physical space of activity where people undertake their routine activities can also present social characteristics that promote criminal behaviour. To cope with this, Bursik and Grasmick (1995) propose the theory of social disorganization, according to which social disorder is presented as the violation of a tacit agreement on rules of public behaviour and is determined by the behaviour of groups which are frequently the target of complaints from the general population (e.g., teenagers gathered in corners, prostitutes and beggars). The physical environment of this theory includes areas with high consumption of alcohol in public roads, prostitution areas and places dedicated to betting. The most frequent social behaviours that this theory addresses are verbal harassment towards women, and the consumption of alcohol and drugs, among others. In this way, the visible social disorder is an indicator of the disorganization at the community level due to the lack of commitment of its residents to work as a team when solving common problems (Skogan, 2015). As social disorder affects collective action, the regulatory capabilities of a community are reduced and, therefore, the ability to obtain state resources to prevent further deterioration (Kubrin & Wo, 2016; Snowden & Pridemore, 2013). The theory of social disorganization identifies the effect of socio-structural factors (e.g., low education levels) on crime (Taylor, 2010), and gains some support from studies that show indirect effects on crime rates of declines in the levels of mutual trust (e.g., social capital) and neighbourhood interaction (Snell, 2001).

Environmental factors may contribute alongside social ones in explaining the motives of crime. Newman (1972) proposes the theory of defensible space as a useful component in the analysis of the incidence of spatial-environmental factors (urban design) in the development of criminality, either by facilitating or inhibiting it. The argument is based on the fact that the existence of a certain class of physical spaces promotes the emergence of antisocial behaviour at an urban level, such as anonymity, the size of residential complexes, the lack of police surveillance, the presence of abandoned lots, and routes that cannot be easily accessed (Newman, 1996). Closely linked to this theory is the environmental theory of crime, proposed by Jeffery (1977). For this criminologist, the incidence of environmental factors in the generation of crime is preponderant, since the way in which the human being perceives his environment generates mental interpretations on how to act. This process can be intervened through the design or redesign of the built environment (Jeffery, 1977; Jeffery & Zahm, 1993). The environmental theory of crime

is often used to intervene in the perceptions of citizens in the face of fear, crime and their identification with the physical environment. Hence the emphasis of this theory on the relationship between the physical environment, human learning, and the behaviour of the individual. The implication of this is that interventions in physical environments could help to prevent or deter antisocial behaviour (Crowe, 2000).

From a theoretical point of view, the environmental theory of crime at a global level allows us to identify some actions aimed at reducing the opportunity for the commission of crimes in urban areas and increasing the chances of capturing the offender when it is actually perpetrated (SIPRI, 2017). Such actions include the reduction of vacant or desolate places, the installation of lighting in dimly lit areas, the improvement of visibility, and the expeditious access to public places, among others.[5] However, the environmental theory of crime does recognize that the modification of the physical environment is not the only solution for deterring crime (Cozens & Love, 2015).

It is notable that most of the world's most violent cities are located in Latin America, in a geographic zone dubbed as the torrid zone. The people living in the torrid zone are exposed to high temperatures and high moisture environments all year long, and consequently, high heat stress is pervasive (Chang, 2016). In this regard, the examination of a potential link between weather and crime is by no means a new phenomenon in scholarly research. For decades, scientists have provided evidence of a link between temperature and criminal behaviour, and there is reliable evidence to indicate that there is a positive correlation between extreme weather conditions and violent crimes (Cohn, 1990; Cotton, 1986; Harries & Stadler, 1983; Harries et al., 1984; Horrocks & Menclova, 2011; Ranson, 2014). Rather than testing or proposing a particular theory about the influence of weather on violence[6], few studies have used formal measures of

[5] For example, an important civil work is being carried out in Sydney to renovate and develop a waterfront site where security factors are being incorporated into the project (SIPRI, 2017, p.15).

[6] Existing research on the link between weather and crime has resulted in the evolution of two antagonistic theoretical approaches. The general aggressive behaviour model (GAM) considers that the weather-crime relationship is linear. That is, extreme weather acts as a stressor by modifying human behaviour and subsequently can be manifested in violent actions (Cohn, 1990). Conversely, the negative affect escape model (NAE) postulates that the association between weather and crime is curvilinear. In short, this theory asserts that the link between weather and crime is linear up to a certain threshold, from which people generally attempt to escape the discomfort caused by the sweltering environment (Baron & Bell, 1976).

heat stress in the search for a link between extreme heat and violence.[7] Hu et al. (2017), in an analysis based in Tangshan, China, combine socio-economic factors (which they assume are a linear function of the gross domestic product) and different heat stress indices in the explanation of six different types of crime. These authors find that heat stress indices reasonably capture the influence of temperature and relative humidity on crime rates. Schinasi and Hamra (2017) examine the association between weather and crime in Philadelphia, Pennsylvania. Using the daily mean of the Heat Index, they find that violent crimes peak when temperatures are comfortable (i.e., cooler), mainly during cold months. Sommer et al. (2018) examine whether changes in the heat index influence the number of violent crimes in Boston, Massachusetts.[8] They find increases in crimes on temperate days compared to extremely cold days, and on dry days compared to rainy days. This growing body of evidence has important implications for urban planners and local governments when designing urban spaces and policies to tackle criminal activities, which will be explored in this research in the novel context of a tropical urban city.

2.4 Data and methodology

2.4.1 Case-study: Barranquilla, Colombia

The geographical framework is the city of Barranquilla, Colombia. Barranquilla is Colombia's fourth most populous city, with 1,148,506 inhabitants (Departamento Administrativo Nacional de Estadística [DANE], 2005). It also acts as the Colombian Caribbean region's main economic and financial centre. Barranquilla has a hot climate year-round characterised by an average temperature of 27.4ºC and an average relative humidity of 80% (Centro de Investigaciones Oceanográficas e Hidrográficas [CIOH], 2020). The rainy season runs from late April until late November; the average annual precipitation is 823 mm (CIOH, 2020). Due to its geographic

[7] The definition of heat stress depends on the methodology used for its calculation. There are four indices of heat stress evidenced in the literature: The Heat Index (HI), Simplified Wet Bulb Globe Temperature, Humidex, and Discomfort Index. For more details on these indices, see Oleson et al. (2015).

[8] The Heat Index (HI; also known as apparent temperature) is an indicator that combines relative humidity with air temperature, in shady locations, to obtain a measure of how the temperature feels like in the human body (Dahl et al., 2019). For details about its calculation, see National Weather Service (2020).

position of low latitude, the city receives a high solar radiation, which does not vary significantly during the year due to the absence of clouds and the almost null variation of the angle of incidence of the sun's rays.[9] Barranquilla's political administration comprises five localities, each of which comprises a set of neighbourhoods (commonly called 'barrios'). There are 193 neighbourhoods, featuring different socio-economic characteristics of the population living in them. As a strategy to mitigate crime, since 1987 the city's police department has provided 49 stations (in Spanish, 'comandos de atención inmediata') to meet the demands of security for the residents of each of the neighbourhoods through community policing (see Appendix A).

2.4.2 Data sources

Urban crime data covers a 9-year series (January 1st, 2010 to December 31st, 2018; 468 weeks in total) of homicides and interpersonal violence in the city of Barranquilla. These data were obtained from the Colombian Department of Criminal Research (DIJIN), a dependent office of the Colombian Police. Urban crime reports include type of crime, date, location and education, sex and age of offender. From this database, I assembled two datasets of total counts of reported homicides and interpersonal violence per week during the study period. Thus, the datasets consist of 468 observations. Homicides refer to the criminal killing of one person by another. Interpersonal violence is a compound crime and it comprises quarrels, retention, including kidnapping and hostage taking, settling old scores, drunkenness, illicit activities, bullying, and stray bullet. For the studied period, most cases of interpersonal violence recorded in our database were quarrels (86.8%), followed by retention, including kidnapping and hostage taking (7.3%).

Information on the education of the offender was obtained from DIJIN, and since the focus of the paper was on weekly crime occurrence counts, this information was converted to a weekly average number of years of schooling of the offender. Information on socioeconomic characteristics relies on the classification of their socio-economic class (SEC) in six categories[10],

[9] The city receives a solar radiation of approximately 600 calories per square centimetre per day (Unidad de Planeación Minero-Energética, 2015). Cities like New York, Paris, and Moscow receive 300, 275, and 225 calories per square centimetre per day, respectively (The World Bank Group, 2016).

[10] The Colombian Act No. 142 of 1994 established the tariff scheme for utilities. This law enacted a classification of households in six socio-economic classes (SEC, called "estratos" in Spanish) based on families' average incomes. This act relies on the principle of progressive taxation

which spatial distribution was obtained from Barranquilla Major Office. This facilitated the classification of each crime location into its corresponding SEC. I used proximity to vacant plots to capture information on the socio-environmental surroundings of the crime. Location of the 166 abandoned lots identified within the urban perimeter was obtained from the local water, cleaning, and sewer utilities provider (Triple AAA). Some of the vacant plots are already transformed in open-air dumps.[11] To account for the impact of police presence, location of the city policy stations was obtained also from the DIJIN. Distance of each crime scene to the nearest vacant lot and police station was computed using ArcGIS 10.1. Meteorological information was obtained from the weather station SKBQ-800280 (latitude:10°53′22″ N, longitude: 74°46′50″ W), a part of the Barranquilla International Airport managed by the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM). The heat stress indicator (*Heat_index*) is constructed using weekly data on temperature and humidity.[12] Moreover, the model controls for the seasonality of crimes captured through the dummy variables *Weekends* and *Rainy_season*.

2.4.3 Empirical strategy

I hypothesized that the determinants of crime in Barranquilla are characterised by a combination of socio-economic, socio-environmental, enforcement, and climatic factors. Thus, I model crime (*C*), as it pertains to either homicides or interpersonal violence[13], as a function of socio-economic

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so that the redistribution of income from the highest socio-economic classes' households (SEC 5 and 6) and from commercial and industrial firms' profits helps households from the lowest estratos (1, 2, and 3) to afford their utilities payments. Households from SEC 4 are considered middle-class and as such do not contribute or receive income transferences. In my analysis, low-income neighbourhoods refers to those neighbourhoods with households classified in SEC 1 and 2.

[11] In general, vacant lots along the time turn into open-air dumps. In my analysis, this variable corresponds to the 166 vacant lots recorded by the local administration regardless of their extension. In Chapter 3, I only consider the 30 critical vacant lots that turned into open-air dumps and that Barranquilla's local administration has planned to eradicate (Alcaldía Distrital de Barranquilla, 2015). This list of vacant lots changed marginally along the study period and I was aware of this fact in my calculations (See Appendix B).

[12] The Heat Index (HI) is calculated with this formula:

HI = − 42.379 + (2.04901523 × T) + (10.14333127 × H) − (0.22475541 × T × H) − (6.83783 × 10−3 × T2) − (5.481717 × 10−2 × H2) + (1.22874 × 10−3 × T2 × H) + (8.5282 × 10-4 × T × H2) − (1.99 × 10-6 × T2 × H2), where T is air temperature in degrees Fahrenheit and H corresponds to relative humidity levels in percentages. Source: https://www.weather.gov/media/epz/wxcalc/heatIndex.pdf

[13] According to the Colombian Institute of Legal Medicine and Forensic Sciences, non-lethal violence cases and their corresponding average participation in Colombia during the period 2010-2016 were recorded as follows: interpersonal violence (54.1%), socio-political violence (14.2%), economic violence (7.3%), and violence against marginalized groups (24.5%).

variables (*S*), an enforcement variable (*P*), a socio-environmental variable (*E*), a climate stress variable (*W*), and temporal variables (*F*). Then, my model takes the following general form:

$$C_t = \alpha_0 + \beta_1 S_t + \beta_2 P_t + \beta_3 E_t + \beta_4 W_t + \beta_5 F_t + \varepsilon_t \qquad \text{Eq. (1)}$$
$$t = 1, 2, \ldots, n$$

The selection of explanatory variables is summarised in Table 2.1. Socio-economic variables comprise low-income neighbourhoods (*Poverty*), which is a dummy (1, if all the crimes during the week were perpetrated in low-income neighbourhoods, or those neighbourhoods classified in SEC 1 or 2; and 0, otherwise); and the aggressors' weekly average years of education (*Education*). The enforcement variable (*Dpolice*) is a dummy that takes the value of 1 if the average weekly distance from the crime scene to the nearest police station is less than 1 kilometre, and 0, otherwise. The socio-environmental variable (*Dlots*) is a dummy that takes the value of 1 if the average weekly distance from the crime scene to the nearest vacant lot is less than 500-metres, and 0, otherwise.[14] The climate stress variable is the *Heat Index*, which is calculated using data from temperature and relative humidity series (see footnote 12). The set of temporal variables includes *Weekends*, a dummy variable that takes the value of 1 if weekly crimes were perpetrated only on weekend days (Friday, Saturday, and Sunday), and 0, otherwise; and *Rainy_season*, another dummy that takes the value of 1 if weekly crimes were committed during the rainy months (from April to November), and 0, otherwise. The fixed effects of time were captured through the inclusion of eight dummy variables of year (from 2011 to 2018; 2010 is the year of reference).

[14] These distances are discretionary reference measures of the influence of the proximity of police stations and vacant lots on the crimes studied.

Table 2.1: Variable list

Variable	Type	Description
Homicides	Discrete	Number of weekly cases of homicides
Interpersviolence	Discrete	Number of weekly cases of interpersonal violence
Poverty	Categorical	Takes the value of 1 if crime committed in low-income neighbourhoods (SEC 1 and 2), and 0 otherwise
Education	Continuous	Aggressors' weekly average number of years of schooling
Dpolice	Categorical	Takes the value of 1 if average weekly distance from the crime scene to the nearest police station is within a radius of 1000 metres, and 0 otherwise
Dlots	Categorical	Takes the value of 1 if average weekly distance from the crime scene to the nearest vacant lot is within a radius of 500 metres, and 0 otherwise
Heat_index	Continuous	Weekly average of the Heat Index
Temperature	Continuous	Weekly average of maximum temperature in degrees Fahrenheit
Humidity	Continuous	Weekly average of relative humidity in percentage
Weekends	Categorical	Takes the value of 1 if weekly crimes are perpetrated only on weekends (Friday, Saturday and Sunday), and 0 otherwise
Rainy_season	Categorical	Takes the value of 1 if the week corresponds to the annual rainy season (from April through November), and 0 otherwise

Source: author's elaboration

Given the discrete nature of my dependent variables and their relatively low variability, the most suitable method for estimation is a count data model, rather than the more commonly employed ordinary least square estimations. I used multivariate regression to elucidate the effects of the explanatory variables on each type of crime (homicides and interpersonal violence). Since the data were overdispersed[15], I used the negative binomial model for the estimations. I then resorted to time-series analysis in order to check the appropriateness of the data. Using the Augmented Dickey-Fuller and the Phillips-Perron's unit-root tests, I tested the series for stationarity, and in all cases, I rejected the null hypothesis of a unit root process. I proceeded to test for first-order serial correlation of the residuals using the Durbin-Watson *d* statistic. An examination of my models' residuals indicated a Durbin-Watson *d* value of 1.87 for homicides and 1.6 for

[15] Overdispersion denotes a large individual variability of the data in comparison with the mean (Greene, 2008). In my case, overdispersion implies that crimes can occur many times on some days, but relatively infrequently on others.

interpersonal violence, which represents a first order autocorrelation of .02 ($p < .01$) and .08 ($p < .01$), respectively. While this does not indicate a serious bias, I adopted a conservative approach by using Newey-West standard errors to control for potential heteroscedasticity and serial correlation.[16] Finally, I estimated the models using a generalized linear model (GLM) with a log-link function. The regressions were carried out using Stata 15® and in a separate manner for both types of crime.

2.5 Results

Descriptive statistics are shown in Tables 2.2 and 2.3. There was a total of 3,246 homicides reported during the nine-year period covered by my analysis, representing 361 homicides on average per year. The total cases of interpersonal violence recorded during the study period reached 32,814, representing a yearly average of 3,646 cases. Figure 2.1 and 2.2 provide a visual illustration of the average weekly rates in both homicides and interpersonal violence in Barranquilla during this study period, showing the higher incidence of crime over the weekend days. Unsurprisingly, both types of crimes were perpetrated mainly in low-income neighbourhoods of the urban area. Table 2.4 reports the estimates relating to my analysis of the factors associated to homicides. I display my estimates in the form of an incidence rate ratio (*IRR*) for a 1-unit change in the covariates.[17]

[16] I replicated the estimations including robust or bootstrapped standard errors instead of Newey-West (see Appendix D). This does affect my estimates as standard errors are somewhat larger, although the change is marginal. I also re-estimated both models of crime using temperature and relative humidity instead of the Heat Index (see Appendix D).

[17] The IRR shows the ratio between the incidence rate in a group of people exposed to crimes (i.e., homicide or interpersonal violence) and the incidence rate in an unexposed group of people, which is taken as a comparison group. For dummy variables such as *Poverty*, the IRR represents the switch from 0 to 1.

Table 2.2: Descriptive statistics for homicides

	Mean	St. Dev.	Min	Max
Homicides	6.94	3.01	1	19
Poverty	0.84	0.37	0	1
Education	7.73	1.02	4.3	10.4
Dpolice	0.63	0.48	0	1
Dlots	0.36	0.48	0	1
Heatindex	121.06	9.98	93.6	147.9
Weekends	0.57	0.50	0	1
Rainy_season	0.67	0.47	0	1

Source: author's elaboration

Table 2.3: Descriptive statistics for interpersonal violence

	Mean	St. Dev.	Min	Max
Interpersviolence	70.12	15.63	23	143
Poverty	0.87	0.34	0	1
Education	11.97	1.48	7.1	16.1
Dpolice	0.98	0.13	0	1
Dlots	0.63	0.48	0	1
Heatindex	121.06	9.98	93.6	147.9
Weekends	0.36	0.48	0	1
Rainy_season	0.67	0.47	0	1

Source: author's elaboration

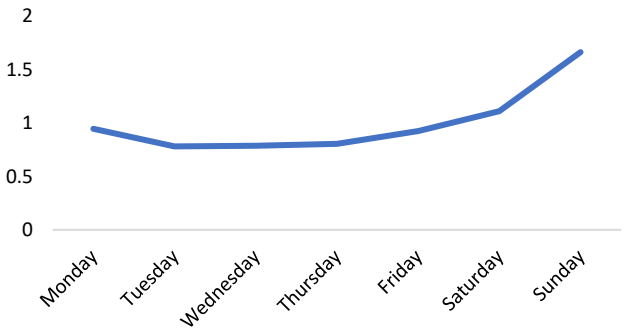

Figure 2.1: Homicides. Barranquilla, 2010 – 2018
Source: author's elaboration

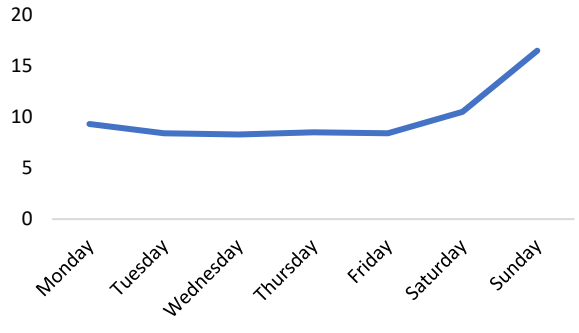

Figure 2.2: Interpersonal violence. Barranquilla, 2010-2018
Source: author's elaboration

I observed a significant and positive association between *Homicides* and *Poverty* (*IRR* = 1.061, $p < .1$) and a significant and negative association between *Homicides* and *Education* (*IRR* = 0.970, $p < .1$). In other words, homicides are 6.1% times more likely in poor neighbourhoods than non-poor ones; and more years of education reduce the probability of committing homicides. These results are in consonance with previous literature, which suggests that homicides are more likely to be responsive to changes in socio-economic conditions. Moreover, homicides appear to be negatively associated with my proxy for police enforcement (*Dpolice*), which resulted statistically significant at 10% (*IRR* = 0.923, $p < .1$). Conversely, my estimate on the influence of the proximity of vacant lots (*Dlots*) was positively associated with the weekly rate of homicides (*IRR* = 1.046, $p < .01$). On the other hand, I found no statistical relationship between heat stress and homicides. I also observed no seasonal differences (rainy v. non-rainy season) in homicide rates. Lastly, I found that homicides were 5.8% higher on weekends than weekdays (*IRR* = 1.058, $p < .05$).

I perform a test of the specification of the dependent variable, which is based on the idea that if a regression equation is properly specified no additional independent variables should be significant; that is, conditional on the specification, the independent variables are specified correctly. I found that this test does not have explanatory power (p-value = 0.619), so the homicides model's specification is correct. On the other hand, testing for omitted variable bias is also important since it is related to the assumption that the error term and the independent variables in the model are not correlated. In the Ramsey RESET test, the p-value (0.2976) is higher than the usual threshold of 0.05 (95% significance), so I fail to reject the null hypothesis and conclude that the model does not have omitted-variable bias.

The Wald test was also performed to determine Granger's causality. From the results of the Granger's causality test it can be concluded that *Homicides* does not cause any of the independent variables in the Granger sense. In other words, the model has no bidirectional causality. Lastly, all the variables are stationary at 1% significance level. That means all the variables are $I(0)$. Therefore, a cointegration test (Johansen) was not performed since a set of variables only presents cointegration if each of them is integrated of order d, with $d > 0$, and there is at least one linear combination of variables that is integrated of order 0.

Table 2.4:Factors associated to homicides

	IRR	Newey-West SE
Poverty	1.061	0.0228***
Education	0.970	0.0088***
Dpolice	0.923	0.0381*
Dlots	1.046	0.0144***
Heatindex	0.999	0.0019
Weekends	1.058	0.0246**
Rainy_season	0.958	0.0370
N	468	

IRR is Incidence Rate Ratio.

SE is Standard Error

Fixed-effect time coefficients of year are omitted.

*$p < .1$ **$p < .05$ ***$p < .01$

Source: author's elaboration

Table 2.5 Factors associated to interpersonal violence

	IRR	Newey-West S.E.
Poverty	1.024	0.03
Education	0.993	0.0032**
Dpolice	0.917	0.0368**
Dlots	1.018	0.0093**
Heatindex	1.002	0.0006**
Weekends	1.087	0.021***
Rainy_season	0.966	0.0094***
N	468	

IRR is Incidence Rate Ratio.

SE is Standard Error.

Fixed-effect time coefficients of year are omitted.

*$p < .1$ **$p < .05$ ***$p < .01$

Source: author's elaboration

Socio-economic variables also appear to play a substantive and statistically significant role in predicting rates of interpersonal violence (see Table 2.5). First, my findings suggest that there is no statistical association between poverty and weekly rates of interpersonal violence. This is not an unexpected result since it is generally observed that interpersonal violence is frequently described as a spontaneous aggressive act in response to a minor dispute. Holding all other factors constant, more years of education on average tend to reduce the weekly rates of interpersonal violence (*IRR* = 0.993, $p < .05$). This result is consistent with previous studies that

emphasize the role of education in the reduction of non-lethal violence. As in the case of homicides, my proxy variable for law enforcement (*Dpolice*) showed a negative and significant association with interpersonal violence cases (*IRR* = 0.917, $p < .05$). That is, being close to a police station seems to reduce the likelihood of interpersonal violence incidents. By contrast, places like vacant lots or open-air dumps induce the committing of interpersonal violence as shown by the estimate of *Dlots* (*IRR* = 1.018, $p < .05$). This result implies that being further from vacant lots was associated with lower occurrence of interpersonal violence cases. On the other hand, the Heat Index significantly influences the probability of interpersonal violence occurring (*IRR* = 1002, $p < .05$). This is congruent with the literature (Hu et al., 2017; Schinasi & Hamra, 2017). In contrast with what happens in homicides, I observed seasonal differences regarding the rainy season and the weekly rate of interpersonal violence (*IRR* = 0.966, $p < .01$). This could well indicate that interpersonal violence acts are less likely to occur during the most humid period of the year. Lastly, confirming the strong seasonality of crimes in Barranquilla, I found that interpersonal violence cases were 8.7% higher on weekends than weekdays (*IRR* = 1.087, $p < .01$).

The test of the specification of the dependent variable (*Interpersviolence*) did not have explanatory power (*p*-value = 0.888). That is, conditional on the specification, the independent variables are specified correctly. I tested the null hypothesis that the model of interpersonal violence does not have omitted-variables bias. The Ramsey RESET test resulted in a *p*-value of 0.7157, which is higher than the usual threshold of 0.05 (95% significance). Thus, I fail to reject the null hypothesis and conclude that the model of interpersonal violence does not need more variables. The results of the Wald test to determine Granger's causality indicated that Interpersviolence does not Granger-cause any of the independent variables. Again, since all the variables are stationary, the cointegration test was not performed.

2.6 Discussion

This study set to evaluate the weekly incidence of crime in the city of Barranquilla with respect to the local weather conditions throughout a nine year period. On doing this, the analysis considers that the underlying societal determinants of the urban crime according a number of

theoretical frameworks (routine activity theory, the theory socio-environmental of crime, and the theory of social disorganisation). By using these frameworks in a complementary way, I provide a better understanding of the complex social processes that underlie urban crime and show that those theories mainly use to urban crime in cities in developed countries (mostly Euro-America cities) have utility in a Latin American context.

My results indicate that socio-economic factors such as poverty and education and socio-environmental characteristics of the neighbourhood such as the presence of vacant lots influence individuals' decisions to perpetrate violent acts. This thesis contributes to the findings of the urban crime literature by also showing that the effect of these determinants varies according to the type of crime in the city of Barranquilla. For instance, poverty influences the perpetration of homicides, but it has no significant impact on interpersonal violence. One way to understanding this would be to unravel the triggers of both crimes. Whilst homicides are generally driven by structural causes like drug-trafficking, gang violence, or score settling, interpersonal violence often emerges as an instinctive aggression act in response to a minor disagreement. In the literature that explores homicide occurrence, my results are consistent with the recent findings of Coccia (2017) that conducts a country level analysis (191 countries) of homicides per 100,000 people. Regarding my results in interpersonal violence, these are consistent with the findings of Antunes and Ahlin (2014) and Golden et al. (2013), who found no impact of economic inequality on youth violence and intimate partner violence, respectively, in US cities. They are also consistent with the findings of Kiss et al. (2012) who found that the risk of women suffering from intimate partner violence does not vary across neighbourhoods according to socioeconomic levels in São Paulo, Brazil.

My results reveal, as expected, that the level of education has a positive influence in the reduction of urban crime. This finding is consistent with Bell et al. (2016), Hjalmarsson et al. (2015), and Jonck et al. (2015), who found that, for the United States, Sweden, and South Africa, respectively, this is an important factor in reducing the likelihood of crime. It is well known that education leads to significant reductions in arrests, and it also affects the individual’s decision to engage in crime (Lochner, 2010, 2011).

Contributing to the environmental theory of crime, as represented by Branas et al. (2018), Garvin et al. (2013), and Kondo et al. (2016), who found that greening vacant lots is an important factor influencing the reduction of violence in deprived neighbourhoods across various locations in the US; this study found a significantly higher likelihood of both homicides and interpersonal violence in areas of the Colombian studied city which are closer to vacant lots or open-air dumps. This adds further weight to the usefulness of this theoretical framework for the crime process in the Latin America region. In the case of Barranquilla, one possible explanation for this finding is that these places are relatively less crowded and frequently dimly lit at night than other spots of the neighbourhood, thereby making surveillance through policing or by cameras more challenging. Another possibility is that these places are frequented by gang members or micro-traffickers of illicit drugs. These individuals typically use these areas to hide from police controls and increase the likelihood of murders and quarrels in the immediately surrounding area.

Research to date has not examined the impact of heat stress in the context of a tropical urban city in a developing country context. My results revealed some important impacts of weather variation on urban crime. After controlling for other societal driving variables in explaining crime counts, I found that heat stress influences positively the likelihood of acts of interpersonal violence, but I failed to observe any impact of heat stress on homicides. I suggest these differences on the impact of heat stress in the crimes studied are due to the different motivations involved and the behaviours required for violent acts. As I argued above, interpersonal violence is most often a spontaneous aggressive reaction to a minor dissention (Anderson, 2001). It is therefore relatively more susceptible to alterations in comfort brought about by extreme weather than lethal crimes. My results on homicides align with those of Ceccato (2005), Coccia (2017) and Peng et al. (2011), who found no relationship between rising temperatures and murders. However, my findings differ from Schinasi and Hamra (2017) and Sommer et al. (2018), who found that heat stress is a significant factor in the daily variation of homicide rates for the cities of Philadelphia, and Boston, US, respectively. In terms of interpersonal violence, my results are consistent with growing body of work to support the suggestion that extreme weather can be an important factor in explaining variations in non-lethal violence in temperate climates. For instances, McLean (2007) found a positive and statistically significant association between temperature and non-lethal violence in Greater Manchester, UK. Mares (2013) showed how

temperature anomalies in St. Louis, Missouri, are associated with higher monthly rates of violence, especially in the most socially vulnerable neighbourhoods. Also, Sorg and Taylor (2011), using monthly data, found a strong and positive relationship between higher temperatures and street robbery in poor neighbourhoods of Philadelphia, Pennsylvania.

Furthermore, and in keeping with much prior work, I also find that weekly rates of interpersonal violence and homicides are substantially higher on weekends (Ceccato, 2005; Rotton & Cohn, 2003). These findings are in keeping with the routine activity theory, which suggests that violent behaviour is more likely to occur during the days of more social interaction among the people.

A potential limitation relates to measurement error when it comes to interpersonal violence. Given it is likely that fewer non-lethal violent acts will be reported than those that actually occurred, there may be under-reporting in the weekly information of interpersonal violence cases (Instituto Nacional de Medicina Legal y Ciencias Forenses, 2016). Measurement error biases the estimates of the determinants of crime. Another limitation comes from the dummy variable I used to capture the proximity to a police station, which could hardly encompass the whole effect of law enforcement in bringing security. In fact, an important issue in this study is the fact that the spatio-temporal patterns of crime across Barranquilla, and the potential spatial heterogeneity in the association between crime and social, climatic and enforcement determinant factors of crimes was not investigated due to data limitations. Further future research that could provide spatial insights into the mechanisms that undergird such relationship could have implications for spatially targeting structural and social policies that can be taken to mitigate the incidence of crime in this city. Finally, I did not include any variable related to social cohesion, which constitutes another important factor of urban crime (Allen et al., 2016; Snell, 2001).

2.7 Conclusions

In this chapter, I provide evidence of the factors that influence the occurrence of crime in Barranquilla, Colombia. I find statistical evidence on how structural factors like poverty and low levels of education affect the city's weekly rate of homicides. Though not affected by poverty, interpersonal violence is also fuelled by the residents' low levels of education, especially those who live in the most deprived neighbourhoods. I present statistical evidence on the role of police

presence nearby in reducing the occurrence of crimes in the city. Contrastingly, socio-environmental factors such as the presence of vacant lots and/or open-air dumps in the neighbourhood, are associated with an increased likelihood of homicides and interpersonal violence acts. I also show the first evidence of the effect of heat stress on non-lethal violence in a hot and humid tropical context, controlling for socio-economic factors. In keeping with the routine activity theory, the evidence also shows that crimes are more likely to be committed on weekends. This finding confirms the strong seasonality of crime in Barranquilla.

The evidence presented on factors that are important in determining the incidence of crime in Barranquilla is of use to security policymakers insofar as it provides a means for identifying potential levers to enhance urban resilience to crime. The analysis also contributes to the understanding of the impact of local weather conditions on crime in tropical cities, a factor which most of the criminological literature has avoided to date. This contribution is particularly relevant considering in the context of climate change and warming temperatures, and the climate change adaptation capacity deficit in developing countries (e.g., IPCC, 2014). Overall, this study underlines the need to deepen our understanding of how social and economic factors interact with weather conditions in affecting levels of crime in other tropical urban zones.

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Chapter 3: An assessment of households' willingness to pay for an illegal waste disposal intervention. The case of open-air dumps in Barranquilla, Colombia

3.1 Abstract

Despite the modernization of solid waste management systems in many Latin American cities, illegal waste disposal activities still persist. This study examines the socio-demographic factors that explain the degree to which households are willing to participate and pay for a public intervention aimed at eradicating the main 30 open-air dumps that still prevail in Barranquilla. To this end, I applied probit and tobit models to a sample of 815 households within the urban territory. The results reveal that factors such as age, type of housing, distance to the nearest open-air dump, awareness of illegal dumping, satisfaction with the neighbourhood, institutional trust, risk communication, household size, education, and income showed a significant influence on the heads of household's willingness to pay for the eradication of open-air dumps. From a policymaking standpoint, prior to designing an initiative that will be successful in eradicating these critical urban areas, these factors must be taken into consideration.

Keywords: consumer economics; solid waste; contingent valuation; household analysis; government policy

3.2 Introduction

Illegal dumping is a problem that persists globally and that threatens human health and the environment, generating a high social cost in local communities and adverse effects on social welfare (Brandt, 2017; Lega et al., 2012; Song et al., 2015). In many cities of Latin America and the Caribbean, the proliferation of open-air dumps has risen at an alarming rate since 2000 and government action has not been successful in mitigating the impact. According to the World Bank (2018), "illegal dump sites serve about 4 billion people and hold over 40% of the world's waste." Undoubtedly, the continued rise in agricultural mechanization and subsequent productivity began displacing workers to urban areas (Carley & Christie, 2017), and increases in urban population and per capita incomes have challenged the public handling of solid waste, posing a serious threat to traditional methods of household refuse disposal. In response to the

burden of dealing with such an immense ocean of rubbish, multilateral institutions like the World Bank have taken the initiative to assist municipal governments in developing countries to design sustainable solid waste management systems (SWMS), which aim to collect, dispose, recycle, reuse, and reduce waste. Since 2000, the World Bank has lent approximately US $4.5 billion for 329 SWMS programmes, including investments in infrastructure, modernization of waste disposal mechanisms, social awareness programmes, and recycling systems (World Bank, 2018). Despite the ambitious international effort to cope with solid waste and the impact of its disposal, the phenomenon has worsened. Between 2005 and 2015, the global total production of solid waste practically doubled and is expected to reach 2.5 billion tons per year by 2025 (McCallister, 2015, p.3).

Latin America and the Caribbean is the world's most urbanized region. Indeed, in 1975 the urban population represented 61% of the total population of Latin America, and by 2017 it had reached 80% (Worldometers, 2018). Projections from the World Bank also warn about the rapid increase in municipal solid waste, which is expected to grow from 131 million tons as reported in 2005 to approximately 179 million in 2030 (Golders Associates, 2006). The inability of infrastructure and land use planning methods (including waste management) to cope with such urban growth is of particular concern in slum areas, which constitute a significant portion of Latin American urban settlements. Municipalities are generally responsible for solid waste management services (SWMS) in Latin American countries (Guerrero et al., 2013; Hoornweg & Giannelli, 2007). However, countries struggle to keep SWMS functioning sustainably because of the mentioned increases in populations and per capita incomes, and illegal dumping has gained momentum in Latin American cities over the last three decades (Guerrero et al., 2013).

This study investigates households' preferences for eradication of open-air dumps and explores the determinants that can influence their support for tackling illegal disposal of solid waste in the city of Barranquilla in Colombia. Quantitative evidence on the links between the illegal disposal of waste and households' socioeconomic conditions, availability of waste landfill facilities, enforcement and social cohesion is rapidly increasing in the literature in the last decade (Hettiarachchi et al., 2018; Nyarai et al., 2016; Zhang & Zhao, 2019). This chapter contributes to this literature by focusing on a mid-size city in Colombia given the limited evidence in

explaining illegal dumping in a developing country context. This is more surprising if one considers that the financial challenges in cities in developing countries are more likely to result in shortages of proper waste treatment facilities, a key factor shown to play a key role in illegal dumping (Ichinose & Yamamoto, 2011). In this line, Al-Khatib et al. (2015) and Guerrero et al. (2013), who explored solid waste disposal challenges in developing countries, report that urban residents believe they have no other options than to resort to environment-unfriendly waste disposal methods, such as open dumping and burning. In Latin American countries, research on illegal dumping in large urban areas has focused mostly in the life conditions and social inclusion of 'waste pickers' (Cruvinel et al., 2019; Fergutz et al., 2011; Marello & Helwege, 2018; Medina, 2000; Zapata-Campos & Zapata, 2013). To my knowledge, only the study of Yousif and Scott (2007), who describe the waste management system in Mazatenango, Guatemala, studied the determinants of illegal dumping of solid waste in Latin American urban settlements. However, this study does not examine social preferences towards local policies or strategies that can contribute to deter households from resorting to illegal activities of solid waste disposal.

More specifically, my study purports to make two contributions. First, it is the first to use the contingent valuation method (CVM) to examine the determinants of urban residents' willingness to join (WTJ) and willingness to pay (WTP) for a programme to eradicate existing outdoor landfills in Latin America. Second, the study can inform waste management policy in the case study city by examining the role of social capital such as community cohesion and institutional trust on the residents' preferences toward the programme. The Prefecture of Barranquilla, Colombia, and the City Council have both made efforts at addressing the problem of illegal open-air dumps, considering the growing prevalence of this phenomenon owing to unforeseen population growth and rapid changes in consumption patterns. In 1991, the Mayor's office contracted a joint venture integrated with domestic and foreign firms to deal with waste treatment and disposal in Barranquilla. The city's waste management has improved significantly since then, even attaining a service comparable to international standards. For instance, since 2009, the city's landfill *Los Pocitos* receives 1,763 tons of solid waste per day, up from 600 tons twenty years earlier (Superintendencia de Servicios Públicos Domiciliarios [SSPD], 2018). Waste disposal was at nearly 0.12 tons per capita yearly between 2005 and 2014 (Alcaldía

Distrital de Barranquilla [ADB], 2015). Importantly, the city's waste management integrated plan 2016-2027 proposes clear sanitation policies that aim to mitigate illegal waste dumping and curb formation of open-air dumps (ADB, 2015). This plan also contemplates different sanctions on individuals caught in activities related to illegal disposal of waste. In addition, there has been a movement to instruct citizens on how to create awareness. This strategy highlights the role of residents in establishing efficient and proper waste management.

Despite these advancements, reaching such goals will prove quite difficult due to the amount of waste still present in some public areas. The population has no collective inclination towards the care of the environment and the practice of illegal disposal of solid waste in unauthorized areas of the city, as well as the ill habit of throwing the wastes in the flash-floods that form when it rains still persists (Rodríguez et al., 2014). Therefore, in the city, it is urgently required to awaken environmental awareness through incentives for the proper use of solid waste. However, to design and implement an urban policy that fosters incentives to eliminate the illegal disposal of solid waste, direct information from households is required. In this sense, there is an informational void on the issue of social preferences towards eradication of illegal disposal of solid waste in Colombia. This study tries to fill that void.

3.3 Literature review and geographical scope

3.3.1 Literature review

Some studies have explored the effects of illegal dumping on human health. For example, Triassi et al. (2015) analysed the health effects of the illegal waste disposal in the 'triangle of death' (Campania region) in Italy, one of the European countries most affected by the presence of illegal dumpsites. Gathering evidence from a set of studies, Triassi et al. (2015) find a long-term positive correlation between illegal disposal and liver and lung cancer mortality, and a short-term positive correlation between the waste mismanagement and congenital malformation. Also, in the Campania region, Mazza et al. (2015) find a statistically significant association between exposure to illegal toxic waste dumping sites and cancer mortality, after controlling by socio-economic factors and other environmental indicators. Not far from Italy, in the Istrian peninsula,

Duh et al. (2017) find that the spread of human pathogens in the environment can be significantly increased by the presence of illegal waste sites.

Recent work has also explored the causes of illegal dumping. Liu et al. (2017) provide a comprehensive analysis on the determinants of illegal waste dumping in England from 2008 to 2014. Using a panel database, the authors find that the increase of landfill cost has a negative impact on illegal dumping whereas more waste landfill facilities, a higher income level and the intensity of fines reduce the occurrence of illegal dumping. Sedová (2016) examines the determinants of illegal waste dumping at the county level in Slovakia, using a truncated regression model. The author finds that income has a positive influence on illegal waste dumping, poverty impacts negatively the rate of illegal dumping, and a higher level of education does not imply a more responsible waste management. In Poland, Macias and Piniarski (2016) describe the problems of local waste management systems taken the case study of Pobiedziska urban-rural commune. The authors show that the low ecological awareness of Pobiedziska commune's residents is the main cause of the widespread illegal waste sites. In Zimbabwe, Nyarai et al. (2016) discuss the management challenges of Mutare's household solid waste system. The authors find that although that solid waste quantities are ever increasing, the disposal of solid waste was far from being environmentally sustainable and most residents have to resort to illegal open dumps, burning or burying of waste. The authors also identify the lack of cooperation and awareness by the residents, local government's financial constraints, poor enforcement of laws by the authorities, and the low residents' participation in the solid waste management system as the main challenges to overcome the critical situation of Mutare's waste management system.

Further, studies have also investigated the role of public measures in influencing people's incentive to dump their wastes illegally, that could be affected by collection tariffs, corruption, and enforcement, including the use of technology to make monitoring more efficient. In a Sweden-based study, Andersson and Stage (2018) analyse how two local policy instruments – weight-based waste tariffs and special systems for the collection of food waste – affect the collected volumes of different types of waste. They confirm Kinnaman and Fullerton (1996)'s results in Virginia, USA. Illegal disposal becomes more attractive if it is less costly than other waste disposal alternatives. The authors conclude that a weight-based waste tariffs instrument

may increase the incentives for illegal dumping. However, the institutional context has been shown to play a key role in deterring illegal dumping. For instance, Cesi et al. (2013) investigates interactions between waste and enforcement policies in the presence of corruptible bureaucrats. Using a three-stage game, where a firm dumping illegally can bribe a government agent in charge of supervising for its disposal, they find that corruption might appear as an equilibrium strategy in the firm waste-policy. Cesi et al. (2013) suggest the avoidance of frequent controls regarding illegal dumping, as these may increase the possibility of corruption. In Italy, D'Amato et al. (2018) investigate how environmental and enforcement policies affect environmental non-compliance. Using a panel database for the provinces in Italy, these authors find that the commitment to a more stringent waste policy tends to increase illegal disposal of waste. Zhang and Zhao (2019), using data on communities from four suburb areas of China, examine households' willingness to involve in activities related to waste disposal monitoring. These authors find that population density, community modernization, and being male increase the likelihood of households' involvement in supervising waste disposal; in contrast, they find that community size, the heterogeneity of wealth and ethnicity restrict the possibility of engaging in waste disposal monitoring. Interestingly, Zhang and Zhao (2019) also reveal that the stock of social capital and peer monitoring increase the households' possibilities of engaging in waste disposal supervision activities. Despite the surreptitious nature that entails the illegal dumping of waste, today's technological advances, particularly in spatial data handling, appear to be an optimistic tool in tracking and monitoring potentially illegal dumpsites. Glanville and Chang (2015) analyse existing remote sensing methods and sensors used to monitor and map illegal waste disposal sites in Queensland, Australia. These authors recommend the application of remote sensing technologies to improve both the detection of illegal waste disposal sites and the cost-effectiveness of waste management systems. In Spain, Navarro et al. (2016) demonstrate the potential of novel real-time GPS tracking of scavenging species to detect environmental crime. Their results show that multi-species guilds of feathered detectives equipped with GPS and cameras could help fight illegal dumping worldwide. Lu (2019) resorts to big data analytics to determine the causes and potential solutions for the illegal construction wastes in Hong Kong. The author suggests a big data method to enhance the identification of hauling trucks suspected of participation in illegal dumping. In the Haifa district of Israel, Seror and Portnov (2018), using multivariate statistical analysis and geographic information system (GIS) tools, identify the areas

under potentially elevated risk of illegal construction and demolition waste dumping. These authors argue that the identification of illegal waste sites can save public resources by acting more efficiently against the offenders.

3.3.2 Solid waste disposal system in Barranquilla: A background

The District of Barranquilla is in the Caribbean region of Colombia at an average altitude of 18 metres above sea level. Its annual average temperature oscillates between 27 and 31 degrees Celsius, with an annual average of relative humidity of 83%. The city has an area of 166 square kilometres, divided into 5 localities and 159 neighbourhoods (see Appendix E). Barranquilla's 2005 population was 1,148,506 (DANE, 2005). In demographic terms, Barranquilla is the fourth Colombian city. The city's economy depends mostly on manufacturing and services and it represents 4.4% of the Colombian GDP. Barranquilla produces 0.89 kg of solid waste per resident per day (Bermejo, 2016, p. 23). In 2010, from the city's total produced waste, approximately 52% is from households and 42% is from manufacturing (ADB, 2015).

The history of the garbage collection service in Barranquilla is quite peculiar within the Colombian urban context. The basic characteristic that makes it atypical is that for almost thirty years (1936-1965), the garbage collection service had a private management exercised by foreign agents. It was a group of US lenders that in the mid-1930s had granted a loan to the municipality and demanded control over the administration of the public service during the entire period of debt recovery. As of 1965, the garbage collection service was administered by a local company with state funds called *Empresa de Servicios Públicos* (ESP). After a couple of years, the ESP became an inefficient, highly bureaucratic body and one of the most corrupt in the country (Jaramillo, 1994). In terms of service coverage, the situation became dramatic during the 1980s. The cleaning service barely covered 55% of urban demand, but even reached periods in which coverage was reduced to less than 30%. The effect of this deficit in the coverage of the cleaning service was mainly in the poorest neighbourhoods of the city. First, the access to the poorest areas of the city was very difficult at the time; and second, the waste disposed by lower income households was less attractive to ESP workers, who illegally recycled the waste and obtained an

additional benefit (Jaramillo, 1994). In fact, some important sectors of the city never received the service, and from there, informal modalities of solid waste collection began to consolidate.[18]

Between 1965 and 1990, the disposal of solid waste in the city was precarious, and open-air dumps began to proliferate in different parts of the city. Meanwhile, the financial situation of the ESP was dramatic. The subscribers of the ESP reached 55% of the urban population and more than half were in serious default. Thus, a vicious circle was consolidated in the waste collection service: Subscribers refused to pay, given the poor quality of the service, and the company received less and less income, and therefore its financial infeasibility was manifest.

In 1990, the proposal for privatization of the waste collection service emerged as a solution to the public health problems facing the city. The local authorities decided to liquidate the ESP and replace it with a private entity. However, no investors interested in the new business were found, and therefore a mixed economy company was formed, in which private and public capital would operate jointly. Finally, in 1991, the *Sociedad de Acueducto, Alcantarillado y Aseo de Barranquilla* (Triple A) was established. More than thirty years of service to the community have already passed and Triple A has achieved high levels of administrative and operational efficiency, as well as significant technological development that contributes to the growth and sustainability of the city (Triple A, 2019).

Despite this greater efficiency in solid waste collection and the efficient operation of the landfill *Los Pocitos*, located at 13 kilometres from the city[19], there are still 30 critical points that Triple A has recognized as open-air dumps (see Appendix F). Figure 3.1 shows the spatial distribution of 30 main open-air dumps. Most of the open-air dumps are located in the southern part of the city, an area that corresponds to the lowest SEC. This seems to be a stylized fact in illegal dumping according to the evidence found elsewhere (Yousif & Scott, 2007; Zhu et al., 2008).

[18] These informal modalities of solid waste collection include the appearance of open-air dumps, the informal collection of solid waste by waste pickers in animal-traction vehicles, and the still in force the ill practice of throwing garbage into flash-floods when it rains.

[19] Colombian media has recognised that the operation of the landfill *Los Pocitos* is a world referent (See El Tiempo, 2019).

3.4 Data and methodology

A proportionate stratified random sample of 825 households was selected in Barranquilla, from which 815 valid responses were obtained. The strata used were their socio-economic classes (SEC).[20] Thus, the sample was built to mirror the existing quotas of households in terms of their socio-economic classes (SEC) of the entire population of households, i.e., the proportion of households officially registered in the District of Barranquilla for each of the SEC (see Table 3.1). I used the command *sample* in Stata 15®. The final sample is the sum of the six randomly selected sub-samples from the households in each of the six SEC. The interview was conducted by at-home personal interviews. A professional data management firm conducted the between July 2017 and March 2018, and no significant problems were appreciated in applying the survey.[21] Figure 3.1 shows the spatial distribution of respondents and open-air dumps.

Table 3.1: Participation of socio-economic classes in the sample

Socio-economic class	Number of households	Participation
1	61,555	24.4%
2	73,656	29.1%
3	53,613	21.2%
4	29,533	11.7%
5	16,977	6.7%
6	17,118	6.8%
Unclassified	308	0.1%
Total	252,760	100%

Source: Empresa de Desarrollo Urbano de Barranquilla (2012)

The questionnaire was designed to include the key elements of the CVM, as suggested by Boyle (2017) (see Appendix H). Some questions were related specifically to their perception on open-air dumps, while other questions focused on their neighbours' collective behaviour in general and towards the presence of open-air dumps around the city. The latter were followed by

[20] It is worth mentioning that in Colombian cities households are classified according to their level of monetary income in 6 socio-economic classes (SEC). SEC 1, 2 and 3 correspond to households with the lowest income levels, and, therefore, they are beneficiaries of subsidies on the fees of utilities. In turn, SEC 5 and 6 correspond to households with the highest income levels, and they are compelled by law to pay an additional contribution to the fee on utilities. The households corresponding to SEC 4 are neither beneficiaries of subsidies nor do they have to pay surcharges, but they contribute to the market value of utilities' fees.

[21] Before starting the survey, interviewers enquiry about the presence of the head of the household; if this was not present a date and time was fixed to return and interview the head of the household. If head of the household decline to participate in the survey, interviewers move to the nearest household.

questions about the households' willingness to pay for a programme to eradicate open-air dumps within the city limits.

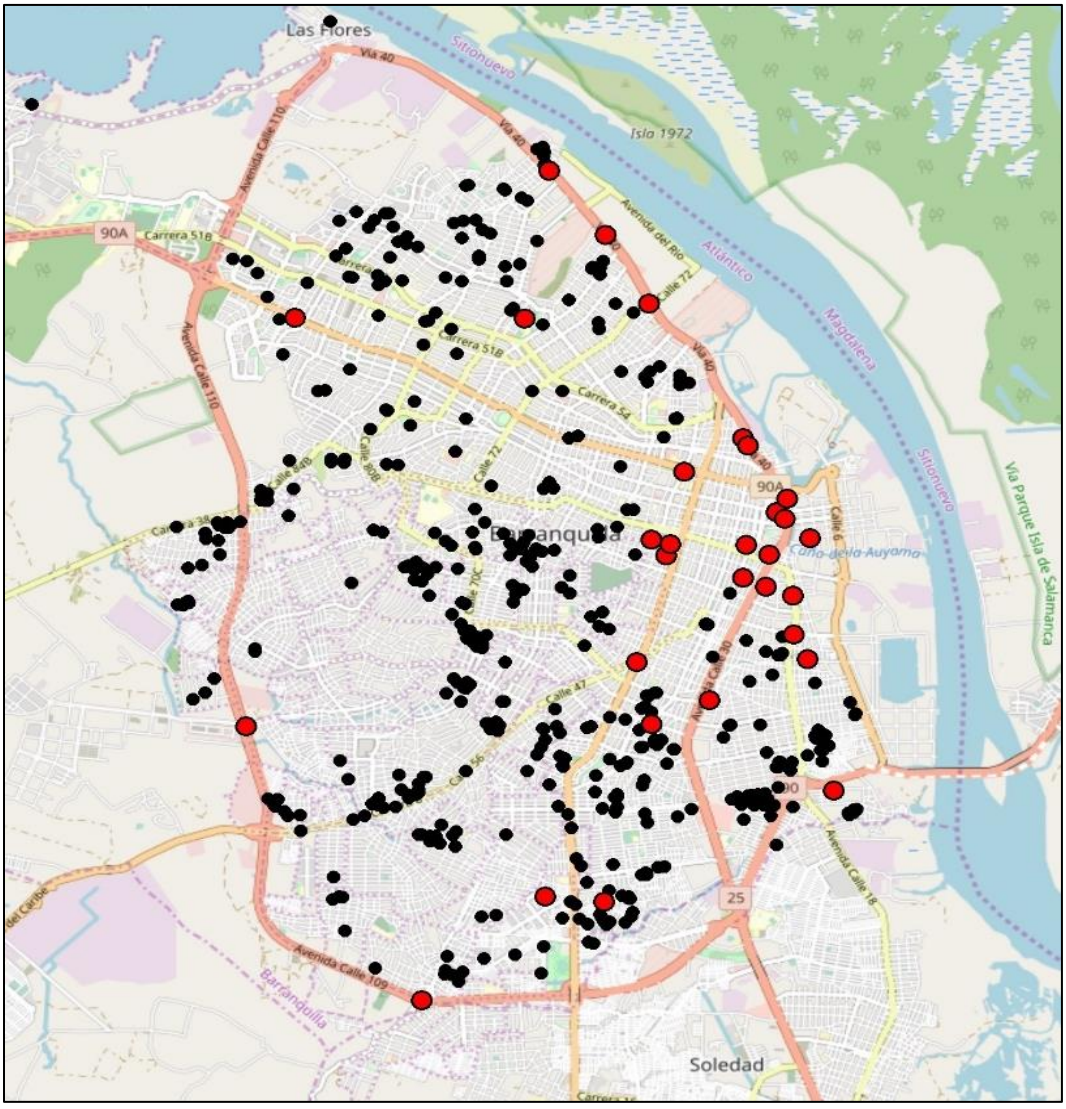


Figure 3.1: Spatial distribution of households and open-air dumps. Barranquilla, 2018.
Note: Each black dot represents a surveyed household. Red dots represent open-air dumps.
Source: author's elaboration.

3.4.1 The contingent valuation method

Methods of evaluating the economic value of non-marketed environmental goods and services are broadly categorised as stated preference methods and revealed preference methods (Hanley et al., 2009). Revealed preference is comprised of techniques such as hedonic price and travel-cost

methods that determine the value of non-market goods by assessing the prices of related commodities in the private market (Hanley et al., 2009). By contrast, stated preference techniques, such as the CVM used here, measure the direct and indirect benefits of environmental non-market goods and services by creating a hypothetical market and gather information on choices over policy options (Guo et al., 2014; Hanley et al., 2009). Monetary values associated to changes in welfare (losses or gains) computed using the CVM correspond to compensatory variation and equivalent variation[22] (Hicks, 1975). Although these concepts were originally developed to explain changes in welfare due to price shifts, they were later extrapolated to analyse changes in quantities or magnitudes (Hanemann, 1991). Related to the theory of consumer demand, the maximum amount that a household is willing to pay provides the value of the policy intervention, whose objective is individual welfare improvement (Arrow, 2001). The amount that individuals are willing to pay is assumed to be cumulative in relation to a specific group of individuals. For instance, the maximum amount that a community is willing to pay is the sum of each household's willingness to pay. Let us assume *i* is the representative head of the household and *k* represents the community of *i* households. Then, for the *i-th* head of the household,

$$\sum_{i=1} WTP_i = WTP_k \qquad \text{Eq. (2)}$$

Assuming the amount a representative head of the household is willing to pay for a utility depends on the income and social welfare of his community. A policy to eradicate open-air dumps is the amount that keeps the utility level the same as before payment. The maximum amount a head of the household is willing to pay for the welfare improvement provided by the eradication of open-air dumps is shown in Figure 3.2. This improvement is represented by the gap between Y_0 and Y_1, measured as Y_0 - Y_1, and where the curve U_0 shows the original utility level and U_1 denotes the improvement in welfare as a result of the intervention. The graph infers that disposable income is lower after the improvement in urban cleaning ($Y_1 < Y_0$), due to payment. However, the head of the household still maintains the same level of utility denoted by U_0, now with greater urban cleanliness. If the head of the household had to pay more than Y_0 - Y_1, the loss in income would be compensated by the increase in welfare due to greater urban

[22] The compensatory variation is defined as the maximum monetary amount an individual would be willing to pay to maintain his/her current level of welfare. On the other hand, the equivalent variation is defined as the minimum monetary amount that an individual would be willing to accept to renounce his/her current level of welfare.

cleanliness. This implies that the amount a head of the household is willing to pay determines the value the head of the household attributes to urban cleaning in relation to level of income and neighbourhood satisfaction. Since public cleaning is not a tradeable good, like most commodities, it is impossible to obtain direct valuations of the willingness to pay. Hence, I must resort to a non-market valuation technique. I decided to use the CVM, since it elicits non-commodity values directly and has been used widely in the context of environmental goods and services and amenities.

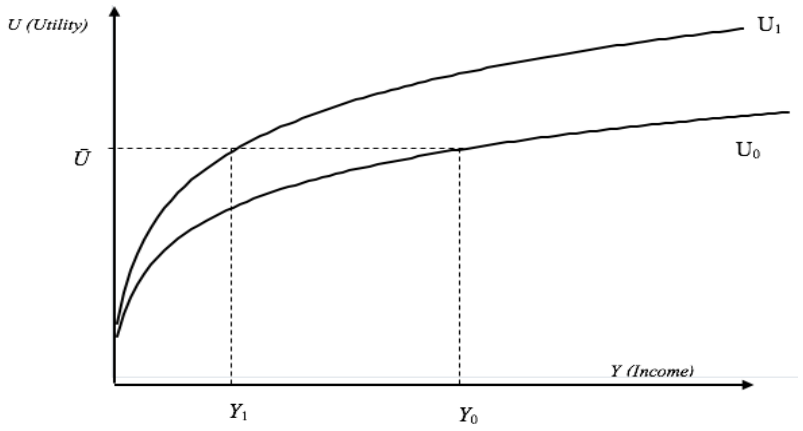


Figure 3.2: The monetary amount a representative head of household is willing to pay
Source: author's elaboration

Consider that the utility of the representative head of the household depends on social factors affecting his community, i.e., frequent contact with neighbours, trust in local authorities, and neighbourhood satisfaction. Let us label these factors *S* and denote by *R* the household's income. For a given level of income, the utility of the representative head of the household would be,

$$U = u\,(S, R) \qquad \text{Eq. (3)}$$

Under a neo-classical framework, given the prices of the elements comprising the utility function, P_S and P_R, the combination of feasible bundles is defined by the budget line satisfying that combination of prices. As Choe and Fraser (1999) point out, the representative head of the household maximizes his utility by choosing the consumption level of the private goods vector given by *R* but cannot choose *S* since such factors are beyond his control. Considering this restriction, the indirect utility function of the representative head of the household can be expressed as

$$V = v\,(\bar{Y}, S, R) \qquad \text{Eq. (4)}$$

where $\bar{Y}$ is the disposable income of the head of the household. Assuming $\bar{Y} > 0$, I use the indirect utility function to obtain the monetary values of the changes in the level of cleanliness of the city. Compensatory variation (CV) is the monetary amount that the representative head of the household is willing to pay for urban cleaning or the improvement in the social environment, holding constant the same level of utility given in equation 4.

If *S* represents the initial level of urban cleaning, and I assume that *S′* is an improvement made by the eradication of open-air dumps, where *S′* > *S*, then the willingness to pay for the improvement in urban cleaning *S* a *S′* is given by,

$$v\,(\bar{Y} - CV, S', R) = v\,(\bar{Y}, S, R) \qquad \text{Eq. (5)}$$

or

$$v\,(\bar{Y} - WTP, S', R) = v\,(\bar{Y}, S, R) \qquad \text{Eq. (6)}$$

The CV or WTP defined in equations 5 and 6 are the same as the Y_0 - Y_1 gap defined in figure 1. This implies that the maximum amount the representative head of the household would be willing to pay for a policy to eradicate the open-air dumps is equal to its CV.

It is worth noting that the CVM has been regarded as a controversial and unreliable method in relation to its results, since it is unclear how respondents will react when the hypothetical question becomes reality.[23] However, previous literature still shows that it is a valid method and recent methodological improvements support the reliability of its results.[24]

3.4.2 Elicitation of households' preferences

The scenario described to each of the heads of household was the following:

> "The proliferation of open-air dumps within the perimeter of the District of Barranquilla is of concern to local authorities. Currently, the Prefecture of Barranquilla recognizes the existence of 30 open-air dumps within the city limits. These open-air dumps are

[23] See Lo and Jim (2015) and Neuteleers and Engelen (2014) for detailed criticisms.

[24] Recent developments have been employed in eliciting individuals' preferences via questionnaire. For instance, the inclusion of feedback loops in the questionnaires and the incorporation of respondents' uncertainty about their answers into further analyses of willingness to pay estimates are some innovations that have improved the CVM and have been already validated. See, for example, Bennett et al. (2017) and Van Houtven et al. (2014).

deteriorating the urban landscape, generating pollution, and causing respiratory diseases in the most vulnerable population. The Prefecture of Barranquilla is currently considering a programme aimed at eradicating these open-air dumps. The time horizon for eradicating all open-air dumps is three years. In order to eradicate all open-air dumps within the perimeter of the city, households would have to assume a monthly increase in water, cleaning and sewage bills for three years to help finance the project."

This description was followed by the question regarding heads of household's willingness to pay: "Would you be willing to pay for this programme, which would eliminate open-air dumps in Barranquilla?" Following the willingness-to-pay question, respondents who answered affirmatively had to select the value the household would pay per month through a payment card. The payment card included fourteen monetary figures ranging from COP $50.00 to COP $3,000.00. These amounts were the modes found on data this study gathered from a pilot.

3.4.3 Determinants of the willingness to pay (WTP)

The selection of the key explanatory variables in my WTP model was heavily influenced by the hypotheses tested in the literature (Afroz et al., 2009; Awunyo-Vitor et al., 2013; Jones et al., 2010; Macias & Williams, 2016; Marbuah, 2016; Nyarai et al., 2016). A head of household's WTP for something depends largely on their income level, regardless of the purpose. Given that public cleaning represents improved environmental quality, following Wheelan's (2019) reasoning, I can classify the eradication of open-air dumps as a superior good; that is, the income-elasticity of the demand for improved environmental quality must increase proportionately more than income. Thus, a higher income could compel the heads of household to pay more for the public cleaning service and thereby increase their property values and make their neighbourhoods more liveable. Hence, income is expected to have a positive impact on the contribution to a programme to eradicate open-air dumps.

Age is another important determinant of head of the household behaviour when facing an environmental policy. In general, older heads of household generate less waste compared with younger ones (Challcharoenwattana & Pharino, 2016; Xu et al., 2016). This hypothesis rests on the fact that elderly people normally adopt an economically cautious way of living, implying less

waste, and therefore less possibilities of poor disposal behaviour. In consonance with this fact, age is expected to have a negative influence on the WTP for a programme to eradicate open-air dumps. Like age, education creates head of the household's awareness to become more engaged with the environment. In Latin American countries, low levels of education constitute a serious barrier to engagement in sustainable waste management systems (Hettiarachchi et al., 2018; Padilla & Trujillo, 2018; Troschinetz & Mihelcic, 2009). Hence, I anticipate that higher levels of education imply higher awareness towards environmental problems affecting the neighbourhoods, resulting in a greater WTP.

Indeed, a higher educational attainment implies a higher probability that a person would be potentially more concerned about the environment in general, and thus such an individual would be willing to cede by either paying a monetary contribution or by shifting their attitudes towards the benefit of a clean urban environment (Macias & Williams, 2016; Marbuah, 2016). Likewise, the persistence of open-air dumps could be explained by a lack of environmental awareness. A low sense of awareness among residents to properly manage solid waste and their lack of knowledge on the hazards of ill-disposed waste are key indicators in explaining illegal dumping behaviour (Macias & Piniarski, 2016; Nyarai et al., 2016; Zhu et al., 2008). In this sense, it is expected that the more concerned individuals are about the urban environment and if people, in general, have a greater knowledge of the adverse consequences of living with open-air dumps, the more inclined they will be towards a pro-environmental behaviour, and hence their willingness to contribute for a healthy environment will be higher.

It is also hypothesised in the literature that socially cohesive communities which have a strong sense of social and place identity will be more supportive of environmentally sustainable attitudes and behaviours compared with those communities where cohesiveness and social and place identities are weaker (Pol, 2002). The analysis therefore anticipates that social capital, defined as the set of values at a neighbourhood level that enable individuals to trust each other and obtain achievements working together, play a key role in understanding illegal dumping. Key elements of social capital explored in previous works include individual trust, institutional trust, community participation and political involvement (Coleman, 1990; Putnam, 1995). This literature reveals that communities that have high levels of social capital show a greater capacity

for cooperation to achieve environmental objectives (Hurlbert et al., 2017; Jones et al., 2009). In the case of illegal dumping, there is evidence that neighbours' social cohesion and satisfaction with the neighbourhood act as determinants of citizens' perceptions towards environmental policies (Caniato et al., 2014; Jones et al., 2010; Mazzanti & Montini, 2014). Thus, social cohesion is regarded as important in terms of presupposing a set of shared values that enables interaction between members of a neighbourhood. In general, more social cohesion among the household is expected to be a positive factor in their WTP for the environment. Nevertheless, the collective action of households and neighbourhoods depends largely on the credibility in the local institutions as they are the implementers of the environmental policies that will ensure the city's sustainability (Macias & Williams, 2016). Narayan and Cassidy (2001) defined institutional trust "as the extent to which citizens have confidence in public institutions to operate in the best interest of society and its constituents." In effect, the legitimacy and the degree of responsiveness from the households regarding the environmental policies and their successful implementation depends on the people's level of trust on government's actions. That is, the lower the heads of household's level of trust in the responsible institutions for the environment, the lower their valuation towards the environmental good or service in question. As a corollary, factors like social cohesion, individual trust, and institutional trust are expected to be relevant when it comes to policy implementation, despite heads of household heterogeneity. These variables also imply a certain degree of generosity among heads of household within a neighbourhood, and the evidence points to the positive effect of these factors on behalf of collective action (Brooks, 2005; Macias & Williams, 2016).

The heads of household's heterogeneity can also be captured through socio-demographic variables like civil status and household size. Previous studies on household behaviour found that married couples and households integrated with large extended families, especially those with children and/or elderly people, are more likely to show a positive impact on waste management (Mukama et al., 2016; Pakpour et al., 2014). I expect that the larger the household, the more willing to pay for eradication of open-air dumps. Among heads of household's heterogeneity, the minimum distance from a household to the nearest open-air dump is another important factor. I hypothesize that households closer to an open-air dump are more adversely affected than those located further away, particularly with regard to health impacts (Ogunrinola & Adepegba, 2012)

or household disposal costs (Awunyo-Vitor et al., 2013), which may be reflected in an overestimation of their WTP.

3.5 Econometric strategy

I opted for dividing the analysis into two stages. Using a probit model, the first stage estimates the determinants of heads of household's willingness to join (WTJ) the programme for the eradication of open-air dumps. The main reason for choosing the probit model over the logit model is the sample size, which is large enough to asymptotically assume there is normality in the stochastic error. However, a logit estimation would have also been valid, because both logit and probit provide similar statistical results for large samples (O'Connell & Amico, 2018). The second stage of the analysis uses a truncated tobit model to estimate the determinants of the amount heads of household are willing to pay for eradication of open-air dumps. The dependent variable in the probit model is the head of the household's decision to participate in the policy of eradication of open-air dumps. This variable is binary in nature, taking numeric value 1 for participants, and 0 for non-participants. In the truncated tobit, the dependent variable is the amount of money participants chose for the three-year programme duration. I use the same set of explanatory variables in both models.

I based my estimations on the threshold decision-making theory, which suggests there is a response threshold when any individual faces a decision-making situation dependent upon several factors (Robinson & Hammitt, 2011). Below the threshold, I would not expect a response from individuals. A probit model may well describe such a decision through the following regression equation

$$WTJ_i^* = \beta' x_i + u_i \qquad \text{Eq. (7)}$$

where WTJ_i^* is the unobservable head of the household's WTJ for the eradication of open-air dumps. The only thing observable is the binary response of the WTJ by the head of the household, which can be expressed as

$$WTJ_i = 1 \text{ if } WTJ_i^* \geq T_i^*$$
$$WTJ_i = 0 \text{ if } WTJ_i^* < T_i^* \qquad \text{Eq. (8)}$$

where T_i^* is the threshold value of the set of explanatory variables x_i.

In this model, the observed values of WTJ are just the outcomes of a binomial process with probabilities given by equation 7, which varies from sample to sample, depending on the value adopted by x_i.

In my formulation, the probit model provides information only concerning the head of the household's decision to participate (or not to participate, WTJ) in the eradication of open-air dumps. However, to estimate the determinants of the amount the heads of household are willing to pay (WTP), I resort to the tobit model.[25] Indeed, in the tobit model the dependent variable WTP_i^* is partially observed and assumes zero values for a substantial segment of the sample. That is, WTP_i^* is observed if $WTP_i^* > 0$ but is not observed if $WTP_i^* \leq 0$. Censored regression, like the truncated tobit model, is generally applied when the explained variable has a large number of zeros, a condition commonly known as "corner solution". The tobit model enables us to identify the factors that actually determine how much the heads of household are willing to pay for the eradication of open-air dumps. Following Hill et al. (2018), the formulation of the tobit model for my purposes is as follows:

$$WTP_i^* = \beta x_i + \varepsilon_i \qquad \text{Eq. (9)}$$

where WTP_i^* is the unobservable WTP for the eradication of open-air dumps. What is observable now is the response of WTP, which can be written as

$$WTP_i = WTP_i^* + \beta x_i \text{ , if } WTP_i^* \geq 0$$
$$WTP_i = 0, \text{ if } WTP_i^* \leq 0 \qquad \text{Eq. (10)}$$

where WTP_i is the head of the household's WTP for eradication of open-air dumps; x_i is the vector of explanatory variables; β is the vector of parameters to be estimated; and ε_i is the stochastic term, which I assume $\varepsilon_i \approx \text{NID}(0, \sigma^2)$.

Several heads of household in the sample answered "No" to the WTP to implement a policy to eliminate open-air dumps, while others declared their maximum WTP to implement such a

[25] The tobit model was developed by Tobin (1958). Since its inception it has been applied to numerous social phenomena in which cross-sectional data sets reflect zeros in some dependent variable observations.

policy. For this latter group, the WTP is a random variable that has its own probability distribution.

$$Prob\ (WTP_i = 0) = Prob\ (\varepsilon_i < \beta x_i) = 1 - F\ (\beta x_i)$$

$$Prob\ (WTP_i > 0) = 1 - \ Prob\ (WTP_i = 0) = F\ (\beta x_i) \qquad \text{Eq. (11)}$$

where *Prob* is the probability distribution and $F\ (\beta x_i)$ is the cumulative density of probability function. The marginal effect in the probability of WTP for the eradication of open-air dumps as the vector of explanatory variables X_i changes, is as follows,

$$\frac{\partial E\ (WTPi)}{\partial Xi} = F\ (Z)\ \beta \qquad \text{Eq. (12)}$$

where, $F(z)$ is the cumulative distribution of Z, Z is the Z-critical point for the area under the Gaussian curve, β is the vector of estimates.

3.6 Results

As presented in Table 3.1, out of 815 heads of household interviewed, 42.8% were male while 57.2% were female. Ages range from 18 to 83 years, with an average of 46.8 years. The survey results also showed that 38.7% of the heads of household were married, while the remaining 61.3% were unmarried. On average, household size was about 4.7 persons, above the national urban average of 3.4 persons (DANE, 2017), with a minimum of 1 person and a maximum of 18 persons per household. The educational status of the sample ranges from 5 to 22 years of schooling, with an average of about 13.8 years. The household survey found that 0.4% of the sampled heads of household terminated their studies in elementary school, while 28.4% attained post-graduate level. The household average income was COP $2,007,388, slightly lower than the nation's average urban household income of COP $2,167,076 (DANE, 2017). More than half of the sample (56.5%) affirmed that paying the "carromuleros" is the most common manner for residents to dispose of their solid waste; and throwing solid waste into flash-floods during rainstorms was classified as the second most prevalent method of illegal disposal (27.5% of the sample). Less importantly, heads of household (13.8%) considered walking or driving to an open- air dump to be another method. When asked about whom they considered to be the largest contributor to open-air dumps, 40% of the heads of households mentioned informal garbage

collectors, 31.2% stated residents and 13.1% identified the refuse left behind by building construction, remodelling and demolitions. Informal garbage collectors are thus considered the main contributors because of residents' bad habits. Heads of household considered respiratory problems, followed by the emission of bad odours caused by a dump in the neighbourhood, to have the greatest negative impact on the quality of life, while the presence of undesired animals had the lowest impact. In terms of environmental hazards, respondents recognised mainly, uncontrolled growth of bushes, soil pollution, and water pollution. When asked which services the Mayor's Office could implement to deter illegal waste disposal, the heads of household responded that a ban on informal garbage collectors is most important, followed by the provision of solid waste containers in specific locations throughout the city and, finally, an increase in the public cleaning workforce, coordinated in conjunction with the consortium Triple AAA.

Table 3.2: Summary of descriptive statistics

Variable name	Variables' breakdown	Description	Percentage	Mean	St. Dev.	Min	Max
Age		Head of household's age		46.81	14.94	18	83
	Young (< 26 years)		7				
	Mature (26-59 years)		72				
	Senior (≥ 60 years)		21				
Male		Head of household is male		1.57	0.50	0	1
	Male		42.7				
	Female		57.3				
House		Head of household's family lives in a house		0.68	0.47	0	1
	Yes		67.9				
	No		32.1				
Time_house		Time the household has lived in the house		22.7	16.2	0.1	78
	< 10 years		28.7				
	< 25 years		26.6				
	< 50 years		35.2				
	< 80 years		9.5				
Time_neighbourhood		Time the household has lived in the neighbourhood		27	16.5	0.2	78
	< 10 years		20				
	< 25 years		25.3				
	< 50 years		43.9				
	< 80 years		10.8				

Variable name	Variables' breakdown	Description	Percentage	Mean	St. Dev.	Min	Max
Distance		Household's distance to the nearest open-air dump		1296.7	809.8	6.58	6282.2
	< 100 metres		1				
	< 500 metres		17				
	< 1000 metres		23				
	< 2000 metres		39				
	< 3000 metres		18				
	> 3000 metres		2				
Concern		Head of household is concerned for the environment		0.59	0.49	0	1
	Yes		59.1				
	No		40.9				
Awareness		Head of household is aware of the illegal dumping of wastes in his/her neighbourhood		0.40	0.49	0	1
	Yes		39.7				
	No		60.3				
Witnessing		Head of household has seen people throwing wastes in open-air dumps		0.55	0.50	0	1
	Yes		55.1				
	No		44.9				
Life_assessment		Head of household's self-rate assessment of his/her own life		0.89	0.32	0	1
	Good		88.5				
	Not good		11.5				
Health_assessment		Head of household's self-rate assessment of his/her own health condition		0.24	0.43	0	1
	Good		24.4				
	Not good		75.6				
Household_size		Number of the members of each household		4.72	2.12	1	18
	Children (under 5 years)		18				
	Children (between 5 and 12 years)		35				
	Teenagers(between 13 and 18 years)		20				
	Adolescents(between 19 and 25 years)		40				
	Adults(between 26 and 59 years)		93				
	Seniors (60 years or more)		50				
Marital_status		Head of household current civil status		0.39	0.49	0	1
	Married		38.7				
	Other		61.3				
Education		Head of household highest level of schooling achieved		13.87	2.62	5	22
	Elementary		0.4				
	High-school		12.6				
	Professional		58.6				
	Post-graduated		28.4				
Income		Household's total average monthly income		2040001	1863907	607145	9954849
	Less than COP $ 1 million		42.1				
	Between COP $ 1 million and $ 3 million		41.2				
	Between COP $ 3 million and $ 5 million		9.6				
	More than COP $ 5 million		7.1				

Variable name		Variables' breakdown	Description	Percentage	Mean	St. Dev.	Min	Max
Social Capital	*Neihbours_care*		Neighbours take care each other		0.78	0.42	0	1
		Yes		77.7				
		No		22.3				
	Neighbours_meetings		Neighbours meet each other at least once a week		0.86	0.35	0	1
		Yes		86.1				
		No		13.9				
	Neighbourhood_satisfaction		Head of household is satisfied with the neighbourhood where s/he lives		0.80	0.40	0	1
		Yes		80				
		No		20				
	Walking_safely		It is safe to walk alone late at night in this neighbourhood		0.21	0.41	0	1
		Yes		21.4				
		No		78.6				
	Community_participation		Head of household is involved in community activities		0.56	0.50	0	1
		Yes		55.7				
		No		44.3				
	Institutional_trust		Head of household trusts on local government		0.67	0.47	0	1
		Yes		66.7				
		No		33.3				
	Environmentalist		Head of household participates in an environmental organization		0.03	0.17	0	1
		Yes		3.1				
		No		96.9				
	Political_activism		Head of household participates in politics		0.25	0.43	0	1
		Yes		24.9				
		No		75.1				

Source: author's elaboration

The willingness-to-pay question was answered "Yes" by 472 (58%) of the heads of household and "No" by 343 heads of household (42%). The reasons heads of household would be unwilling to pay are presented in Figure 3.3. Following the willingness-to-pay question, the respondents who answered affirmatively were asked to choose how much more they would be willing to pay on a monthly basis through a payment card. The payment card included fourteen monetary figures ranging from COP $50.00 to COP $3,000.00.

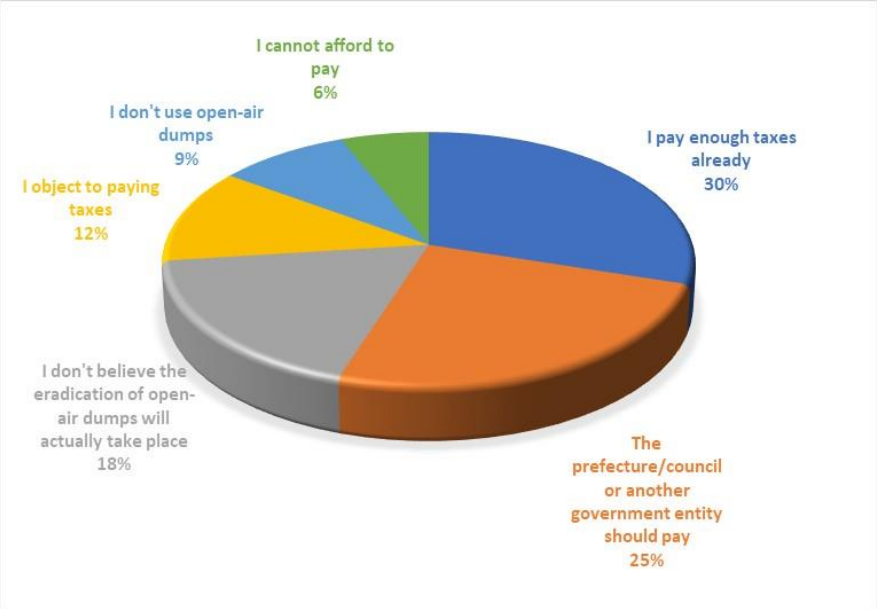


Figure 3.3: Reasons for the unwillingness to pay

Source: author's elaboration

3.6.1 Programme participation

The probit regression results of factors influencing the willingness to join (WTJ) are presented in Table 3.2. The log likelihood ratio (LR) statistic is significant at one percent, which means that it fits considerably better overall than a model with no predictors. Therefore, I can conclude that the logit model used is appropriate to explain the heads of household's WTJ the sanitary intervention.[26] The validity of the logit model in estimating the WTJ for improved waste disposal is consistent with related studies (Awunyo-Vitor et al., 2013; Jones et al., 2010). It is noteworthy here that neither the probit nor the tobit parameter coefficients can be interpreted, therefore, the marginal effects have been calculated for each for both models.

As expected, *Age* was statistically significant at a level of 1% and reflected a negative sign, implying that a one-year increase in the head of household's age reduces the probability of participation by 0.0036. Likewise, the coefficient of *House* was negative and significant at a level of 10%, indicating that heads of household living in houses are less willing to participate, as compared to apartment dwellers. This counterintuitive result is explained by the current

[26] The list of explanatory variables corresponding to either the head of household or the household itself is shown in Appendix I.

preference for apartments in the local real-estate market, as well as high land taxes on houses and security issues. *Distance* is another significant factor influencing the WTJ. As the distance to open-air dumps decreases, the likelihood of a head of the household's WTJ increases; that is, the closer the open-air dump, the greater the household's exposure to its negative effects. However, the marginal effect is almost negligible: each 1km closer to a dump raises the likelihood of a head of the household's WTJ by 0.03%.

As expected, heads of household's environmental concern turned out positive and statistically significant at 10%. However, the households' acknowledgment of the presence of open-air dumps in the neighbourhood is also related to their likelihood of participation. Indeed, the estimate of *Awareness* was significant and attracted a negative sign, implying that greater awareness of the presence of urban dumps signifies a lesser likelihood of participation. A plausible explanation is that proliferation of dumps may create the perception that local authorities do not properly enforce laws, thus causing distrust in the city's SWMS. However, witnessing illegal waste disposal positively influences the likelihood of participation. The marginal effect of *Witnessing* indicates that every time a head of the household witnesses illegal dumping, the likelihood of participation increases by 18%.

Estimates from variables directly related to social capital like *Neighbours_care*, *Neighbours_meetings*, *Neighbourhood_satisfaction*, *Walking_safely*, *Community_participation*, and *Institutional_trust* resulted positive and statistically significant. The number of household members was positive and statistically significant at a level of 10%. That is, the larger the household, the greater the likelihood of participation. Conversely, the number of years of education showed a negative and significant relationship to the WTJ. This counterintuitive result is possibly explained by a link between education and low levels of trust in local authorities. Higher education could make heads of household more cautious about the effectiveness of local policies. Thus, educated heads of household are less likely to participate, especially if they do not consider themselves participants in illegal dumping. The marginal effect revealed that an additional year of education would decrease the likelihood of participation by about 0.0186. Finally, income was positive and significant at a level of 1%. The higher the head of household's

income, the greater their concern for the environment and urban sanitation, holding other factors constant.

Table 3.3: Determinants of the willingness to join

	Coefficient	Marginal Effect
Age	-0.01	-0.00
	[0.00]***	
Male	-0,14	-0.05
	[0.10]	
House	-0.18	-0.07
	[0.11]*	
Time_house	0.01	0.00
	[0.01]	
Time_neighbourhood	-0.01	-0.00
	[0.01]	
Distance	-0.00	0.00
	[0.00]*	
Concern	0.11	-0.04
	[0.10]*	
Awareness	-0.26	-0.09
	[0.13]*	
Witnessing	0.51	0.18
	[0.13]***	
Marital_status	0.11	0.04
	[0.10]	
Household_size	0.04	0.014
	[0.02]*	
Education	-0.05	-0.02
	[0.02]**	
Income	0.00	2,32E-08
	[3.18E-08]**	
Life_assessment	0.22	0.08
	[0.15]	
Health_assessment	-0.12	-0.04
	[0.12]	
Neighbours_care	0.11	-0.04
	[0.12]**	
Neighbours_meetings	0.23	-0.08
	[0.15]*	
Neighbourhood_satisfaction	0.23	0.08
	[0.12]*	
Walking_safely	0.21	0.08
	[0.12]*	
Community_participation	0.15	0.06
	[0.10]*	
Institutional_trust	0.26	0.09
	[0.10]***	
Environmentalist	0.38	0.14
	[0.29]	
Political_activism	-0.08	-0.03
	[0.11]	
Observations	815	
McFadden Pseudo R2	0.07	
McKelvey-Zavoina Pseudo R2	0.14	

Standard errors in brackets

* $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

Source: author's elaboration

3.6.2 Programme contribution

The tobit model was applied to determine which factors (identified using the probit model) influenced the amount a head of the household was willing to pay. The analysis results are presented in Table 3.3. The model truncation resulted from elimination of heads of household unwilling to pay. The log likelihood ratio (LR) statistic was significant at 1%, confirming that my general model fits considerably better than any model without predictors. The tobit regression results yielded an adjusted Mckelvey-Zavoina's pseudo R-square of 0.55, implying that at least one of the explanatory variables included in the model had a coefficient different from zero. Given this goodness-of-fit measure (adjusted *R*-squared), I conclude that the tobit model's general explanatory power is reliable. All included explanatory variables met the a priori expectations, except education.

The coefficient of *Age*, at a level of 10%, showed a negative and significant relationship with the monetary amount heads of household are willing to pay, possibly explained by the fact that older people generate less waste than younger people, as previously argued. Thus, as *Age* increases by one year, there is a 0.002-point decrease in the predicted value of the amount heads of household are willing to pay. In turn, *Male* was also negative and significant at a level of 10%, supporting the expectation that female heads of household are more likely to participate, as compared with their male counterparts.

The type of housing again yielded significant and negative results, which is unsurprising since house-dwelling heads of household would be willing to pay a lower amount. The reason could be related to high annual taxes on residential land use. As I expected, *Distance* again resulted negative and statistically significant at 10%. Concern for the environment was captured through the variable *Concern*. This estimate resulted positive and significant at a level of 10%, meaning that the higher the heads of household's environmental concern, the higher their likelihood of participation. This result is straightforward, because a higher environmental concern implies a greater commitment to keep neighbourhoods clean, and therefore a higher likelihood of contributing to the eradication of open-air dumps.

Table 3.4: Determinants of the willingness to pay

	Coefficient	Marginal Effect
Age	-8.83	-0.00
	[4.76]*	
Male	-226.99	-0.06
	[124.40]*	
House	-292,729	-0.07
	[140.89]**	
Time_house	-0.22	-0.00
	[7.22]	
Time_neighbourhood	0.35	0.00
	[6.99]	
Distance	-0.08	-0.00
	[0.08]*	
Concern	212.37	-0.05
	[125.19]*	
Awareness	-424.29	-0.11
	[166.02]**	
Witnessing	713.46	0.18
	[162.98]***	
Marital_status	87.76	0.03
	[132.81]	
Household_size	52.14	0.01
	[30.71]*	
Education	-47.28	-0.01
	[28.82]*	
Income	0.00	0.00
	[4.01E-05]***	
Life_assessment	350.52	0.09
	[199.26]*	
Health_assessment	-143.36	-0.04
	[152.62]	
Neighbours_care	218.90	-0.05
	[148.45]*	
Neighbours_meetings	500.05	-0.12
	[189.43]***	
Neighbourhood_satisfaction	427.74	0.11
	[164.05]***	
Walking_safely	237.04	0.06
	[147.14]	
Community_participation	-153.76	0.04
	[123.36]*	
Institutional_trust	125.54	0.03
	[131.50]***	
Environmentalist	603.06	0.14
	[335.85]*	
Political_activism	-56.42	-0.01
	[141.17]	
Observations	815	
McKelvey-Zavoina Pseudo R2	0.55	

Standard errors in brackets

* $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

Source: author's elaboration

Heads of household's awareness of the presence of open-air dumps in the neighbourhood (*Awareness*) and being witness of illegal dumping of wastes (*Witnessing*) again yielded significant results and obtained the same signs achieved with the probit model. As previously

mentioned, being aware of the presence of open-air dumps could be related to perceived government inaction on public sanitation issues. Nevertheless, once a head of household witnesses illegal dumping, the likelihood of participation increases by 17%. The variables representing social capital yielded significant results and their expected corresponding signs, except *Community_participation*. The negative sign of this variable is consistent with the social capital theory described earlier. I hypothesize that the negative relationship between community participation and the amount heads of household are willing to pay is deeply rooted in low social trust. This result imply that although neighbours in Barranquilla see each other frequently, it is insufficient to create a sense of collective action to contribute towards sanitation. Expectedly, being a member of an environmental organization increases the probability to contribute with higher taxes in Barranquilla. In fact, being an environmental activist increases the likelihood of contribution by 14%. However, just 3.1% of the heads of household surveyed considered themselves environmentalists.

Since I expected a positive and statistically-significant relationship between education and the amount of money the heads of household are willing to pay, the negative coefficient sign and its insignificance require further explanation. I suggest that education itself does not have enough explanatory power to influence the practice of pro-environmental behaviour, unless it is combined with a high level of trust in the institutions responsible for policy implementation. To confirm this argument, I interacted *Education* and *Institutional_trust* and the resulting coefficient yielded a significance level of 5% and indicated a positive sign (see Appendix I). In sum, trust in local government is critical when considering any policy to improve human welfare. On the other hand, the household income coefficient was positive and significant, consistent with evidence found in the environmental economics literature regarding the positive relationship between income and demand for improvements in environmental quality.

3.6.3 Willingness to pay

Table 3.4 summarizes the main results from households' WTP per income. The average monthly WTP is COP $ 852.4 (US $ 0.2). Analysis of low-income households (SEC 1 and 2) indicated a monthly WTP in the range of COP $191.9 – 1,995. Similarly, an analysis of middle-income

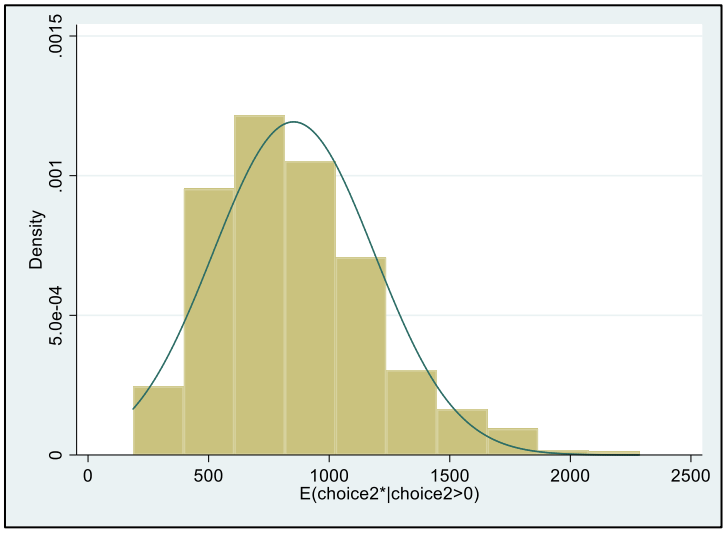
households (SEC 3 and 4) resulted in a greater monthly WTP of between COP $217.5 and 1,846. Corresponding to the wealthiest households, SEC 5 and 6, the estimation shows a monthly WTP in the range of COP $370.1 – 2,234.9.

Table 3.5: Willingness to pay for the eradication of open-air dumps

	Total	Low Income	Middle Income	High Income
WTP	852.4	784.7	843.5	1142.8
WTPmin	191.2	191.9	217.5	370.1
WTPmax	2234.9	1995.4	1846.4	2234.9

Monetary figures in Colombian currency (COP)
Source: author's elaboration

In general, the analysis per SEC confirmed that heads of household were willing to pay a monthly sanitation bill increase to fund a programme to eradicate open-air dumps in Barranquilla. Figure 3.4 shows the histogram of the WTP values found in the sample.



Mean = 852.4, Standard Deviation = 334.5, *N* = 815

Figure 3.4: Monthly monetary increase heads of household are willing to pay for the eradication of open-air dumps
Source: author's elaboration

3.7 Discussion

This chapter shows that most heads of household surveyed in Barranquilla recognize that paying the illegal garbage collectors is the most common way for residents to dispose of their solid waste, followed by throwing solid waste into flash-floods during rainstorms. This finding on the challenge of eradicating illegal dumping as a problem of deterring the bad habits of residents is consistent with other solid waste management studies in developing countries, for example Achu et al. (2015) in Nigeria and Shraddha (2017) in India. Nevertheless, I also show that residents recognise the need for local stronger action by implementing a ban for illegal garbage collectors and/or increasing solid waste containers, in order to address some of the key problems associated with illegal dumps such as impacts on human health, bad odours and associated populations of unwanted animals. Because the benefits of eradicating illegal dumping are potentially so great, this study evaluates the residents' willingness to pay for a sanitary scheme that improves solid waste management services and identifies the socioeconomic and environmental conditions that determine their engagement and level of contribution.

I found that most of the interviewed heads of household were willing to participate (contributing to the hypothesized fee) in a policy scheme that eradicates illegal open-air dumps, which indicates a preference for living in healthier conditions. The willingness to participate was shown to be affected by type of housing (e.g., apartment, house, etc.), distance to the nearest open-air dump, level of environmental concern, awareness of illegal dumping, witnessing the illegal dumping of wastes, satisfaction and involvement with the neighbourhood, neighbours' reciprocity, and institutional trust, together with a set of sociodemographic characteristics such as household size, education, age and income. This shows the importance of social capital as cohesion and satisfaction with the neighbourhoods in initiatives to stop illegal disposal of solid waste in a Latin America urban setting. This complements the evidence on the role of social capital in other regions. For example, Zhang and Zhao (2019) found that social capital increases the households' possibilities of supervision of waste disposal activities in four suburb areas of China. Similarly, in an African context, Nyarai et al. (2016) observed the households' lack of cooperation and awareness, and their low community participation as the main challenges to solve the problems of the local waste management system in Mutare, Zimbabwe. However,

Awunyo-Vitor et al. (2013) found that households' satisfaction with the neighbourhood was not significant in explaining their participation in an improved social waste disposal services in Kumasi Metropolis, Ghana.

The factors influencing the amount households were willing to pay to eradicate illegal dumping were determined using a tobit model, and its determinants included environmental concern, awareness of illegal dumping, witnessing illegal dumping, and socioeconomic characteristics such as age, gender, type of housing, education and household income, as well as social capital factors such as satisfaction with the neighbourhood, reciprocity between neighbours, community involvement in neighbourhood activities, and membership to an environmental association. Contrary to expectations, I found that educated heads of household are less likely to be willing to contribute to an increased waste disposal fee for the eradication of illegal dumping. This contrasts with some of the CVM reporting on waste management improvements, which find a positive effect on the WTP of the respondents (e.g., Awunyo-Vitor, et al. 2013; Boateng et al., 2019). This result may be due to the heads of household being more cautious in relation to their expectations regarding the effectiveness of any future implementation of eradication measures, or that they believe that this should be the sole responsibility of the government. This explanation is consistent with the positive effect of institutional trust on the WTP of Barranquilla households. This complements the findings of early studies as Murad et al. (2007) and Afroz et al. (2009), which find a positive effect of the satisfaction on the present waste collection and disposal services on the WTP towards potential improvements in Kuala Lumpur and Dhaka, respectively.

The results found a positive but not substantial willingness to pay by the heads of household for eradication of illegal open-air dumps, with mean values of COP $852.4 (US $ 0.2) per month (i.e., this is US $ 7.2 per the 3-year programme). This low WTP was also found in studies. For example, Afroz et al. (2009) finds a similar value of (US $ 0.18) per month and household in Dhaka, Bangladesh. Awunyo-Vitor et al. (2013) and Boateng et al. (2019), found that the majority of their respondents were willing to pay $ US 0.94 per month in Kumasi, and other major cities in Ghana, such as Accra, Takoradi, and Tamale. As these authors argue, the low WTP could be associated with the lack of awareness on (*i*) the impacts of waste management on

the socio-development of a nation, (*ii*) the existing laws, and (*iii*) the need of imposing the polluter pay principle to address pollution externalities, which in the case of Barranquilla, emerges from illegal dumping. Afroz et al. (2009) justify its findings on WTP as a reasonable amount given the existing waste collection charge. Cowee and Curtis (2010) also found a similar monthly WTP for illegal dumping sites clean up in public lands of US $ 0.315 in Nevada. Other authors have found higher monthly WTP values for waste management improvements, such US $ 1.9 in Enugu State, Nigeria, and US $ 2.9 in Kuala Lumpur Malaysia (Fonta et al., 2007; Murad et al., 2007). The aggregate value of WTP of the respondents in Barranquilla given the total number of households (252,760) is COP $7.8 billion (US $ 1,934,827).

3.8 Conclusions

This chapter sheds light on the heads of household's attitudes and willingness to contribute towards the implementation of a sanitary programme to eradicate the critical open-air dumps that prevail in the city of Barranquilla. Overall, this work highlights the relevance of social capital aspects such as collective awareness and institutional trust to curb the phenomenon of illegal disposal of waste, which is consistent with the evidence on solid waste management (e.g., see Hänninen (2018) in relation to recycling behaviour and Zhang and Zhao (2019) on participating on community waste disposal supervision). My findings suggest that residents in Barranquilla view the eradication of illegal dumping to be primarily the responsibility of local government rather than as a societal responsibility. Therefore, as a policy implication, this analysis suggests that strict sanitary laws must be enacted and widely communicated to encourage the collective engagement of residents. For instance, the city's Integrated Solid Waste Management Plan 2016-2027 requires revision in areas that promote the participation of households in the city's waste management system in order to instil collective responsibility towards the negative externalities posed by open-air dumps. Moreover, the results outline how the education of the heads of household can be an important starting point to support a public eradication programme. This finding also suggests that the plan should incentivize waste management education and should promote source-separated recycling through workshops to strengthen the first stage of solid waste management. In addition, the prefecture's website could provide an abbreviated and

educational version of the plan accessible to all residents. Greater efforts in governance transparency and more frequent contact with community leaders would facilitate the building of a long-lasting, trustworthy relationship between parties. This study concludes that illegal dumping is perceived as a major public and environmental health challenge, and, there is evidence that enhancing the social fabric will increase support for local policies to eradicate open air dumps.

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Chapter 4: Green and grey infrastructure for flood risk management in Barranquilla, Colombia. Assessing the potential implementation of a sustainable urban drainage system

4.1 Abstract

This study analyses the determinants of households' preferences for implementing a sustainable urban drainage system (SuDS) to cope with the phenomenon of flash-floods formation in Barranquilla. Recent climate change literature ranks Barranquilla as the world's second most rainfall flood-prone city for the year 2050. I perform a discrete choice experiment on a large sample of households to estimate their willingness to pay (WTP) for three benefits of a SuDS, which would reduce harm from flash-floods in terms of reduction in the number of fatalities, improvements in vehicular mobility and pedestrian mobility. I calculate the WTP values for each benefit and found that WTP values varied largely because of the heterogeneity of households' preferences. The results reflected that there is a positive relationship between heads of households' socio-demographic factors such as being older, male, married, and wealthier with their WTP for SuDS implementation and its associated benefits. In addition, results show a positive relationship between perceived risk and risk communication and the utility households derive from SuDS implementation. This study provides evidence that it is important to enhance the risk communication between local authorities and households so as to raise awareness about how to prevent the consequences of flash-floods. Therefore, local policymakers and planners must provide all relevant information about the social benefit of the flash-flood mitigation measures framed in the SuDS.

Keywords: green infrastructure; stormwater management, pluvial flooding, SuDS, household analysis; Latin American cities

4.2 Introduction

In a milieu of climate change, urban planners have the challenge to search for innovative strategies to manage water systems in order to increase the resilience of cities prone to flood risk. In urban areas with frequent storm surges and more intense rainfall events, flood risk can be

considered ‘pluvial flood risk’[27] (Hoang & Fenner, 2017; Mguni et al., 2014). Projected climate change impacts such as rising sea levels and more intense precipitation will severely affect human welfare through sudden changes in food and drinking water availability, and also increasing in pluvial flood risk, among other consequences (Norton et al., 2015). As the evidence shows, the increasing flood risk will be even higher in those cities that nowadays do not count with a proper infrastructure to cope with such an excess of precipitation expected (Veronesi et al., 2014). Hitherto, the strategies to face pluvial flood risk in some cities of developing countries have been centred on enlarging or enhancing the capacity of current water sewer systems (Dong et al., 2017).

While these latter developments have proven to be relatively useful in controlling extreme rainfall events, they are not fully exempt of many economical and technical drawbacks, such as downstream flooding, degraded habitats, and contaminated streams (Sun et al., 2019). These disadvantages associated to the water management systems may potentially put at risk the sustainability of some urban settlements around the world, particularly those with a serious deficit in infrastructure (Charlesworth & Mezue, 2016; Lamond et al., 2015; Veronesi et al., 2014). Therefore, under a climate change context, current water management systems need to be complemented with substantial investments in alternative urban drainage systems (Li et al., 2017).

From a strictly hydrological point of view, impervious surfaces in urban zones increase the risk of flooding by intensifying the amount of runoff (Chui & Ngai, 2016; Li et al., 2017). Therefore, the implementation of SuDS[28], in theory, provides many advantages derived from the partial absorption of runoff through an improved urban green infrastructure (UGI) (Chini et al., 2017). These include mitigation of the urban heat-island effect (Emmanuel, 2005; Norton et al., 2015), better conditions for urban agriculture (Mguni et al., 2014), improvements in water and air quality, the provision of sites for recreation (Ossa-Moreno et al., 2017), and the setting for an inclusive decision-making process regarding urban affairs with the involvement of all

[27] Pluvial flooding occurs when an extremely heavy downpour of rain saturates drainage systems and the excess water cannot be absorbed.

[28] This relatively new approach to stormwater management is referred to as ‘sustainable drainage systems’ (SuDS) in the United Kingdom, ‘low impact development’ in the United States, and ‘water-sensitive urban design’ in Australia. I only use the term SuDS throughout this thesis.

stakeholders (Pelling, 2010). SuDS makes use of several strategies classified within UGI such as green roofs, green areas, and rain gardens, whereas other strategies can fit into the notion of grey infrastructure (GI), such as porous pavements, green pavements, and rain tanks, in order to control surface runoff and reproduce the natural hydrological cycle (Pandit et al., 2017). By releasing the runoff in a prolonged time, these strategies act as bioretention systems, minimising peak flows during heavy rainfall events and creating opportunities for stormwater harvesting (Campisano et al., 2017). In addition, SuDS strategies have proven to be a more flexible and economical option to face the increased flood risk (Frantzeskaki et al., 2012; Mguni et al., 2014).

Environmental strategies associated with human intervention to enhance flood control can generate non-market goods and services, such as water quality improvements or increased recreation opportunities through river landscaping and avoided human health impacts and property damages (Markantonis et al., 2013). It is vital for city planners to determine public preferences towards non-marketed benefits of flood mitigation efforts from SuDS nature-based solutions. Contingent valuation method (CVM) is a stated-preference technique that have been used in flood management in order to estimate respondents' willingness to pay (WTP) for mitigating flooding risk (Zhai et al., 2006). However, CVM is limited in scope as typically compares a status quo with a single management option and cannot capture the trade-offs among the multiple attributes that can characterised individual flood mitigation strategies (Young & Loomis, 2014). An alternative to CVM is the discrete choice experiment technique (DCE), in which the trade-offs of policy alternatives provided by respondents are the informational inputs to further estimate the marginal value for the attributes of environmental goods and services (Hanley et al., 2009).

There is a growing body of work concerning people's WTP for SuDS implementation in highly populated cities. I am interested in studies that have assessed the implementation of SuDS through greening strategies or a combination of green and grey infrastructure; though SuDS do not necessarily include only the implementation of urban greening elements. This chapter contributes to the few studies that have estimated the economic value of some SuDS urban green strategies. For example, Veronesi et al. (2014) implement a DCE on a large representative sample of the Swiss population, with about 70% of the respondents willing to pay in order to

reduce the risk of wastewater overflowing in rivers and lakes. Similarly, using the Decoy Brook catchment in London, UK, as a case study, Ossa-Moreno et al. (2016) perform an economic appraisal of the benefits from SuDS implementation, using an avoided damage approach to monetise its benefits in reducing flood risk. In contrast, Zinia and McShane (2018) estimated the value of the provisioning ecosystem services (food) urban green spaces including rooftop gardens and parks in Dhaka, Bangladesh. Chui and Ngai (2016) uses a CVM to investigate the perception of Hong Kong urban residents on SuDS and the WTP for the broad range of benefits these strategies can provide (reducing the greenhouse effect, improving the environment, providing additional recreational space, improving citizen's heath, or beautifying the city). This study finds that although the participants' understanding of the stormwater management was not strong, they supported the adoption of SuDS, and those respondents who were relatively younger, better educated, wealthier, and had a previous flooding experience had higher WTP. I therefore extend this work by focusing on WTP preferences toward the implementation of SuDS strategies in tropical cities exposed to high levels of rainfall all year long (Charlesworth & Mezue, 2016). In this empirical context, Miguez et al. (2014) discuss how to integrate SuDS strategies, combining grey infrastructure (channelization) and a stormwater management approach, within the urban planning process in the metropolitan region of Rio de Janeiro, to reduce the runoff risk. More related to my work is the recent study of Reynaud and Nguyen (2016) who employ a DCE, to estimate the households' WTP for flood risk reduction in the Nghe An Province, Vietnam, and identify three key attributes that influence the WTP for flood management policies, that is, reduction of economic losses, reduction of human losses, and the political level in charge of implementing the flood management policy. My research contrasts with this work by focusing in an urban context. Moreover, I estimate the WTP for SuDS benefits in terms of mitigating pedestrian and vehicle restriction mobility from flash-floods, not previously studied in the literature.

This study advances the knowledge on households' preferences regarding the transition towards the implementation of some of the SuDS strategies associated with UGI (green spaces, rain gardens, and green roofs), and GI (porous pavement, green pavement, and rain tanks) in a tropical city, Barranquilla, Colombia. Barranquilla is a geographical target for major rainstorms. During the rainy season, from April to November, stormwater runoff flows street surface,

forming flash-floods that drain into the Magdalena river. Moreover, according to Hallegatte et al. (2013, p. 805), Barranquilla is the World's second coastal city most prone to annual losses from floods in 2050 if no protective measures are taken. Two facts contextualize a potential SuDS implementation in Barranquilla. First, in most of its built area, the city has no pluvial sewage system, leaving rainwater runoff above the standard critical levels. Second, slopes are pervasive, especially in the north-western area opposite of the river. Slopes give speed to the river-bound stormwater runoff, reducing catchment times of the runoff and causing flash-floods (Ávila et al., 2016). Consequences include damage to civilian infrastructure, paralysis of certain utilities, and the interruption of vehicle and pedestrian circulation. The city's economic activities slump abruptly during the rainy season. Residents suffer the destruction of their homes, and the death toll is estimated at 2 people on average per year (Ávila et al., 2012, p. 368), especially in the lower SEC. According to the Colombian Institute of Environmental and Meteorological Studies (IDEAM), Barranquilla's annual average precipitation is 850 mm, and the pluviosity measurements are similar in both of the year's seasons. The data also show that the city has a rain intensity higher than 120 mm in a single hour.

I use a DCE to elicit the willingness to pay for implementing six green urban strategies framed within the SuDS concept in Barranquilla. I contribute to the literature by focusing on exploring urban residents' WTP for SuDS perceived benefits in terms of reduction of fatalities and improvements in pedestrian and vehicular mobility taken as DCE attributes. The focus on these benefits can be justified because these were identified by the residents within this analysis as the most influential benefits for mitigating flash-floods in the city. The use of information on social awareness and perceptions on this hazard, gathered through the choice experiment questionnaire, offers greater insights in the determinants of the residents' WTP for SuDS, that contributes to previous research, and can be informative to policy makers. The DCE findings suggest the city residents perceive the value of the social benefits of implementing SuDS, as a potentially cheaper and more sustainable approach to flood risk in the long run than GI (channelization), particularly regarding the improvements in mobilization. Policy makers should acknowledge the role of risk communication in the utility households derive from SuDS implementation.

4.3 Literature review: The need to understand social perceptions of SuDS

One of the most pressing challenges of urban sustainability nowadays is precisely the transition from hard infrastructures to more ecological ones. Pandit et al. (2017) classify SuDS and UGI techniques as an example of what they call 'infrastructure ecology'. According to Pandit et al. (2017), the complex interrelationships between stormwater management, green infrastructure, and socio-economic development function analogous to natural ecological systems. Besides the commonly known benefits of flood control, stream bank restoration, and erosion control, these authors mention some other co-benefits of SuDS/UGI implementation such as reduced air and water pollution, decreased heat mortality, reduced heat island effect, increased property values, and a higher aesthetic value of the neighbourhoods. Indeed, Ward Thompson et al. (2013) show how UGI may also help improve the perception of local residents on the quality of the neighbourhood (Ward Thompson et al., 2013). In turn, Li et al. (2017) propose the concept of 'urban ecological infrastructure' (UEI) as an alternative to GI in order to provide a more resilient and sustainable urban system. The UEI combines blue (water-based), green (vegetated) and grey (non-living) strategies to create an integrated relationship between artificial and natural systems. However, these authors warn the need for innovative policies to overcome challenging obstacles for the implementation of UEI such as rigid thinking, institutional fragmentation and inflexible policies. In southern Italy, Pappalardo et al. (2017) propose the design of policies to incentivise private landowners to adopt SuDS strategies for the retrofitting of urban settlements, as their assessment of SuDS implementation concluded that green roofs performed better than permeable pavements, which reveals the restriction in the capacity of run-off regulation achieved with SuDS deployment in public areas only. Similarly, Chini et al. (2017) assess green infrastructure plans in 27 municipalities across the United States and conclude that green infrastructure plans should incorporate community involvement and communication, evaluation based on project motivation, and a recurrent process of knowledge production. In addition, Zinia and McShane (2018) evaluated green adaptation strategies (parks, gardens, green roof, rainwater harvest, green façades/wall, porous pavement, and green and blue belts) in the context of three wards of Dhaka, Bangladesh, using household surveys and find that successful implementation of beneficial green adaptation strategies requires public participation complemented with environmental awareness raising campaigns.

A few studies have assessed the technical functionality and public support for a combination of SuDS strategies, either with green (vegetated), blue (water-based), or grey (non-living) infrastructure. For instance, Casal-Campos et al. (2015) explore the robustness of a range of watershed-scale "green" and "grey" drainage strategies in the future. Using a regret-based approach to assess the relative performance of strategies in multiple impact categories (environmental, economic, and social) of a hypothetical urban context, these authors observed a higher robustness of green strategies (particularly rain gardens) over end-of-pipe grey alternatives (surface water separation or sewer and storage rehabilitation). In Portugal, Silva et al. (2015) perform an in-house experiment of rainwater harvesting in two households of the cities of Porto and Almada, aiming to determine the economic feasibility of this SuDS technique. Their results show no major differences between the two locations, despite the dissimilar precipitation patterns, but they observe a sensible influence of water fees on the economic viability of rainwater harvesting (RWH) systems at a household-level. Campisano et al. (2017) review the practical, theoretical and social aspects of RWH and find that the degree of rainwater harvesting systems implementation and the technology selection are strongly influenced by economic constraints and local regulations. Among other recommendations, they call for the understanding of how institutional and socio-political support can be best targeted to improve system efficacy and community acceptance. In China, Duan et al. (2016) investigates the optimal design and application of a retention tank network for achieving the benefits of SuDS. Their results indicate that retention tanks can be locally efficient to reduce the flooding risk. Wang and Zimmerman (2015) find diverging economic results in rainwater harvesting in Seattle, Washington, and Phoenix, Arizona. Their conclusion is that overall sustainability of implementing rainwater harvesting devices depends on the site-specific functional, economic, and environmental benefits, as well as their trade-offs. Yang and Chui (2018) analyse the hydro-environmental impact of green roofs and bioretention cells in different areas of New York City, US. Their results show a relatively better performance of bioretention cells over the green roofs, but they warn that design guidelines for different catchments should be fitted according to their drainage characteristics. Similar results were found by Chui et al. (2016) in a comparison between Hong Kong, China, and Seattle, US. Lastly, Lamond et al. (2015) suggest that SuDS strategies are an important aspect of modern urban design and new regulations have emerged in many parts of the world. Nevertheless, they consider that SuDS retrofit is much less developed than in relation to

current building designs. Lamond et al. (2015, p. 8) affirm that most SuDS strategies are suitable for retrofit to cope with runoff, but this process of retrofitting can be difficult when applied to dense urban centres. In this case, the most appropriate SuDS strategies are green roofs, RWH, rain gardens and permeable paving. Lastly, in Kunming, China, Dong et al. (2017) compare the effect of green and grey infrastructure strategies in the enhancement of urban resilience and costs. Using different system configurations including green roofs, permeable pavement and storage tanks, these authors find that green infrastructure strategies have a higher adaptability and resistibility in terms of urban sustainability than grey infrastructure strategies.

Recent literature also assesses the barriers to SuDS adaptations, highlighting also the need for public support. For instance, Hoang and Fenner (2016) identify key barriers towards the implementation of SuDS or GI in the UK, which include physical barriers (i.e., limitations of grey infrastructure), perception/information barriers (i.e., SuDS/GI perceived as short-term solutions with a low perception in the reliability of their functions), and organisational barriers (i.e., the split responsibilities of the local government and the stakeholders involved were not well defined). Dhakal and Chevalier (2017) explore the barriers to SuDS/GI and suggest policies that can both overcome these barriers and expedite implementation in 10 US cities. The findings show that most of the barriers stem from cognitive limitations and socio-institutional arrangements. These authors also suggest a wide set of policies which span from conducting public education and awareness programmes. Similarly, Staddon et al. (2018) emphasise the need of context appropriateness and socially inclusiveness to overcame SuDS/GI challenges regarding: (1) standards; (2) regulation; (3) socio-economic factors; (4) ease of financing; and (5) innovation. These authors suggest ways in which these challenges are should be faced all over the world, emphasising in use of approaches that are both. They conclude therefore that more needs to be done to make GI approaches socially inclusive. In relation with UGI, Du Toit et al. (2018) review the research on the implementation of UGI in Sub-Saharan African cities. These authors find that barely 38% of Sub-Saharan countries has had any study on UGI carried out in them. Du Toit et al. (2018) argue that seven categories of barriers need to be overcome to obtain the sustainable delivery of ecosystem services provided by UGI. These challenges are: (1) socio-cultural values and perceptions; (2) lack of capacity; (3) social inequality and urban planning; (4) lack of data; (5) ecosystem disservices; (6) conflicts; and (7) climate change. Also, in the context

of Sub-Saharan cities, Mguni et al. (2016) assess the theoretical value of using UGI for stormwater management as an alternative to traditional stormwater management systems highlighting its potential for flood risk reduction, urban agriculture, amenity, and water supply.

4.4 Geographical framework

Barranquilla is located in the northern part of Colombia, close to the Caribbean Sea shore and next to the Magdalena river. The built urban area extends to 166 square kilometres. Barranquilla and its conurbation have 1,148,506 inhabitants, based on DANE (2005). In 2013 the city became the fourth most populous in Colombia. The city's 17% ten-year growth rate was driven by displaced rural people expelled from their lands by civil conflict. Because of the lack of a proper stormwater sewer system in the city, when it rains heavily, flash-floods result that partially impede pedestrian and vehicular mobility, depending on the amount of runoff. The main flash-floods are characterised in Table 4.1.

Table 4.1: Barranquilla's main flash-floods

Flash-flood	Flow rate (m3/sec)	Length (metres)
Calle 92	21	4186
Calle 84	62	5200
Country	58	5163
Coltabaco	28	3845
Carrera 65	34	4590
La Felicidad	63	5759
Carrera 40	21	2903
Rebolo	105	4826
Carrera 8	55	3354
Don Juan	85	7906
El Salao	48	9155
El Platanal	82	6800
Santo Domingo	122	4280
Sourdis	37	2350

Source: Ávila et al. (2012) and Colegio Marco Fidel Suarez (2018)

4.5 Methodology

I employ a discrete choice experiment (DCE) to analyse household preferences for SuDS implementation. Choice experiments, based on Lancaster's theory of consumer choice and discrete choice theory by McFadden (1973), use attribute-based models used to extract information on preferences for actual or hypothetical goods, services, or public policies (Louviere et al., 2011). In a DCE, individuals obtain utility from the attributes of the good and not from the good itself. I consider SuDS benefits to be a combination of attributes. When deciding whether to contribute to fund SuDS implementation, households assess the expected benefits of the system.

4.5.1 Sampling strategy, questionnaire, and experiment design

The sampling strategy involved dividing the entire population of households registered in the District of Barranquilla based on the households' socio-economic class (SEC)[29] (see Table 3.1). Sampling procedure follows the approach explained as in previous analysis (see section 3.4). Figure 4.1 shows the spatial distribution of the households and the flash-floods. Households with less income are located in areas at risk of flash-floods and landslides. Homes located near the river are also affected by flash-floods.

The experiment examines household WTP for the permanent implementation of SuDS through a structured 6-section questionnaire (see Appendix J). Section A concerns income, housing characteristics, and tenure in housing and neighbourhood. Section B investigates the head of household's environmental attitudes and their risk profile using a 10-point Likert scale. Section C refers to the head of household's personal experience with flash-floods, damage from floods, perception and awareness of the problem, reasons for mitigation, preparation strategies, institutional trust, and prior knowledge of the six SuDS strategies, as suggested by Voskamp and Van de Ven (2015). The pictures of these strategies are shown in Appendix K.

[29] See sections 2.4 and 3.3.2 and 3.4 in this thesis, for a detail explanation of the notion of socio-economic classes in the context of Barranquilla.

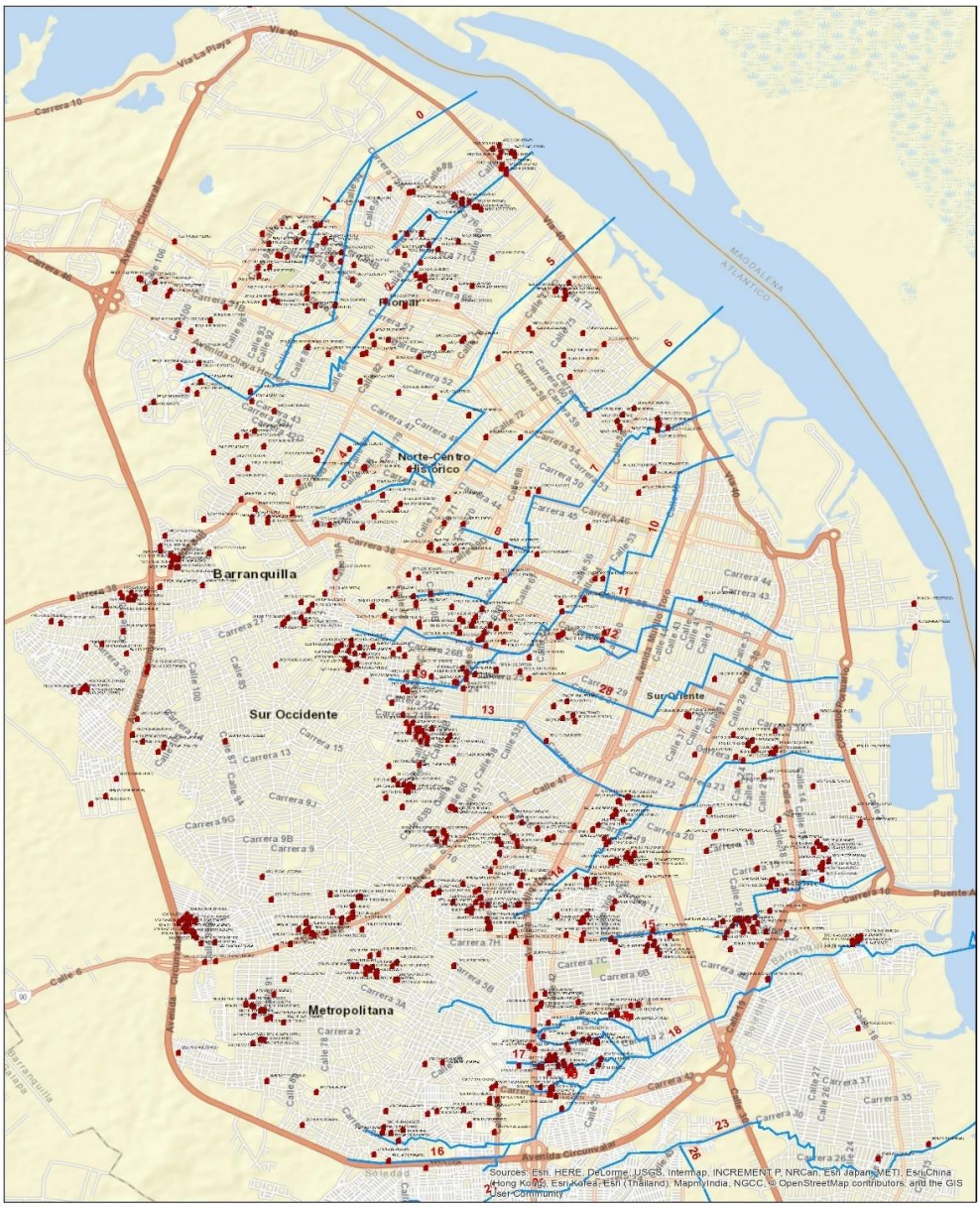


Figure 4.1: Spatial distribution of households and flash-floods. Barranquilla, 2018.
Note: Each brown dot represents a surveyed household. Blue lines indicate the extent of the flash-floods.
Source: author's elaboration

Section D presents the choice experiment for implementing SuDS. It begins with a brief description of the flash-flood problem and past proposed solutions. Then it shows the attributes of the flood risk reduction programme and presents a prop-card to distinguish the deepening

levels of SuDS implementation (Figure 4.2). Respondents choose one of three alternatives, including the current situation (see Figure 4.3).

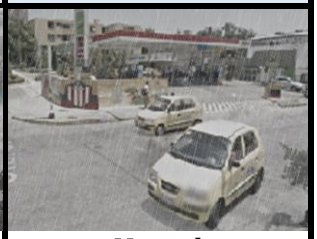
Prop-card			
Attribute	**Current situation**	**SuDS 1**	**SuDS 2**
Vehicular mobility after 30 minutes of intense rainfall			
	Zero	**Restricted**	**Normal**
Pedestrian mobility after 30 minutes of intense rainfall			
	Zero	**Restricted**	**Normal**

Figure 4.2: Prop card

Source: author's elaboration

Section E asks about the strength of relationships with neighbours. Section F collects heads of household's socio-demographic characteristics. In August 2017, I piloted the questionnaire using face-to-face interviews. Six trained and supervised pollsters interviewed 51 randomly selected households. I modified the questionnaire following an analysis of pilot data, and to be more in line with the cognitive abilities of the respondents. Ethical approval was obtained from the Environment and Geography Department Ethics Committee at the University of York.

The final survey took place between January and March 2018, a period without floods. Some contacted households (less than 5%) refused to participate. Heads of household were asked for approval and informed of the academic nature of the study before contact and at the beginning of each interview. The average interview time was 45 minutes. The choice of attributes and their levels were obtained through an exploratory mini-survey, previous to the pilot test, to identify the key impacts of flash-floods in the study area, and therefore the benefits of implementing SuDS. Table 4.3 summarizes the experiment. Attributes include:

(1) Fatalities per year (death rate due to floods), described as "*Number of deaths due to flash-floods in the next 10 years*". From 1995 to 2015, forty people died as a consequence of flash-floods (Suarez, 2018). Also, during this time the city grew dramatically in size and infrastructure. Given this growth and how climate change may affect rainfall, I assumed 45 deaths over the next 10 years as the baseline, and allow SuDS to reduce this to 40, 35, 25, 15 or 5 deaths.

Table 4.2: Attributes and levels in the choice experiment

Attributes	Levels
Fatalities	45, 40, 35, 25, 10, 5, 0
Vehicular mobility	Zero, Restricted, Normal
Pedestrian mobility	Zero, Restricted, Normal
Annual SuDS fee ($)	0, 1, 2, 5, 10, 18, 20

Underlined levels correspond to the baseline.
Monetary units expressed in ten thousand of COP
Source: author's elaboration

(2) Vehicle mobility and (3) Pedestrian mobility describe the benefit of SuDS implementation in improving vehicular and pedestrian mobility half an hour after a torrential downpour. The current situation shows zero mobility, which can be improved depending on the level of implementation of SuDS, to restricted mobility, or to normal mobility.

(4) Household contribution to funding the implementation of SuDS. Because of low compliance and limited government ability, the choice of an adequate payment method has proven difficult when applying CE in developing countries (Whittington, 2010). The survey was applied only to homeowners, so I use an increase in annual land use tax as the payment vehicle. I considered five monetary figures (in Colombian Pesos, COP) that were the most frequent values given by the respondents of the exploratory mini-survey, mentioned above, with an open ended willingness to pay question to address the impacts of flash floods in the city in the: 10000, 20000, 50000, 100000, 180000 and 200000 (range of values equivalent to US$2.50 to US$50).

To construct the choice sets, I implemented an efficient Bayesian design using the Ngene®. I took the pilot test estimates as priors. I built 30 choice sets, each of which represents three SuDS implementation programmes (current situation, plus two different levels of SuDS implementation), having as a point of reference the D-optimal criterion. To reduce cognitive demands, I split the 30 sets of choices into 3 blocks with 10 sets each. Figure 3 shows the choice

card used in the experiment. Once I obtained the first 200 surveys in the sample, I re-estimated the utility model and took the new estimators as priors to the rest of the sample.

Below are 3 alternatives: the current situation, and 2 versions of the SuDS.
In the current situation, there is no change in land tax, there will be 45 deaths over the next 10 years and there is zero mobility for cars and pedestrians during a flash-flood.
If these were the only options available – which would you prefer?

	Card 11 A		
	Current situation	**SuDS Version 1**	**SuDS Version 2**
 **Fatalities**	**45 deaths** over the next 10 years	**35 deaths** over the next 10 years	**25 deaths** over the next 10 years
 **Vehicular mobility**	Vehicular mobility during rainfall **Zero**	Vehicular mobility during rainfall **Normal**	Vehicular mobility during rainfall **Restricted**
 **Pedestrian mobility**	Pedestrian mobility during rainfall **Zero**	Pedestrian mobility during rainfall **Normal**	Pedestrian mobility during rainfall **Zero**
$ **Cost for your household per year**	$ **0** Annual increase of land tax	$ **10,000** Annual increase of land tax	$ **10,000** Annual increase of land tax
Which do you prefer? (choose only one)	☐	☐	☐

Figure 4.3: Choice card
Source: author's elaboration

4.5.2 Modelling households' choices

I begin by assuming that household *i*'s unobserved utility of version *j* of SuDS can be divided into the deterministic indirect utility function *V* and a stochastic random error ϵ, which is a term capturing unobservable components and errors in decision-making. Utility is then

$U_{ij} = V(X_{ij}\,\boldsymbol{\beta}) + \epsilon_{ij} = V_{ij} + \epsilon_{ij}$ (Eq. 13)

where X_{ij} is a vector of SuDS and household attributes describing alternative *j* and household *i*, and $\boldsymbol{\beta}$ is the vector of coefficients. Each head of the household selects the alternative *j* if U_{ij} is higher than the utility for any other option *j′* in the choice set *k.* Since the observed result is the selection of one out of *j* alternatives, the most suitable econometric specification is a discrete choice model.

4.5.3 Random parameter logit model (RPL)

I also use an RPL model to account for unobserved heterogeneity (Greene et al., 2006; Hensher & Johnson, 2018). In an RPL, the coefficients $\boldsymbol{\beta}$ are allowed to follow a random-effects distribution, rather than being fixed across the sample. This serves two purposes. First, unlike the standard logit, the RPL model is not subject to the independence of irrelevant alternatives (IIA) assumption, which can bias estimates if it does not hold (Hensher et al., 2005). Second, it allows for households to have different preferences from each other, which is likely to be true.

The RPL uses equation 13, except that $\boldsymbol{\beta}$ varies over households with a determined density function $\boldsymbol{\beta}_i \sim f(\boldsymbol{\beta})$, which is assumed to be independent of ϵ_{ij}. In each case, *f* is assumed to be the normal distribution. The normal distribution does not restrict preferences to be of a certain sign or within a certain range but does assume that average preferences are predictive of individual preferences. While other distributions can be selected, there is no strong theoretical reason to select a non-normal distribution. The model is estimated by maximum simulated likelihood (Revelt & Train, 1998).

The deterministic part of the individual indirect utility indirect utility function for a basic model without household attributes takes the form:

$$V_{ij} = \beta_{StatusQuo} + (\beta_1)Price_j + (\beta_2)Fatal_j + (\beta_3)VehicleMobilityRestricted_j + (\beta_4)VehicleMobilityNormal_j + (\beta_5)PedestrianMobilityRestricted_j + (\beta_6)PedestrianMobilityNormal_j + \varepsilon_{ij} \quad \text{(Eq. 14)}$$

The choice data from the DCE to estimate this probability of choosing an alternative given the levels of attributes in that chosen alternative, were analysed using Stata 15®, using 500 Halton draws, as suggested by Lancsar et al. (2011). I allow all coefficients except price to vary normally, assuming that the marginal utility of money is invariant over the sample. Moreover, this study also fits an RPL model including interactions between household attributes and the ASC (alternative-specific constant), allowing both for random heterogeneity and heterogeneity in SuDS preferences based on observable attributes (Greene et al., 2006). The model includes the ASC to measure the utility of the base alternative, the status quo option in the choice set. The ASC is a dummy variable coding 1 if the current situation alternative was chosen in the choice card, and 0 otherwise. Indirect utility is

$$V_{njt} = \left(\beta_{SQ0} + \beta_{SQ1}Age + \beta_{SQ2}Male + \beta_{SQ3}Married + \beta_{SQ4}Income + \beta_{SQ5}Education + \beta_{SQ6}Distance + \beta_{SQ7}Instrust + \beta_{SQ8}Percep + \beta_{SQ9}Communic\right) xStatusQuo + (\beta_1)Price_j + (\beta_2)Fatal_j + (\beta_3)VehicleMobilityRestricted_j + (\beta_4)VehicleMobilityNormal_j + (\beta_5)PedestrianMobilityRestricted_j + (\beta_6)PedestrianMobilityNormal_j + \varepsilon_{ij} \quad \text{(Eq. 15)}$$

I calculate the WTP for a change in one unit of an attribute by dividing the coefficient for each attribute with the coefficient on individual contribution (price), as given in equation 16, which gives the value of each attribute in relation to the value of money.

$$WTP_i = -\frac{\beta_i}{\beta_{price}} \quad \text{(Eq. 16)}$$

4.6 Results

Table 4.4 shows descriptive statistics for the main demographic and socio-economic characteristics for the 815 households in the sample. The survey data is very similar to city averages in *Encuesta Nacional de Calidad de Vida* (Departamento Administrativo Nacional de Estadística [DANE], 2017), suggesting my sample is statistically representative of Barranquilla's households; 43% of heads of household were male while 57% were female. Age ranged from 18

to 83 years, with an average of 46.8. 38% of heads of household were married. Household size was about 4.7 persons on average, compared to a national urban average of 3.4 (DANE, 2016). Schooling levels ranged from 5 to 22 years, with an average of about 13.8 years. On average, respondents had lived in their house for 22.7 years and in their neighbourhood for 27. Average income was COP $2,040,001 (US $638.5), marginally lower than the national urban average of COP $2,167,076 (US $678.2) (DANE, 2016). 60% of surveyed heads of household acknowledged they were affected by flooding; 38% showed a high risk perception towards the flash-floods. 47% said they were exposed to some type of communication from the local government related to prevention of flash-flood consequences, but 60% declared either a null or low trust in the local government.

4.6.1 Households' perception of SuDS

Heads of household were asked if they had previous knowledge of the SuDS strategies. Figure 4.4 shows that SuDS strategies were unknown, except for rain gardens and green zones. This result is unsurprising as rainwater collection and green roofs are not tradition in the city. Respondents favoured implementing rainwater tanks, but they were uninterested in adopting either green roofs or rain gardens (Figure 4.5). Respondents also ranked the SuDS benefits against alternatives like channelization. Surprisingly, most respondents classified SuDS first over channelization and a combination of both, confirming that heads of household have a strong environmental awareness despite the highly urbanized dynamics of the city (Figure 4.6). These high levels of support were similar to those observed by Forero et al. (2011) concerning implementing green roofs in Bogotá's low-income areas. The main inference from these findings is that Barranquilla's residents support the idea of green living, despite their densely urbanized environment

Table 4.3: Descriptive statistics

Variable	Mean	St. Dev.	Min	Max
Age	46.8	14.9	18	83
Male	0.43	0.5	0	1
Education	13.8	2.6	5	22
Civil Status	0.38	0.48	0	1
Time House	22.7	16.2	0.1	78
Time Neighbourhood	27	16.5	0.2	78
Distance	609	834	0.01	8476
Household Size	4.7	2.1	1	18
Income	2040192	1862690	607145	10000000
Affected	0.6	0.48	0	1
Institutional Trust	0.68	0.46	0	1
Risk Perception	0.38	0.48	0	1
Risk Communication	0.47	0.5	0	1
N	48900			

Source: author's elaboration

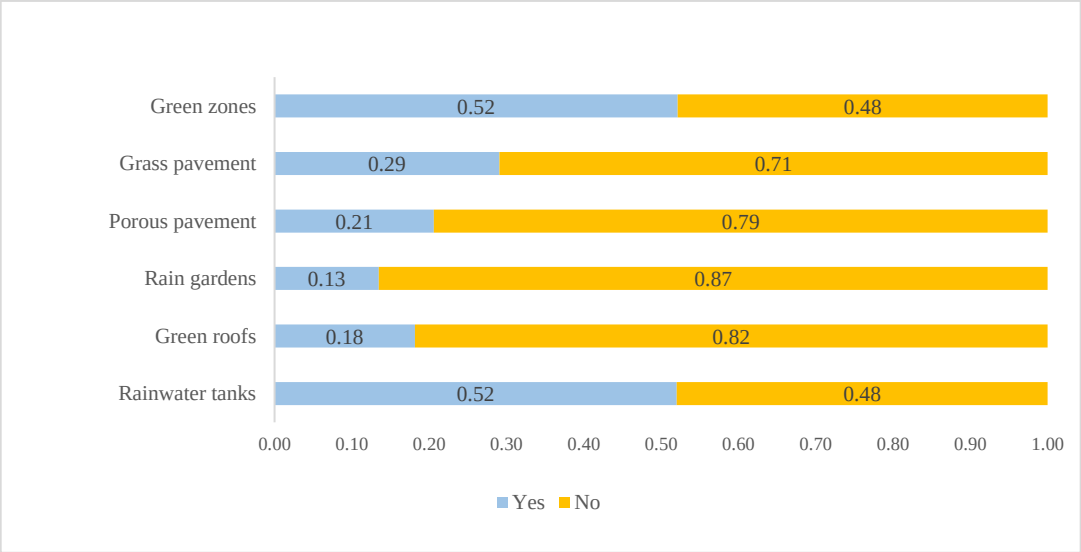


Figure 4.4: Previous knowledge of SuDs strategies. Percentages of respondents aware of SuDS strategies: green zones, grass pavement, porous pavement, rain gardens, green roofs and rainwater tanks.

Source: author's elaboration

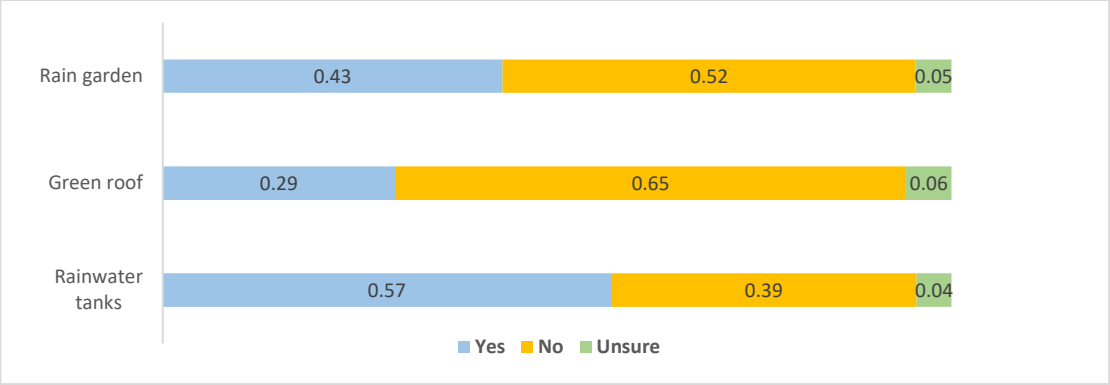


Figure 4.5: Implementation of in-house SuDS strategies. Percentages of respondents willing to implement in-house alternative SuDS strategies: rain garden, green roof and rainwater tanks.
Source: author's elaboration

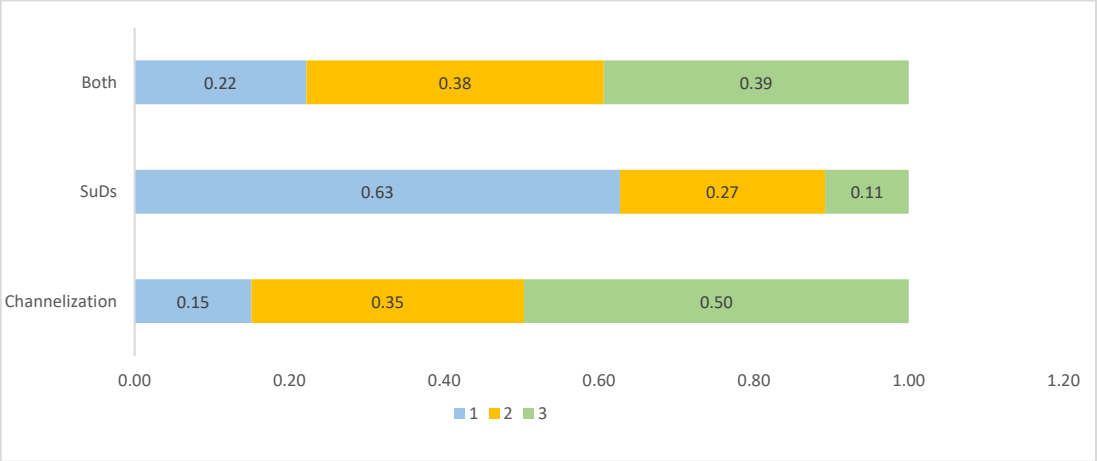


Figure 4.6: SuDS vs. channelization. Percentages of respondents that place the alternatives suggested (SuDs, channelization, both) as first-preferred option (in blue), as second-preferred option (in yellow), and as third-preferred option (in green).

Source: author's elaboration

4.6.2 Households' choices in the DCE

In each choice set, each head of household chose his/her preferred alternative among three possible options (SuDS 1, SuDS 2, and current situation). SuDS 1 and 2 were selected in 34% and 30% of the cases, respectively. The opt-out option ranked first with 36%. This latter result is common in the DCE literature. Samuelson and Zeckhauser (1988) coined the term "status quo bias" to explain this situation. To cope with this issue, I include an ASC in the random utility model, which incorporates the unobserved attributes of each option (Hensher & Johnson, 2018).

4.7 Econometric strategy

4.7.1 The basic RPL model

Table 4.4 shows the estimates of the basic RPL model. McFadden's pseudo R2 is 0.37, indicating a good overall fit of the model. All SuDS attributes are significant and in the anticipated direction except for Restricted Pedestrian Mobility. Many of the standard deviation estimates are high, indicating high preference heterogeneity, in particular for Fatalities. I can reject that all standard deviations are zero at the 1% level.

The coefficient on *Fatalities* is negative, indicating that utility is, as one would expect, negatively affected by deaths. The coefficients on normal mobility were positive and significant. Versions of SuDS that improve vehicular or pedestrian mobility to normal levels are more likely to be supported. As expected, the coefficient on *Price* was negative and significant. Finally, the ASC coefficient is negative and significant, indicating that households, in the abstract, prefer SuDS to the current situation.

Table 4.4: Conditional logit and RPL basic models

Variable	Parameter	CL	RPL
Price	Mean	-0.13	-0.18
		[0.01]***	[0.02]***
Fatalities	Mean	-0.00	-0.01
		[0.00]***	[0.00]***
	Standard Deviation		0.04
			[0.00]***
Vehicular mobility:			
Restricted	Mean	-0.02	-0.08
		[0.03]	[0.05]
	Standard Deviation		0.79
			[0.05]***
Normal	Mean	0.16	0.20
		[0.03]***	[0.05]***
	Standard Deviation		1.02
			[0.05]***
Pedestrian mobility:			
Restricted	Mean	-0.03	-0.05
		[0.03]	[0.05]
	Standard Deviation		0.77
			[0.05]***
Normal	Mean	0.10	0.28
		[0.03]***	[0.06]***
	Standard Deviation		1.04
			[0.07]***
Status_quo	Mean	0.15	-1.18
		[0.04]***	[0.21]***
	Standard Deviation		6.02
			[0.28]***
Log Likelihood		-17786.27	-11143.76
McFadden's Pseudo R2		0.01	0.37
WTP Fatalities	Mean	-0.03	-0.03
	Standard Error		[0.02]*
WTP Restricted vehicular mobility	Mean	-0.17	-0.43
	Standard Error		[0.39]
WTP Normal vehicular mobility	Mean	1.23	0.97
	Standard Error		[0.22]***
WTP Restricted pedestrian mobility	Mean	-0.21	-0.24
	Standard Error		0.22
WTP Normal pedestrian mobility	Mean	0.81	1.17
	Standard Error		[0.41]***

*p < .10 **p < .05 ***p < .01

Values in brackets are standard errors. LRI denotes Likelihood-Ratio Index. Except for Price, which is fixed, all RPL coefficients follow a normal distribution.

All WTP values in 100K COP. WTP values estimated using the Stata 15® command 'wtp' (Hole, 2007).

Source: author's elaboration

4.7.2 The RPL extended model

Table 4.5 presents the estimates of the RPL model with household attributes. McFadden's pseudo R2 (goodness of fit) is 0.34, lower than the basic RPL. All error component terms resulted significant, except *Education*, indicating that heads of household's socio-demographic factors predict their interest in SuDS implementation. Just as in the basic model, the negative sign and significance of the coefficient of *Price* indicates that higher payments reduce utility. The results show that a higher valuation for SuDS alternatives is found for heads of household who are older, male, and married. Unexpectedly, *Education* did not have a significant result on households' preferences for SuDS, at least not while *Income* is controlled. *Income* attracted a negative estimate, which consistent with most middle-income and high-income households being in zones of the city far from the risk of flash-flood damage.[30] The negative sign of the *Distance* estimate corroborates the former result. That is, increasing closeness of a household to a flash-flood means higher utility from the SuDS implementation in the long run.

The results also showed that those heads of household who trusted more in the local government, have a significantly higher WTP than those who did not. As expected, head of household's WTP increased with a higher perception of risk from flash-floods. According to Maidl and Buchecker (2015), it is reasonable to assume that heads of household who are more informed about the risk of flooding, should also have a higher probability of paying for an increment in the public good "protection against the risk of pluvial flooding," than people with little or no information on this issue. My results confirm that hypothesis: The higher their exposure to communications about flood risk, the lower their preference for the current situation.

[30] Medium-income and high-income households are affected by flash floods, but indirectly. The result obtained here partly reflects the positive expectations generated by the already advanced process of flash-flood channelization in the northern part of the city (the city's wealthiest). In this regard, see Ayala et al. (2017).

Table 4.5: The RPL extended model

Variable		Parameter	Coefficient
Price		Mean	-0.17
		Standard Error	[0.01]***
Fatalities		Mean	-0.01
		Standard Error	[0.00]***
		Standard Deviation	0.03
		Standard Error	[0.00]***
Vehicular mobility:	*Restricted*	Mean	-0.07
		Standard Error	[0.04]*
		Standard Deviation	0.42
		Standard Error	[0.05]***
	Normal	Mean	0.18
		Standard Error	[0.041]***
		Standard Deviation	0.77
		Standard Error	[0.04]***
Pedestrian mobility:	*Restricted*	Mean	-0.05
		Standard Error	[0.04]
		Standard Deviation	0.43
		Standard Error	[0.04]***
	Normal	Mean	0.22
		Standard Error	[0.04]***
		Standard Deviation	0.70
		Standard Error	[0.05]***
Status_quo		Mean	1.71
		Standard Error	[0.79]**
		Standard Deviation	5.51
		Standard Error	[0.19]***
*Status_quo*Age*		Mean	0.04
		Standard Error	[0.01]***
*Status_quo*Male*		Mean	0.56
		Standard Error	[0.16]***
*Status_quo*Married*		Mean	1.00
		Standard Error	[0.15]***
*Status_quo*Income*		Mean	-1.14
		Standard Error	[0.19]***
*Status_quo*Education*		Mean	-0.013
		Standard Error	[0.04]
*Status_quo*Distance*		Mean	-0.00
		Standard Error	[0.00]***
*Status_quo*Instrust*		Mean	3.51
		Standard Error	[0.20]***
*Status_quo*Percep*		Mean	1.01
		Standard Error	[0.59]*
*Status_quo*Communic*		Mean	2.75
		Standard Error	[0.27]***
Log Likelihood			-11272.54
McFadden's Pseudo-*R*2			0.34
WTP Fatalities			-0.02
WTP VehicleMobilityRestricted			-0.42
WTP VehicleMobilityNormal			1.08
WTP PedestrianMobilityRestricted			-0.30
WTP PedestrianMobilityNormal			1.30

*$p < .10$ **$p < .05$ ***$p < .01$

Values in brackets are standard errors. LRI denotes likelihood-ratio index. Except for Price and all interaction terms, which are fixed, all RPL coefficients follow a normal distribution.

All WTP values in 100K COP. WTP values estimated using the Stata 15® command 'wtp' (Hole, 2007).

Source: author's elaboration

4.7.3 Welfare effects: Estimation of the marginal willingness to pay

My results of marginal WTP provide an average value of COP $215,810 per household in one year (US $ 53.4), which can be aggregated to the universe of households (252,760 in 2012), for a value of COP $55 billion per year. As the main purpose of a CE is to estimate the welfare effects of changes in attributes (McFadden & Train, 2000), economic welfare management involves an analysis of the difference between the households' utilities that could be attained under the status quo and the alternatives proposed. The marginal WTP for *Fatalities*, *Normal Vehicular Mobility*, and *Normal Pedestrian Mobility* were all significant in all specifications. Marginal WTP in the RPL basic specification was COP $ 2,827 per fatality, COP $ 96,461 for normal vehicular mobility, and COP $ 116,522 for normal pedestrian mobility. In all cases, heads of household's marginal WTP to reduce fatalities from the highest level, 45, to the lowest, zero, was lower than the marginal WTP to improve vehicular and pedestrian mobility both to normal. In the same vein, marginal WTP for normal pedestrian mobility was higher than for normal vehicular mobility. This result can be explained by the fact that most of the heads of household surveyed do not own a vehicle.[31]

4.8 Discussion

According to Robles (2016), the cost of the solution of flash-floods in Barranquilla through channelization only was estimated at COP $662 billion, considered a costly option (Ávila, 2012, p. 57). In this chapter, I contribute to the literature by investigating households' preferences towards implementing SuDS as an alternative solution to flash floods in a tropical developing country urban context. Results provide the urban residents' marginal WTP for mortality reduction and mobility improvements associated with SuDS implementation, suggesting an opportunity to build support for SuDS by raising awareness about its benefits. My results of marginal WTP leads to a value of COP $55 billion per year which sheds light on the high social opportunity cost the local government has incurred in looking for a long-run solution of flash-

[31] According to data from Barranquilla Cómo Vamos (2018), approximately 80% of the population of the city does not own a vehicle and uses public means at their service (rapid transit system, bus, taxi, others).

floods by only resorting to channelization.[32] Therefore, a combination of green infrastructure strategies alongside the system channelization might prove a potential solution to capture some of the societal SuDS benefits examined in this chapter.

Moreover, by approaching this topic from a DCE methodology, my results add new insights to the literature on the trade-offs between the different societal benefits of SuDS based here on reducing fatalities and reducing mobility impacts of flash-floods. I observed that mobility attributes of SuDS greatly impact households' preferences towards. A combination of lower flash-flood mortalities with normal vehicular and pedestrian mobilities is preferred by households to the current situation. Results also indicate that reducing the price burden on the urban households, perhaps by making in-house SuDS infrastructure tax deductible, as suggested by Chui and Ngai (2016), could also improve their interest in taken up this technology. However, housing in Barranquilla is quite heterogenous and many houses are inadequate to setup in-house SuDS strategies.

Furthermore, I find evidence that supports communicating with households about the risks derived from flash-floods as a factor that influences their preferences for a SuDS alternative.[33] Nevertheless, I cannot conclude about the effectiveness of such communication. Further studies must emphasize the magnitude and quality of the risk communication strategy from the institutions responsible for the management of hazards and the corresponding degree of responsiveness among the population. The policy-makers task is then determining the SuDS strategies that will provide the attributes selected. On this issue, my results show that heads of household show a strong preference for using rainwater tanks and some inclination towards employing rain gardens. The issue of nuisance biota could significantly reduce households' preferences for green roofs. Overall, my RPL basic model's estimates indicate that households prefer a sustainable solution to the flash-floods, which is further supported by the significant and

[32] From a strictly hydrological point of view, the channelization of flash floods has many disadvantages in the long term. Among these are the following: (1) Generation of flash-floods in streets where they did not exist before; (2) Accumulation of sediment and solid wastes in the grids; (3) Little attention from local government in the creation of green areas, and (4) potential damage to infrastructure due to the greater intensity of rainfall as climate change worsens. See Chang and Franczyk (2008) for more on this subject.

[33] Among those heads of household exposed to communication from the local government about the risks flash floods (47.5 % of the sample), the majority responded that they saw the warnings daily. Importantly, the vehicle of communication they reported as the most frequent was the regional television channel.

negative effect of the ASC. Estimates of relative importance in the RPL extended model partially support these results and indicate that, while price is a key factor, the risk perception of the consequences of flash-floods impacts positively on heads of household's choices towards SuDS implementation.

4.9 Conclusions

This study applied the methodology of choice experiments to assess households' preferences towards SuDS in a tropical city. My study reveals strong household preferences for the social benefits of a potential implementation of SuDS in both public places and houses in Barranquilla, with the greatest attention to benefits in improvements in mobility. As expected, heads of household's previous understanding of SuDS mechanisms to solve flash-floods is limited. Even though they still generally support adopting in-house SuDS strategies such as rainwater tanks, they are more reluctant to others such as green roofs and rain gardens. Budget constraints may have influenced their response, as the households must cover the cost of implementing such strategies. Moreover, unlike to what it has been found in similar literature on temperate climates (Chui & Ngai, 2016; Silva et al., 2015; Veronesi et al., 2014), households in this analysis might expect these strategies to bring disease vectors like mosquitoes, among other nuisance biota, given the tropical context (Fatti & Patel, 2013; Maksimović et al., 1993; Sutton & Lambrinos, 2015). Another conclusion from this study is that the preference for the status quo differs abruptly among household attributes, varying with factors such as income, schooling, and trust in local government. This adds to the literature on the role of these factors in potentially opting to investing in in-house SuDS. It also informs policy interventions, which can be tailored towards increasing education or trust in institutions as these factors influence the preference for SuDS, which it is an important implication for local governments with strict budget constraints and inevitably needs some private funding for in-house SuDS implementation. This study also contributes to the environmental valuation literature in the benefits of SuDs, that risk perception and the frequent exposure to risk communication proved to be important factors in households' WTP. My findings are consistent with the wider literature that explores flood risk perceptions in temperature climates (Kellens et al., 2013; O'Neill et al. 2016). Overall, my results highlight the importance of maintaining a frequent government-led warning about flash-floods. Communication of risk is essential for raising public awareness and the corresponding level of

preparedness. However, government communications strategies still require appraisal in future research. Finally, by incorporating households' distance to flash-floods in estimating the WTP, my results show that benefit aggregation of SuDS implementation based on sample average WTP with no information of the spatially distributed flash-food mitigated impact may result in biased estimates.

The limitations of the study lie in the application of the DCE, which allows only a small number of attributes to be assessed. I consider only three attributes to describe the benefits of SuDS: reduction in fatalities due to pluvial flooding, and the improvements of pedestrian and vehicular mobility. However, future studies need to recognise the broader range of attributes derived from SuDS implementation such as the reduction of the urban heat island effect, the quality of the air, the quality of the stormwater that runs into the Magdalena river, and the improvement of the urban landscape. Further studies could also address a spatial analysis that provide information on the heterogeneity of marginal WTP values for different areas of the city, which would also be salutary to complement individual data retrieved, in order to inform urban planners on the feasibility of introducing a local tax (often property taxes) to cover some of the costs of SuDS implementation.

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Chapter 5: Discussion

5.1 Thesis aim and approach

This dissertation contributes to a deeper understanding of the interlinkages among social, economic and environmental factors that influence societal preferences towards the development of local policies to address sustainability challenges regarding urban crime, solid waste management, and flood risk at the urban level.

In Chapter 2, I contribute to identify, for policy design purposes, the factors that influence the perpetration of two types of crimes, homicides and interpersonal violence, in Barranquilla. I extend previous work, particularly, in the Latin America context, by exploring the determinants of crime based on a broad range of existing theories and models, which provide evidence in the complexity of the phenomenon of urban crime in this region. These include: (i) the economic theory of crime proposed by Becker (1968), Ehrlich (1973) and Block and Heineke (1975), which relates criminal activity to income inequality; (ii) the theory of crime proposed by Gottfredson and Hirschi (1990), for whom the years of education of the aggressor is one of the main predictors of crime; and (iii) the routine activity theory, which argues that crime is based on the socio-economic conditions of the individual (Schreck, 2017), and the social interactions, which determine the opportunities for criminal activity (Felson, 2017). Violent crimes have also been explained in the literature by the theory of social disorganization (Jones & Pridemore, 2019). Following Lynch and Boggess (2016) and Roman and Reid (2012), the empirical analysis in Chapter 2 considers both individual factors such as unemployment, economic inequality, and lack of education as well as contextual aspects in which crimes are propitiated. Thus, neighbourhood-variables included in Chapter 2 were the presence of physical vacant spaces, as these tend to increase the residents' perception of insecurity (e.g., Branas et al., 2018), and proximity to police units to capture the presence of law enforcement (e.g., Cortes-Nieto & Ansari, 2017; Rubio, 2017). Using data on weekly crimes during the period 2010-2018, I have shown in consonance with the wider literature (e.g., Lochner & Moretti, 2004; Oosterveld et al., 2018; Salahub et al., 2019) that homicides in Barranquilla are likely to be responsive to changes in socio-economic conditions as improvements in education and income inequality. Moreover,

results in this chapter are consistent with the social disorganization and routine activity theories (Branas et al., 2018; Kondo et al., 2016; SIPRI, 2017) supporting local public interventions that remediate vacant urban plots to reduce crime and violence and highlighting the effect of police presence on crime reduction. I also found evidence of local weather conditions (heat stress) on interpersonal violence.

In chapter 3, I addressed the urban challenge of the illegal disposal of solid waste, a crime more rarely investigated in the socioeconomic urban sustainability literature, even though its cross-cutting nature makes it a critical component of urban sustainability. This chapter contributes to understand societal preferences towards the need to eradicate open-air dumps that persist in the Barranquilla urban perimeter, despite the existence of an efficient garbage collection system. The work done in this chapter allowed me to understand the residents' perceptions towards illegal dumping, and their willingness to pay (WTP) for a sanitary scheme that eradicates open-air dumps, informing thus the development of a local public intervention that tackles this sustainability challenge. To my knowledge this is the first study that evaluates the eradication of illegal dumping sites. Using the contingent valuation method (CVM), I designed a hypothetical 3-year policy scheme for the eradication of the 30 more critical open-air dumps in the city, in order to estimate household's WTP through a higher public service fee. Using a large representative sample of 815 respondents, this work shows, as happens in other developed country cities studied in the literature, that heads of household recognize that the illegal disposal of solid waste is a problem rooted in the bad habits of residents (see Achu et al., 2015; Machmud, 2017; Shraddha, 2017). I found that heads of household expressed a clear preference for the eradication open-air dumps. On average, the WTP for eradication of illegal dumping per household per month was COP $ 852.4 (US $ 0.2), equivalent to COP 10,228 (US $ 2.4) per year. This low WTP is in line with the literature in developing countries where values under $ US 1 are also found (see Afroz et al., 2009; Awunyo-Vitor, et al. 2013; Balasubramanian, 2019), and could be connected to the dissatisfaction among heads of households with the role of the government in generating improvements in illegal dumping. The proliferation of dumps may contribute to this perception that local authorities do not properly enforce laws, causing distrust. Community participation also affected negatively the WTP, which suggests that heads of household do not see this as a problem that needs to be addressed by collective social

responsibility. Policy makers need to be aware of the need to build societal trust in institutions to address this problem and increase community-based involvement to influence the willingness to pay for it.

Chapter 4 addresses one of the serious problems face by the District of Barranquilla, the lack of a storm sewer system that can contain the flows of rain expected in a context of climate change and in a tropical geographical environment (Charlesworth & Mezue, 2016). I used a discrete choice experiment (DCE), an attribute-based survey method for estimating the WTP of heads of household's for reductions in the risk of flash-floods through SuDS implementation, in a novel context, a tropical city. Moreover, advancing previous work, I was able to show that the societal benefits associated with the implementation of the proposed SuDS, which were given the greatest attention by Barranquilla households and monetarily valued in the DCE, were the reduction of fatalities, the improvement in vehicular mobility, and the improvement in pedestrian mobility. I found that heads of household who are older, male, married, wealthier, and who are more vulnerable, because they live closer to the main flash-floods and have suffered recurrent damages from the flash-floods, are more willing to pay for the reduction of risks from pluvial flooding with the implementation of both green and grey infrastructure strategies derived from SuDS. The average WTP per family was COP $215,810 per year (US $53.4). This is consistent with previous studies (Chui & Ngai, 2016; Reynaud & Nguyen, 2016; Torgersen & Navrud, 2018), although in geographical contexts different from that of Barranquilla (i.e., temperate climates). Policy-makers could compare this amount with the actual annual costs of developing a SuDS scheme in Barranquilla. I also found that societal risk perception and being exposed to risk communication are positively associated with the willingness to pay for SuDS strategies. Therefore, this chapter is consistent with previous work by Brouwer et al. (2009), Fatti and Patel (2013), and Kellens et al. (2013) regarding the need to build institutional trust and increase residents' knowledge around the risks of flash-floods to increase awareness of SuDs benefits.

5.2. Summary and implications of overall findings

This section presents the contributions of this thesis grouped into the categories below, highlighting the policy implications that emerge for the urban challenges studied in the thesis:

(a) ***Mitigating urban crime requires spatially targeted policies prioritising education and restoration of urban vacant plots in vulnerable areas.***

Low levels of education reinforce the tendency towards criminal behaviour (Roberson, 2018). This is based on the findings of chapter 2, where poverty and low levels of education were found to increase Barranquilla's weekly homicide rate. Education was also shown to play a role in the occurrence of non-lethal violent crimes in the city, while this was not the case for poverty. Interpersonal violence incidents like the ones examined in the thesis have been defined as spontaneous aggressive crimes that generally escalate from a minor dispute (Anderson, 2001), and the results here suggest that this type of crime seems to be influenced by the residents' low levels of education. Therefore, the findings in this thesis are consistent with previous work (e.g., Cruz, 2016; Koonings & Kruijt, 2015; Vilalta et al., 2016), and illustrate that social policies that tackle poverty in the most deprived neighbourhoods (e.g., income-generation programmes, fostering the creation of small businesses through cooperatives), need to be hand in hand with strategies that promote education. Moreover, it is evident from this dissertation that both lethal and non-lethal crimes are more frequent in urban areas characterized by the presence of abandoned vacant lots and open-air dumps that, in addition to the negative externalities that residents recognised such as unwanted animals or water pollution (see Chapter 3), also favoured the perpetration of violent crimes (Chapter 2). This high incidence of crime in neighbourhoods with urban vacant spaces, often concurrent with the most deprived areas of the city, has been observed for other cities in Latin America (García-Ayllón, 2016; Rivera, 2016), and elsewhere (see Kondo et al., 2018, for New Orleans, and Troy et al., 2016, for Baltimore). The concentration in these areas of poverty, low education, and high crime, can lead to out-migration of those people who have the financial and human capital means to do so, and this can lead to a spiral of decay in these urban neighbourhoods (Branas et al., 2018). Therefore, this thesis concludes that direct changes that address the restoration of abandoned urban lots, for example by transforming them intro green spaces, are imperative, and could also have a positive effect on mitigating the impacts of flash-floods on mortality and pedestrian/vehicle mobility (see Chapter 4). When those urban vacant lots are indeed open-air dumps and are eradicated for example through their restoration to green spaces, Chapter 2 showed that there are societal benefits to be gained also in terms of crime reduction.

(b) ***Thermal stress plays an important role in occurrence of interpersonal violence crimes***

This thesis provides evidence that thermal stress proxied by NOAA's Heat Index is associated with an increased rate of urban interpersonal violence in Barranquilla. This finding contributes to an increasing evidence on the incidence of temperature and other climatic variables on urban crimes (e.g., Ceccato, 2005; Cohn, 1990; Hu et al., 2017; Mares & Moffett, 2016). To the best of my knowledge, this thesis is the first to show the effect of thermal stress on violence crime in a tropical city, while controlling for socio-economic individual and neighbouring factors. Interestingly, the thesis also shows that thermal stress has not impact on homicides. Previous work in tropical urban areas such as São Paulo (Ceccato, 2005) supports this result. This could be explained by the fact that lethal crimes are pre-planned acts that respond mainly to structural triggers such as poverty and low education levels but are not influenced by the spontaneous character of weather conditions. It is also important to point out the limitations imposed by the sample size in time series estimations because homicide is less frequent than other crimes, which may affect the robustness of the estimations (Cohn, 1990; Mares & Moffett, 2016). In fact, there is evidence that shows a statistical association between climate and homicides (see Mares & Moffett, 2019).

(c) ***Law enforcement might help not only to reduce violent crimes but to monitor and eradicate illegal dumping of wastes, thereby contributing to mitigate the negative effects caused by flash-floods***.

The lack of police surveillance is often shown to promote the emergence of criminal behaviour in neighbourhoods (Jeffery & Zahm, 1993; Sohn, 2016). This thesis demonstrated the benefits of police surveillance in counteracting the occurrence of murders and non-lethal crimes in Barranquilla. While the effort to bring police control to vulnerable areas has not been successful in the cities of Bolivia, Guatemala and Honduras (Cruz, 2016; Nivette, 2016), this thesis argues that enhancing the police presence has a role to play in reducing violence crimes, as crime incident counts were lower when police stations were nearby. This effect has also been noted in Salem (2016) for Rio de Janeiro, Brazil, and Rubio (2017) for Bogotá, Colombia, who

emphasize the importance of the spatial distribution of police units in reducing lethal violence. In Bogotá and Rio de Janeiro police control were not only been directed towards strict compliance with the law through deterrence, but community participation programmes were also been designed to achieve relative pacification of the participating neighbourhoods (Cortes-Nieto & Ansari, 2017). Therefore, based on this literature and findings of this thesis, I argue that local policy measures that lead to an increase in police surveillance, especially during weekend days (which were found to be associated with an increase in crime activity), can have an impact on urban crime reduction.

Moreover, I also found evidence that households perceive stronger enforcement is needed by local authorities regarding violations of residents who are found in acts of illegal disposal of solid waste by either through paying informal collectors in animal-drawn vehicles, by depositing them at the critical points indicated in Chapter 3, or by throwing them into the flash-floods when it rains. In fact, the large investment in channelization to reduce flash-floods in Barranquilla, described in Chapter 4, can fail if the bad habits of solid waste disposal by residents are not definitively banished. Thus, my thesis illustrates that one of the main problems of the illegal disposal of solid waste around the city is the proximity of open-air dumps to the 14 flash-floods identified, to the extent to which these water streams drag much of this waste (see Appendix M), and end up in the Magdalena river or obstructing the drains of channels. In fact, although some of these flash-floods have already been channelized, this problem still exists. Chapter 3 emphasises that heads of household regard illegal dumping of wastes mainly as a challenge for which the local government must provide a solution, e.g., a ban on informal garbage collectors that needs to be enforced. In this line, I show that awareness of the presence of open-air dumps and perceptions of government inaction on this illegal behaviour, leads to respondents to be less willing to participate in a programme to eradicate illegal dumping. Therefore, this suggests that in order to build residents support for public initiatives on illegal dumping eradication schemes, institutions need to send clear signals that can effectively enforced any measures needed to tackle illegal disposal of waste. However, designing strategies that increase communities' enthusiasm for waste disposal monitoring can be challenging (Nyarai et al., 2016; Zhang & Zhao, 2019).

(d) ***The promotion of strong government-neighbourhood links can improve residents' attitudes towards illegal waste disposal***.

This thesis found that social capital factors play a central role in achieving successful implementation of interventions that address illegal dumping. The households' social behaviour, captured through the neighbours' reciprocity and satisfaction with the neighbourhood in which they live, and the communication of the risk by the local government, points out the importance of social cohesion within the neighbourhoods to stop the crime of illegal disposal of solid waste. Moreover, the significant effect of the institutional trust variable in determining willingness to pay is consistent with the evidence found in other waste management studies about the relevance of trusting in local institutions when considering the contribution in government's environmental interventions (see Kazuva, 2017; Marbuah, 2016). Therefore, if households' participation in community activities is not promoted in the neighbourhoods (which may be done through the legally established democratic channels[34], or through the informal social sector as mentioned in Henry et al. (2006), among others) in a way that an atmosphere of peer care in the neighbourhood and institutional trust between the government and the households is built, it is plausible that the crime of disposing of solid waste in the areas investigated in the hypothetical eradication scheme of chapter 3 will prevail. Thus, successfully programmes aimed at reducing the illegal disposal of solid waste requires social cohesion between households in the most vulnerable neighbourhoods, institutional trust between households and the local administration, as well as educational promotion strategies through local schools and universities on the proper management of solid waste and the possibilities of recycling. In addition, specific actions such as the provision of garbage containers at critical points, as mentioned by residents in the survey, could contribute to tackle this problem. This is in line with previous research that points out the importance of local governments in fostering an environment of intra-neighbourhood social cohesion (see Córdova & Layton, 2016; Schlueter, 2017).

[34] The city has 15 democratically elected leaders (*Ediles*, in Spanish) for each of the five administrative localities outlined in chapter 2.

(e) ***Green infrastructure and green spaces can reduce the likelihood of illegal activities (both, crimes and illegal dumping), and enhance protection against flooding hazards.***

This thesis contributes to an understanding of household's preferences for more green areas in the urban perimeter in Latin America. These social preferences were investigated within the framework of the potential implementation of a sustainable urban drainage system that articulates both grey infrastructure and green infrastructure. Thus, the potential benefit of greening abandoned lots is twofold: Green spaces not only reduce runoff caused by rainfall but may also have an effect on reducing crime. This is consistent with current literature that suggests that the greening of these spaces reduces the likelihood of crimes (see Bogar & Beyer, 2016; Branas et al., 2018; De Biasi, 2017; Heinze et al., 2018).

A plausible initiative that would help urban sustainability would be the greening of the critical points of accumulation of waste and, *pari passu*, the installation of ecological containers to legally dispose of garbage, with the proper separation of waste. This would not only contribute to the improvement of water and air quality (Ossa-Moreno et al., 2017), but would substantially improve the landscape environment (Lennon et al., 2014), and could contribute to reduce crime rates in the most vulnerable areas of the city, as argued in Chapter 2.

This research found that households respond positively to the proposed green infrastructure strategies as a complement to flash-flood channelization. Although the results show that the knowledge of the heads of household on the SuDS was limited, there is a favourable perception towards environmentally sustainable solutions such as the installation of green areas in public places. However, the perception of the heads of household changes dramatically when the installation of green roofs and rain gardens in homes and buildings is suggested. Green roofs can provide a potential breeding ground for vectors that transmit tropical diseases (Lundholm, 2006; Sutton & Lambrinos, 2015), which may explain the reluctance of the heads of household regarding the domestic installation of green roofs. However, rainwater harvesting systems through tanks arranged inside the houses had a positive perception from the heads of household, a result that is consistent with what was observed in other geographical latitudes (Campisano et al., 2017; Silva et al., 2015).

Overall, these findings of this thesis contribute to the recent literature on SDG interlinkages (e.g., Maes, 2019; Zhao et al., 2020), as key to ensure that progress towards one goal does not undermines achievement in others. The thesis shows that a crucial step for sustainability urban planning calls for the implementation of green infrastructure (e.g., tree planting) in vacant lots, as strategy that can provide win-win outcomes in a wide variety of areas (i) safer cities (SDG 11), by reducing the crimes nearby these lots; (ii) human health (SDG3) and clear water and sanitation (SDG6), by eradicating illegal dumping existing in many of these vacant lots which create a health risk and contribute to flood hazard by ameliorating the run-off; (iii) mitigation of climate change (SDG 13), by sequestering carbon; and (iv) life on land (SDG 15), by reducing pollution from dumping sites, and creating habitats for wildlife. Moreover, trees create microclimates that can contribute to reducing the heat island effect, leading to another concurrent benefit in making cities safer, and thus being better able to improve investment opportunities to foster economic growth (SDG 8). A more general implication, emerging from this finding, is the understanding of how net zero carbon policies such as promoting green infrastructure impact in multiple facets of urban sustainability in a Latin America context. Nevertheless, the thesis also provides an illustrative case study of the role of social capital to address solid waste management and in particular, the eradication of illegal dumping, concluding that, without efforts to improve which the above mentioned SDGs could not be tackled. The social capital could take the form of partnerships between the local council and local communities; as the thesis illustrate the willingness of private individuals to both eradicate illegal sites and contribute to green infrastructure.

5.3 Limitations and opportunities for future work

Previous research on urban sustainability has found that crime resilience, the proper disposal of solid waste, and a combination of green and grey infrastructures convey useful information about new paths to be followed by urban planners. My research complements these studies by highlighting the importance of: (i) considering socio-environmental factors to address crime; (ii) having sound government-neighbourhood links to ensure institutional trust and the strengthening of social capital; and (iii) introducing alternative strategies associated with SuDS in order to cope

with the problem of flooding. The previous section discussed my contributions for Barranquilla using administrative data in chapter 2 and household primary data in chapters 3 and 4. Here, I discuss its limitations and the implications of my findings for future research.

Some limitations emerge from my dissertation that would help to increase the understanding of the challenges to urban sustainability that currently faces Barranquilla. First, the analysis of the determinants of crime was carried out using time-series models but ignores the spatial variation in crime occurrence, and its determinants. Thus, for example, even though the analysis included a proxy for distance to vacant lots and police stations as predictors of crime, it failed to provide an association between crime counts in each administrative unit (e.g., neighbourhood), and its determinants such as the proportion of neighbourhood that is classified as vacant lots, the proportion of the neighbourhood population with no formal education, or income inequality in the neighbourhood. Similarly, I also assume that both the temperature and the relative humidity, which serve as inputs for calculating the Heat Index, are constant throughout the city. Recent studies on the urban heat island effect show that climatic variables may differ in different neighbourhoods of the city (Edmondson et al., 2016; Qaid et al., 2016), and this spatial heterogeneity may be key when it comes to large cities.

In my analysis of the illegal disposal of solid waste, the sample size does not allow me to make inferences about the socio-economic factors of the heads of household for each of the six established socio-economic classes. In fact, the literature shows the importance of analyzing the problems derived from solid waste management at the household level by different income levels in order to establish the heterogeneity of households and better refine the results in order to tailor the increases in public services fees to address illegal dumping eradication (Padilla & Trujillo, 2018). Importantly, I acknowledge that I am unable to address potential issues of endogeneity between social capital and WTP (e.g., neighbours' closeness and the head of household's WTP) for the eradication of open-air dumps. Finding appropriate variables to use as an instrument for social capital proved to be a challenging task from the survey data used. A fourth limitation of my research originates from the attributes derived from SuDS implementation. Although I identify three attributes as benefits of a SuDS strategy (this is, reduction of fatalities and improved vehicular and pedestrian mobilities) from a pre-pilot test to the Barranquilla residents, I recognise that these are too general and can be related to other flood alleviation measures.

Finally, this thesis combines both CVM and DCE as alternatives stated preference methods to measure the marginal value of changes in non-market goods. Even though a previous study to measure WTP for improvements in waste disposal of solid waste in a developing country context using both DCE and CV provided similar values (Jin et al., 2006), the fact that DCE has some recognised advantages over CV can question whether the low WTP found in Chapter 3 would be obtained if DCE were used. The advantages of DCE, which include the ability to study preferences for attribute levels associated with a given policy initiative, as well as giving respondents multiple chances in the interview to express a positive preference for a valued policy attribute over a range of payment amounts, may have increased awareness of the benefits of reducing illegal dumping (e.g., reducing respiratory health problems), and affected the WTP values obtained.

Further studies need to focus on three issues that will be central to complement the results obtained herein. First, the use of spatial-temporal models to identify the city's hotspots of criminality will be helpful to better allocate heterogeneously across the city the resources of a civilian security policy. Second, to ascertain the determinants of the negative externalities of the critical points of illegal waste disposal will provide useful information on how to address the causes of their prevalence. Third, to explore other attributes derived from SuDS implementation such as the reduction of the heat island effect as well as to suggest other SuDS strategies such as those associated with blue infrastructure.

5.4 References

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Appendices

Appendix A (Chapter 2), Barranquilla´s localities and police stations

Source: author's elaboration

Appendix B (Chapter 2), List of vacant lots

ITEM	OPEN-AIRE DOUMP NAME	ADDRESS
1	La Compra Venta de 26	Cra 26 de Calles 29 a 30
2	Cruz Cañón	Cra 28 de Calles 29B a 30
3	La Montana	Cra 33 de Cl 29 a 30
4	Callejón de Hospital	Cra 35 de Cl 30 a 28
5	Pared de la Olímpica	Calle 38 de Cras 36 a 35
6	Callejón de San Roque	Cra 36 de Calles 30 a 29
7	Bolis el Chavo	Cra 32 Calle 17
8	La Zona Cachacal	Cra 36 de calles 31 a 36
9	La estación de Buses	Cra 36 Calle 40
10	Piso Alto	Cra 35 calle 38
11	La esquina de Calle 38	Calle 38 con Cra 33
12	Parque Almendra	Cl 37 a 38 Cr 30 a 32
13	Orejas del Teatro Bolívar	Cl 45 de Cras 22 a 23
14	Parque Universal	Cra 36 de calles 45 a 47
15	Cementerio Universal por la 37	Cra 37 de Calles 45 a 50
16	Callejón Parque Universal	Cra 36B de calles 45 a 47
17	Cementerio Calancala	Diagonal 31 de Calle 53D a 50
18	El CASD	Cra 21B de Calles 53D a 57
19	Los Cocos	Calle 37 de Cras 21 a 21ª
20	La Jhonsson de la 21	Cra 21 de Calles 36 a 37
21	Virginia Rossi	Calle 37 de Cras 19D a 18
22	Hamacas El Zaque	Calle 56 de Cras 12C a 11
23	Canal de Metrocentro	Cra 1 de Calles 45 a 46
24	Pared de los Mecánicos	Cra 26 de calles 38 a 39
25	Puente de Covadonga	Cra 30 con Calle 6
26	El Canal de la Bomba de Terpel	Cra 18 de Cl 17 a 14
27	El Debajo Puente de la Calle 30	Circunvalar Calle 30
28	Callejón del paramo	Cra 4A de Calles 30 a 31
29	Electrificadora Unión	Calle 31 de Cras 11 a 13C
30	Torre de la 11	Cra 11 de cl 30 a cl 31
31	La 35B	Cra 35B cl 17
32	Jardín Botánico	Calle 40 de Cras 14 a 13C
33	Pared del colegio Parque Olaya	Cra 30 de Calles 70C a 71
34	Atrás Cementerio Universal	Calle 50 de Cras 37 a 35
35	Atras de Calancala lavaderos	Calle 53D las Cras 25 a 31
36	La Calle 47B	Cl 47B de Cras.18 a 19

ITEM	OPEN-AIRE DOUMP NAME	ADDRESS
37	La Ceiba	Cra 11 de Cls. 54 a 56
38	La Pared Azul Fab	Calle 54 de Cras 10 a 10B
39	Telefónica de la ciudadela	Calle 45G de cras 2E a 3ª
40	Canal Metropolitano	Cl 45 de Cras 1 a 11Sur
41	Entrada Ambulancias al Metro	Cra 7Sur de ClS. 45 a 46
42	Callejón Coliseo-Amira Rosa	Cl 55 de Cras 54 a 55
43	Villatarrel	Cra 72 Cl 72 a 75
44	El Ateneo	Cl 52 de Cras 39 a 42
45	Colegio Lourdes	Cra 50 de Cl 70 a 72
46	Colegio San José	Cra 41D de Cl 74 a 76
47	Canal del Parque	Cl 79 de Cras 59 a 60
48	Canal del Centro Bíblico	Cra 59B de Calles 77B a 78
49	Antiguo Minuto de Dios	Cra 50 de Calles 53 a 54
50	La Piragua	Cl 59 con Cra 43 Esquina
51	Estadio Romelio Martínez	Cl 72 a 74 Cras 44 a 46
52	Canal de Robertico	Cra 51 de Calles 75 a 76
53	Colegio La Salle	Cra 41 de Calles 47 a 50
54	Boxcoulver Bco Popular	Via 40 No. 70 -134
55	La Pared de Marisol	Via 40 de Calles 72 a 75
56	Boxcoulver Arquicentro	Vía 40 No. 78 -340.
57	Boxcoulver Aluminio Reynold	Vía 40 Con Calle 79
58	Lotes de la 96	Cl 96 de Cras 44 y 45B
59	Debajo del Puente de la Cra 38	Cl 65 Cra 38
60	Bodega Águila	Cl 42 a 43 de Cra 50B a 51
61	El Zoológico	Cra 70 de Cl 76 a 77
62	Atrás de la Iglesia	Cra 45 de Calles 66 a 67
63	Suri Salcedo	Cr 47 de Cl 70 a 72
64	Apanexda	Cra 44 de Cl 82 a 84
65	Parque del Sol	Cra 39 de Cl 73B a 74
66	Esquina de la 53B	Cra 44 Cl 53B
67	Parqueadero Clínica del Norte	Cl 70 de Cra 48 a 47
68	La Isla	Cr 42 de Cl 83 a 84
69	Lote Nazar	Cl 81 de Cras 56 a 57
70	Boxcoulvert de calle 92	Cra 51B de Cl 92 a 91
71	Parque América	Cra 50 de Cl 65 a 63
72	La Plaza de la Paz	Cra 45 de Calles 50 a 53

Source: author's elaboration

ITEM	OPEN-AIRE DOUMP NAME	ADDRESS
73	Boxcoulver de la calle 76	Cl 76 con Cra 38
74	Pared de la Nissan	Cl 56 de Cras 43 a 44
75	Uniatlantico	Cl 50 a 51 de Cras 41 a 43
76	Confamiliar	Cra 53 de Cl 60 a 61
77	Esquina de la 94	Cl 94 de Cra 51B a 52
78	Bellas Artes	Cra 53 de Cl 68 a 68B
79	Alrededor Colegio Cervantes	Cl 90 de Cr 51B a 50 - Cr 50 de Cl 87 a 91
80	Canal del Comandante	Cl 84 a 85 de Cras 50 a 52
81	Hotel Majestic	CL 54 de Cras 50 a 53
82	Frito Express	Cra 60 de Cl 77 a 79
83	Antigua Yidi	Cl 78 de Cra 73 a Vía 40
84	Estadio Tomas Arrieta	Cl 45 a 48 de Cra 54 a 56
85	Canal del Pestalozzi	Cra 60 de Calles 68 a 70
86	Boxcoulvert de Gracetales	Vía 40 Cra 65
87	La Bomba	Cra 43 de Cl 57 a 58
88	Hospital de Barranquilla	Cra 35 de Calles 33 a 35
89	Helados Colombia	Calle 41 de Cras 35 a 36
90	El Universitario-Cari	Cra 24 de Calles 57 a 53D
91	Puente Lux Kola	Cra 21 Cl 30 a 37
92	Batea Arroyo de Rebolo	Cra 26 Cl 17 a 21.
93	Puente Peatonal de los Girasoles	Circunvalar de Calles 48 a 49
94	Pavimento Universal	Cra 6 de Calles 98 a 99
95	RCN y 3 las Orejas del Puente	Cordialidad con Circunvalar
96	El puente de la 35	Cra 35 Calle 17
97	Coolechera-Escopiel	Cra 14 de Calles 17 a 18
98	Avenida Hamburgo	Cra 30 de Cl 17 a Cl 6
99	Postobón	Calle 31 de Cras 21 a 21ª
100	El M.O.P.T.	Cra 8B Cl 5 al Puente
101	La Cra 2E	Cra 2E de Cl 45G a Cl 47
102	Canal del Matadero	Cra 2B de Calles 41B a 42
103	Estadio Metropolitano	Cra 4B Sur a 11Sur de Calles 45 a 46
104	Pallares	Cl 28 Cr 5B A 6C

ITEM	OPEN-AIRE DOUMP NAME	ADDRESS
105	Normandy	Cl 8 Cr 7B a 8.
106	El Control de la 10	Cl 56 de Cra 10 a 9
107	Los Chivos.	Cra 27 de Cl 81D a 79
108	La Pared del Uclad	Calle 109 de Cras 35 a 36
109	Canal del Arroyo Rebolo	Cl 30 a Cl 6.
110	Sasoned	Cl 40 de cras 51 a 53D
111	Cudecóm	Cra 54 de Cl 45 al Caño
112	Imocóm	Vía 40 de Cl 77A.
113	Puente Siape	Via 40 con Cl 82
114	Canaletas 46	Cra 46 de Cl 96 a Circunvalar
115	Gabriela Mistral	Cra 38 con Calle 81
116	Vía Juan Mina	Cra 38 de Circunvalar a Km 5 Motel Capri
117	Tres Postes	Cra 71 de Cl 85 a 86
118	Ferretería Reyna	Cl 71 de Cra 72 a Via 40
119	El Oasis	Cl 74 de Cras 68 a 70
120	Vía Agrecóm	Cra 65 de Cl 87 a 98.Cl 98 Cra 65 a 51B
121	Villa Carolina	Cl 88 a CL 92 de Cras 75A a 71
122	Colegio Lourdes	Cra 50 de Cl 70 A 72
123	Villa Santos	Cra 47 de Cl 99 a 104
124	Lote Gerlein	Cl 85A Cra 73
125	Alfredo Stecker	Cl 48 Cra 65 a 67
126	Arroyo Country	Cl 77 de Cra 53 a 59B
127	Arroyo Paraiso	Cl 82 de Cras 74 a 76
128	Circunvalar- Via 40	Circunvalar con Vía 40
129	Kico	Cra 70 de Cl 68B a 69
130	Yidi	Cra 67 de Cl 64 a 66
131	Lote Caracol	Cra 58 Cl 85
132	Remaches	Cra 73 de Cl 75 a 76
133	Rafael Muvdi	Cra 44 No. 32-22
134	Pared Pesquera	Cra 45 de Cl 10 a Cra 46
135	Canal Aduana	Calle 36 de Cra 50 a via 40
136	Tres Puentes	Cl 48 de Cra 44 a 50

Source: author's elaboration

Appendix C (Chapter 2), Robust and bootstrapped standard errors

	Robust SE		Bootstrapped SE	
	Homicides	Interpersonal Violence	Homicides	Interpersonal Violence
Poverty	1.06	1.02	1.06	1.02
	[0.05]	[0.03]	[0.06]	[0.04]
Educ	0.97	0.99	0.97	0.99
	[0.02]	[0.01]	[0.02]*	[0.01]
Dpolice	0.92	0.92	0.92	0.92
	[0.04]**	[0.07]	[0.04]**	[0.09]
Dlots	1.05	1.02	1.05	1.02
	[0.04]	[0.02]	[0.04]	[0.02]
Heatindex	1.00	1.00	1.00	1.00
	[0.00]	[0.00]	[0.00]	[0.00]
Weekends	1.06	1.09	1.06	1.09
	[0.05]	[0.02]***	[0.05]	[0.02]***
Rainy_Season	0.96	0.97	0.96	0.97
	[0.06]	[0.03]	[0.06]	[0.22]
N	468	468	468	468

Estimates are Incidence Rate Ratios (IRR).
Fixed-effect time coefficients of year are omitted.
Standard errors (SE) appear in brackets
*$p < .1$ **$p < .05$ ***$p < .01$
Source: author's elaboration

Appendix D (Chapter 2), Split effect of temperature and relative humidity on crime

	Homicides	Interpersonal Violence
Poverty	1.06	1.02
	[0.03]***	[0.03]
Educ	0.97	0.99
	[0.01]***	[0.00]***
Dpolice	0.93	0.92
	[0.04]*	[0.04]*
Dlots	1.05	1.02
	[0.01]***	[0.01]**
Temp	0.99	1.00
	[0.00]	[0.00]**
Humid	0.99	0.99
	[0.01]*	[0.00]***
Weekends	1.06	1.08
	[0.03]**	[0.02]***
Rainy_Season	1.00	1.00
	[0.06]	[0.01]
N	468	468

Estimates are Incidence Rate Ratios (IRR).
Fixed-effect time coefficients of year are omitted.
Standard errors (SE) appear in brackets
*$p < .1$ **$p < .05$ ***$p < .01$
Source: author's elaboration

Appendix E (Chapter 3), Neighbourhoods per locality

Locality	Neighbourhood
Norte Centro Histórico	América
	Alameda del Río
	Colombia
	Los Alpes
	Nuevo Horizonte
	Granadillo
	Los Nogales
	La Cumbre
	Miramar
	Campoalegre
	El Country
	El Tabor
	Ciudad Jardín
	Altos del Prado
	El Prado
	La Campiña
	El Porvenir
	Villa Country
	La Loma
	Bendición de Dios
	Centro
	Barlovento
	Barrio Abajo
	Boston
	San Francisco
	La Concepción
	Modelo
	La Felicidad
	Santa Ana
	Villanueva
	Bellavista
	El Boliche
	Montecristo
	El Rosario

Locality	Neighbourhood
Suroccidente	El Silencio
	La Libertad
	La Manga
	Nueva Colombia
	Mequejo sector Loma Roja
	Olaya
	Nueva Granada
	Las Delicias
	Las Mercedes
	Las Colinas
	Kalamary
	Los Jobos
	Terrenos Pastoral Social
	Betania
	Los Andes
	El Recreo
	Lucero
	Los Niños
	Los Pinos
	San Felipe
	Alfonso López
	Bernardo Hoyos
	Villa Flor
	Villa San Pedro
	Los Rosales
	California
	Ciudadela de la Salud
	Ciudadela de la Paz
	El Golfo
	Romance
	El Bosque
	Las Malvinas
	Evaristo Sourdis
	La Ceiba
	La Gloria
	San Pedro Alejandrino
	La Cordialidad

Source: author's elaboration

Neighbourhoods per Locality

Locality	Neighbourhood
Riomar	Siape
	San Salvador
	Las Flores
	La Playa
	Villa Carolina
	La Floresta
	Las Tres Ave Marías
	Buenavista
	Altos del Limón
	Altos de Ríomar
	Villa Santos
	Paseo La Castellana
	Paraíso
	San Vicente
	Villa Campestre
	El Poblado
	Santa Mónica
	Andalucía
	Villa del Este
	El Castillo
	Solaire
	El Golf
	San Marino
	Adela de Char
	Altamira

Locality	Neighbourhood
Metropolitana	San Luis
	Villa San Carlos
	Ciudadela 20 de Julio
	Las Granjas
	Buenos Aires
	El Santuario
	Kennedy
	La Alboraya
	La Victoria
	Las Gardenias
	Los Continentes
	Los Girasoles
	San José
	Santa María
	Urbanización Las Cayenas
	Villa San Pedro II
	Villa Sevilla
	Las Américas
	La Sierrita
	Veinte de Julio
	Santo Domingo de Guzmán
	Carrizal
	San Martín
	Cevillar

Source: author's elaboration

Neighbourhoods per Locality

Locality	**Neighbourhood**
Suroriente	La Luz
	La Chinita
	Pasadena
	Primero de Mayo
	Las Nieves
	Las Palmas
	Tayrona
	Urbanización El Limón
	Boyacá
	San José
	La Magdalena
	Ciudadela 20 de Julio
	El Campito
	El Ferri
	El Limón
	Bella Arenas
	Buenos Aires
	José Antonio Galán
	San Nicolás
	Simón Bolívar
	Costa Hermosa
	Universal I y II
	Villa del Carmen
	El Milagro
	Atlántico
	Urbanización la Luz
	Villa Blanca
	La Alboraya
	Las Dunas
	Los Laureles
	Santa Elena
	Rebolo
	San Roque
	La Victoria
	Moderno
	Los Trupillos
	La Unión
	Montes
	Chiquinquirá

Source: author's elaboration

Appendix F (Chapter 3), List of open-air dumps

Number	Address	Latitude	Longitude
1	Carrera 39 de Calle 30 a 32	10.96854	-74.78132
2	Carrera 39 de Calle 35 a 36	10.96854	-74.78132
3	Carrera 44 # 32 – 22	10.9843715	-74.7847245
4	Calle 31 de Carrera 43 a 44	10.96854	-74.78132
5	Calle 10 de Carrera 45 a 46	10.96854	-74.78132
6	Carrera 42 de Calle 8 a 9	10.96854	-74.78132
7	Vía 40 con Calle 82	10.96854	-74.78132
8	Calle 48 de Carrera 44 a 50	10.96854	-74.78132
9	Vía 40 con Calle 77ª	10.96854	-74.78132
10	Calle 71 de Carrera 72 a Vía 40	10.96854	-74.78132
11	Calle 77 # 53 - 59B	11.0063629	-74.8016586
12	Carrera 46 de Calle 96 a Circunv.	10.96854	-74.78132
13	Calle 40 de Carrera 51 a 53	10.96854	-74.78132
14	Carrera 51 con Vía 40	10.96854	-74.78132
15	Carrera 30 de 17 – 7	10.96854	-74.78132
16	Carrera 35 de Calle 30 a 28	10.96854	-74.78132
17	Carrera 35 de Calle 35 a 33	10.96854	-74.78132
18	Carrera 35 con Carrera 47	10.96854	-74.78132
19	Canal arroyo de Rebolo 17 a 14	10.96854	-74.78132
20	Cordialidad con Carrera 22	10.96854	-74.78132
21	Carrera 2B Calle 41B – 42	10.9364426	-74.7902205
22	Carrera 2E de Calle 45G a 48	10.96854	-74.78132
23	De Calle 30 a Calle 6	10.96854	-74.78132
24	Carrera 35 Calle 17	10.9843055	-74.8111314
25	Calle 50 Carrera 37 a 35	10.96854	-74.78132
26	Calle 47 Carrera 35 a 37	10.96854	-74.78132
27	Circunv. con Carrera 9G-Acera	10.96854	-74.78132
28	Calle 37 de Carreras 19D a 18	10.96854	-74.78132
29	Carrera 8 de Calle 10 a Calle 12	10.96854	-74.78132
30	Calle 51B con Circunvalar	10.96854	-74.78132

Source: author’s elaboration

Appendix G (Chapter 3), Survey questionnaire

Barranquilla, August 2017 – March 2018

Hi! My name is _____. I am a Research Assistant for Infocaribe. This is my badge. My purpose is to ask you some questions about your attitudes the eradication of open-air dumps in Barranquilla. This survey is sponsored by the Prefecture of Barranquilla. This institution plans to use the results to improve project planning for the current Mayor's policies. Your participation in this study is voluntary and you may decline to answer any of the questions. At your request, we will terminate the interview. However, your participation is very important for the successful completion of this study. The information you provide will be strictly confidential and will only be reported in statistical summaries. It should take about 30 minutes to complete the entire interview. As we proceed, please note that there are no right or wrong answers in this survey. Only your personal views on these projects are important for this interview.

(If person accepts to be interviewed, then proceed. If person rejects it, say thanks kindly and go away)

I. SURVEY FILTER

Date: dd/mm/yyyy | | | **2017** | **Start time:** | | **No.** | | | |

Q1. Do you live in your own home?

YES **1** NO **2**

Q2. Are you a person who makes decisions at home?

YES **1** NO **2**

Q3. Have you have lived in Barranquilla at least 8 months?

YES **1** NO **2**

(CONTINUE WITH THE INTERVIEW) **(END THE INTERVIEW AND REPLACE THE HOME)**

II.GENERAL IDENTIFICATION

Q4. Neighbourhood	**Q5. Socio-Economic Division**	**Q6. Address**
Q7. Interviewee's Name	**Q8. Age**	**Q9. Gender** **Mal** **1** **Female** **2**

III.HOUSING

Q10. Type of housing *(If not answered House, skip to Q12)*

1 House: 2 Apartment: 3 Lot-House:

4 Other: Specify _____

Q11. What type of house do you live in?

1 Detached 3 Terraced

2 Semi-detached 4 Other: Specify

IV.ENVIRONMENTAL ATTITUDES (GENERAL)

Q12. How long have you lived in this property?

Years ☐ Months ☐

Q13. How long have you lived in this neigbourhood?

Years ☐ Months ☐

Q14. How concerned are you about environmental issues in general? Read

1 Not at all concerned 2 Moderately concerned 3 Extremely concerned

V. RISK AVERSION (GENERAL)

Q15. How do you see yourself: Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks? [DISPLAY CARD A].

Not at all willing to take risks (0)	1	2	3	4	5	6	7	8	9	Very willing to take risks (10)

VI. AWARENESS

Q16. Are you aware of any open-air dump located in your neighbourhood?

(Tick)

1 YES 2 NO

(If the answer is No, skip to Q38)

VII. DEGREE OF AWARENESS

Q17. How would you rate the problem of illegal dumping in Barranquilla? Read options.

[1] Not a problem [2] Minor problem [3] Moderate problem [4] Severe problem [5] Extreme problem

VIII. WITNESSING ILLEGAL DUMPING

Q18. Have you seen any person or group of people in your neighbourhood dumping wastes illegally? Tick.

[1] **YES** [2] **NO**

IX. FREQUENCY OF OCCURRENCE

Q19. How frequently have you seen the disposal of waste in open-air dumps? Tick.

[1] Daily [2] Weekly [3] Monthly [4] Annually [5] Other (specify) _____

X. DURATION OF THE PHENOMENON

Q20. For how long has it been occurring? Tick.

[ ] A few weeks [ ] A few months [ ] A year [ ] 2-5 years [ ] 6-9 years [ ] >10 years [ ] I don't know

XI. WAYS OF DISPOSAL

Q21. When it comes to dumping waste illegally, which methods do you think that people commonly use in Barranquilla? Tick all that apply

a. Driving to an open-air dump	**1**
b. Walking to an open-air dump	**2**
c. Throwing it in the nearest creek	**3**
d. Paying animal traction vehicles to dispose of the waste	**4**
e. I don't know	**5**
f. Other	**0**

Specify

_____

XII. POSSIBLE CAUSES

Q22. Who do you think is the biggest contributor to open-air dumps? (Please, rank the following in order of importance: 1 biggest contributor, 6: least significant contributor; DISPLAY CARD H.

a. Construction, demolition, refurbishing, roofing or landscaping contractors	
b. Garden services	
c. Vehicle repair or tire shops	
d. Scrap collectors	
e. Waste pickers (animal traction vehicles)	
f. Local residents	

XIII. REASONS FOR ILLEGAL DUMPING

Q23. Why do you think people you ordered first in the above question dump waste illegally? (Please, rank the following in order of importance: 1 least significant contributor, 6: biggest contributor; DISPLAY CARD I.

a. They don't know what else to do with it	
b. Proper disposal is costly	
c. It's much easier	
d. Missed refuse collection day	
e. No/unreliable waste collection services	
f. Unaware of the services available to them	
g. Bad habits of residents	

XIV. QUALITY OF LIFE (SPECIFIC)

Q24. Do you think having an open-air dump in your neighbourhood affect the residents' quality of life?

1 **YES**

2 **NO**

(If answer is NO, Skip to Q46)

Q25. In what way(s) do you think the presence of an open-air dump affects quality of life? Please, rank the following in order of importance: 1 biggest contributor; 6: least significant contributor, DISPLAY CARD J.

1 a. Respiratory problems

2 b. Vagrants

3 c. Aesthetics

4 d. Smell

5 e. Noise

6 f. Unwanted Animals (stray dogs, snakes, donkeys)

XV. ENVIRONMENTAL ATTITUDES (SPECIFIC)

Q26. Open-air dumps have negative effects on the environment due to the different kinds of pollution they generate. Please, rank the following types of pollution generated by open-air dumps in order of importance: 1 biggest contributor, 5: least significant contributor; DISPLAY CARD K.

1 Vegetation growth	3 Water pollution	5 Air pollution
2 Soil pollution	4 Harmful to animals	

XVI. IMPORTANCE OF ERADICATION

Q27. On a scale of 1 to 5, how important do you think it is to eliminate illegal dumping in Barranquilla? Read options.

1 Not Important	3 Don't know/Neutral	5 Extremely Important
2 Not Very Important	4 Quite Important	

XVII. PREVENTION MEASURES

Q28. In your opinion, what services can the local government improve upon to prevent illegal dumping? Please rank the following in order of importance: 1 biggest contributor, 6: least significant contributor; DISPLAY CARD L.

1 a. Provide waste containers to specific locations of the city

2 b. Employ more workers for public cleaning

3 c. Timely waste collection services

4 d. Fence off area

5 e. Enlarge the official landfill of the city

6 f. Ban scrap collectors (carromuleros)

7 g. Other, (Specify) _____

XVIII. NEIGHBOURHOOD INVOLVEMENT IN COMBATTING ILLEGAL DUMPING

Q29. Is the community of your neighbourhood involved in combatting illegal dumping?

[1] **YES** [2] **NO**

XIX. INSTITUTIONAL TRUST

Q30. How much confidence do you have in the local government to solve the problem of illegal dumping?

[1] Very low [3] Moderate [5] Very High

[2] Low [4] High

XX. RISK COMMUNICATION

Q31. Do you know about any informational campaigns from the local government aimed at preventing the illegal dumping in Barranquilla?

[1] **YES** [2] **NO**

(If the answer is No, skip to Q54)

Q32. Through which means have you seen local government information about risk prevention for the presence of open-air dumps? Read options.

[1] Regional TV channel [4] Road signs

[2] Radio [5] Other

[3] Press (specify)

Q33. How often have you observed information from local government aimed at preventing the risks caused by the presence of open-air dumps?

[1] Daily [4] Once a week [7] Once a month [10] Once a year

[2] 3-6 times a week [5] 3-6 times a month [8] 3-6 times a year

[3] Twice a week [6] Twice a month [9] twice a year

XXI. VALUING THE ERADICATION OF OPEN-AIR DUMPS

Depicting the environmental scenario

The proliferation of open-air dumps within the perimeter of the District of Barranquilla is of concern to local authorities. Currently, the Prefecture of Barranquilla recognizes the existence of 30 open-air dumps within the city limits. These open-air dumps are deteriorating the urban landscape, generating pollution, and causing respiratory diseases in the most vulnerable population. The Prefecture of Barranquilla is currently considering a programme aimed at eradicating these open-air dumps. The time horizon for eradicating all open-air dumps is three years. In order to eradicate all open-air dumps within the perimeter of the city, households would have to assume a monthly increase in water, cleaning and sewage bills for three years to help finance the project.

Payment question

Q34. Would you be willing to pay for these measures which would eliminate open-air dumps in Barranquilla?

1	YES	2	NO

(If answered "No", skip to Q37)

Q35. Bearing in mind the information presented earlier, **what of the following monthly figures would you be willing to pay to finance the eradication of open-air dumps in Barranquilla in three years?**

Please, bear in mind that whatever the amount you choose it will come from your available income.

☐ $ 50	☐ $ 100	☐ $ 300	☐ $ 500
☐ $ 1,000	☐ $ 1,200	☐ $ 1,500	☐ $ 1,700
☐ $ 2,000	☐ $ 2,300	☐ $ 2,500	☐ $ 2,800
☐ $ 3,000	☐ More than $3,000	How much? ☐	

Q36. Which one of the following statements best describes the main reason why you would not be willing to pay anything?

1 I cannot afford to pay

2 I object to paying taxes

3 The eradication of illegal dumpsites is not important to me

4 The Prefecture/ Council or another public entity should pay

5 I don't believe the eradication of illegal dumpsites will actually take place

6 I don't use illegal dumpsites

7 I pay enough tax already

8 Other (Please specify):_____

XXII. QUALITY OF LIFE

Q37. Thinking about the good and bad things in your life, which of these best describes your life as a whole?

1 Very Bad 2 Bad 3 Neutral 4 Good 5 Very good

6 Exceptional

Q38. How is your health in general? Would you say that it is…?

1 **Very bad** 2 **Bad** 3 **Fair** 4 **Good** 5 **Very good**

6 **Exceptional**

Q39. Would you say that…

1 Neighbours never care about each other in this area

2 Neighbours rarely care about each other in this area

3 Neighbours sometimes care about each other in this area

4 Neighbours almost always care about each other in this area

5 Neighbours always care about each other in this area

Q40. How often do you speak with your neighbours? Please select the option that most closely applies to your case.

1 Every day

2 A few times per week

3 About once a week

4 A few times per month

5 About once a month

6 3-6 times per year

7 About twice per year

8 About once per year

9 Less than once per year

Q41. How safe do you feel walking alone in your neighbourhood late at night? Read. Circle.

1 Very unsaf 2 A bit unsafe 3 Very safe

4 Fairly safe 5 Safe

XXIII. HOUSEHOLD SOCIO-DEMOGRAPHIC PROFILE

Q42. Overall, how satisfied or dissatisfied are you with the area where you live?

1	2	3	4	5
Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied

Q43. How many people make up (live in) your home?

Q44. From these people, how many are:

a. Children (under 5 years): ___

b. Children (between 5 and 12 years):___

c. Teenagers (between 13 and 18 years):___

d. Adolescents (between 19 and 25 years):

e. Adults (between 26 and 59 years):___

f. Seniors (between 60 years and more): ___

Q45. From these people, how many work:

Q46. Civil status?

- 1 Single
- 2 Married
- 3 Divorced
- 4 Widowed
- 5 In a relationship but not married
- 6 Other (specify) _____

Q47. What is your highest level of education?

- 1 Elementary school
- 2 High school
- 3 Technical
- 4 Technological
- 5 College diploma
- 6 Specialization
- 7 Master's degree
- 8 PhD degree, Post-doc
- 9 Other (specify) _____

XXIV. POLITICAL VIEWS

Q48. Are you interested in politics?

1	**YES**
2	**NO**

(If the answer is No, skip to Q71)

Q49. Which political party do you identify with?

1	Partido de la U	6	Partido Liberal
2	Partido Conservador	7	Alianza Verde
3	Partido Cambio Radical	8	(MIRA)
4	Polo Democrático Alternativo	9	Other
5	Partido Opción Ciudadana		specify_____

XXV. ENVIRONMENTAL ENGAGEMENT

Q50. Do you belong to (or support) an environmental organization?

1	**YES**	2	**NO**

XXVI. ORIGIN

Q51. Were you born in Barranquilla?

1	**YES**	2	**NO**

XXVII. JOB PROFILE

Q52. What is your current work status?

- 1 In employment full-time
- 2 In employment part-time
- 3 Retired
- 4 Home domestic duties
- 5 Not in employment
- 6 Unable to work due to permanent illness/disability
- 7 Other

Q53. Do you work for the Government?

1 **YES** 2 **NO**

Q54. Are you an independent worker?

1 **YES** 2 **NO**

Q55. Do you drive any vehicle (private car, taxi, motorbike, bus)?

1 **YES** 2 **NO**

Q56. Do you own any vehicle (private car, taxi, motorbike, bus)?

1 **YES** 2 **NO**

Q57. In which of the following intervals is your household's monthly income?

- 1 **Less than $500,000**
- 2 **$500,000- $ 737,717 (legal minimum wage)**
- 3 **$737,717 - $ 1,000,000**
- 4 **$1,000,000 - $ 2,000,000**
- 5 **$2,000,000 - $ 3,000,000**
- 6 **$3,000,000 - $ 4,000,000**
- 7 **$4,000,000 - $ 5,000,000**
- 8 **More than $5,000,000**

Source: author's elaboration

Appendix H (Chapter 3), Variable list

Variable	Type	Description
Age	Discrete	Head of household's age
Male	Categorical	Head of household's gender
House	Categorical	Head of household's family lives in a house
Time_house	Discrete	Time the household has lived in the house in years
Time_neighbourhood	Discrete	Time the household has lived in the neighbourhood in years
Distance	Continuous	Household's distance to the nearest open-air dump in metres
Concern	Categorical	Head of household is concerned for the environment
Awareness	Categorical	Head of household is aware of the illegal dumping of wastes in his/her neighbourhood
Witnessing	Categorical	Head of household has seen people throwing wastes in open-air dumps
Marital_status	Categorical	Head of household current civil status
Household_size	Discrete	Number of the members of each household
Education	Discrete	Head of household highest level of schooling achieved
Income	Continuous	Household's total average monthly income
Life_assessment	Categorical	Head of household's self-rate assessment of his/her own life
Health_assessment	Categorical	Head of household's self-rate assessment of his/her own health condition
Neighbours_care	Categorical	Neighbours take care each other
Neighbours_meetings	Categorical	Neighbours meet each other at least once a week
Neighbourhood_satisfaction	Categorical	Head of household is satisfied with the neighbourhood where s/he lives
Walking_safely	Categorical	It is safe to walk alone late at night in the household's neighbourhood
Community_participation	Categorical	Head of household is involved in community activities
Institutional_trust	Categorical	Head of household trusts on local government
Environmentalist	Categorical	Head of household participates in an environmental organization
Political_activism	Categorical	Head of household participates in politics

Source: author’s elaboration

Appendix I (Chapter 3), Interaction between institutional trust and education

	Coefficient	Marginal Effect
Age	-9.49	-0.00
	[4.75]**	
Male	-253.64	-0.06
	[124.45]**	
House	-290.95	-0.07
	[140.38]**	
Time_house	0.25	0.00
	[7.20]	
Time_neighbourhood	0.01	0.00
	[6.97]	
Distance	-0.09	0.00
	[0.08]*	
Concern	202.55	-0.05
	[124.77]*	
Awareness	-416.70	-0.10
	[165.40]**	
Witnessing	735.83	0.18
	[162.68]***	
Marital_status	84.82	0.02
	[132.26]	
Household_size	58.36	0.02
	[30.71]*	
Education	-127.90	-0.03
	[43.83]***	
Income	1.38E-04	0.00
	[4E-05]***	
Life_assessment	363.63	0.09
	[198.46]*	
Health_assessment	-156.25	-0.04
	[152.14]	
Neighbours_care	222.37	-0.05
	[147.88]	
Neighbours_meetings	518.06	-0.12
	[188.77]***	
Neighbourhood_satisfaction	431.05	0.11
	[163.51]***	
Walking_safely	233.61	0.06
	[146.50]*	
Community_participation	-136.37	0.03
	[123.05]*	
Institutional_trust	1552.73	-0.36
	[696.33]**	
Environmentalist	618.94	0.15
	[334.51]*	
Political_activism	-64.37	-0.02
	[140.74]	
Intrust_Education	122.24	0.03
	[49.90]**	
Observations	815	
McFadden Pseudo R2	0.07	

Standard errors in brackets
* $p < 0.1$ **$p < 0.05$ ***$p < 0.01$
Source: author's elaboration

Appendix J (Chapter 4), Survey questionnaire

Barranquilla, August 2017 – March 2018

Hi! My name is _____. I am a Research Assistant for Infocaribe. This is my badge. My purpose is to ask you some questions about your attitudes towards the implementation of a sustainable urban drainage system that would contribute to mitigate the effects of the "arroyos". This survey is sponsored by the Prefecture of Barranquilla. This institution plans to use the results to improve project planning for the current Mayor's policies. Your participation in this study is voluntary and you may decline to answer any of the questions. At your request, we will terminate the interview. However, your participation is very important for the successful completion of this study. The information you provide will be strictly confidential and will only be reported in statistical summaries. It should take about 30 minutes to complete the entire interview. As we proceed, please note that there are no right or wrong answers in this survey. Only your personal views on these projects are important for this interview.

(If person accepts to be interviewed, then proceed. If person rejects it, say thanks kindly and go away)

I. SURVEY FILTER **Date: dd/mm/yyyy** [ ][ ] 2017 **Start time:** [ ] **No.** [ ][ ][ ][ ]

Q1. Do you live in your own home?

YES [1] NO [2]

Q2. Are you a person who makes decisions at home?

YES [1] NO [2]

Q3. Have you have lived in Barranquilla at least 8 months?

YES [1] NO [2]

(CONTINUE WITH THE INTERVIEW) **(END THE INTERVIEW AND REPLACE THE HOME)**

II.GENERAL IDENTIFICATION

Q4. Neighbourhood	**Q5. Socio-Economic Division**	**Q6. Address**
Q7. Interviewee's Name	**Q8. Age** [ ]	**Q9. Gender** Male [1] Female [2]

III.HOUSING

Q10. Type of housing *(If not answered House, skip to Q12)*

1 House: 2 Apartment: 3 Lot-House:
4 Other: Specify _____

Q11. What type of house do you live in?

1 Detached 3 Terraced
2 Semi-detached 4 Other: Specify _____

Q12. How long have you lived in this property?

Years ____ Months ____

Q13. How long have you lived in this neigbourhood?

Years ____ Months ____

IV.ENVIRONMENTAL ATTITUDES (GENERAL)

Q14. How concerned are you about environmental issues in general? Read

1 Not at all concerned 2 Moderately concerned 3 Extremely concerned

V. RISK AVERSION (GENERAL)

Q15. How do you see yourself: Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks? [DISPLAY CARD A].

Not at all willing to take risks (0)	1	2	3	4	5	6	7	8	9	Very willing to take risks (10)

FLASH-FLOODS

VI. EXPERIENCE

Q16. Have you been affected by flash-floods in the last 10 years? Read options.

YES 1 NO 2

(If the answer is No, skip to Q18)

Q17. What kind of damage have you suffered on account of the flash-floods in the city of Barranquilla in the last 10 years? Read options. Please, tick all that apply.

1 House flood
2 Vehicle damage
3 Health issues
4 Public transportation delay
5 Death of someone you know
6 Other (specify): _____

VII. RISK PERCEPTION

Q18. What is your perception regarding the risks that bring about the flash-floods in Barranquilla? Read options.

- [1] The flash-floods are not dangerous at all
- [2] The flash-floods are sometimes dangerous
- [3] The flash-floods are very dangerous

Q19. How many people do you think will die as a result of flash floods over the next 10 years?

[ ]

VIII. RISK COMMUNICATION

Q20. Have you seen/ heard/ read about any informational campaigns from the local government aimed at preventing the dangers of flash floods in Barranquilla?

YES [1] NO [2]

(If the answer is No, skip to Q23)

Q21. Through what means have you seen/heard/read information from the local gov't aimed at risk prevention by flash floods? Read options.

- [1] Regional TV channel "Telecaribe"
- [2] Radio
- [3] Press
- [4] Road signs
- [5] Mobile app
- [6] Other (specify):_____

Q22. How many times have you seen/heard/read information from the local gov't aimed at preventing the dangers caused by flash-floods? Read options.

- [1] Daily
- [2] 3-6 times a week
- [3] Twice a week
- [4] Once a week
- [5] 3-6 times a month
- [6] Twice a month
- [7] Once a month
- [8] 3-6 times a year
- [9] Twice a year
- [10] Once a year

Q23. Have you seen / heard / read information aimed at preventing the dangers caused by flash floods by any other public or private entity?

[1] YES (Which entity?) _____ [2] NO

IX. AWARENESS

Q24. Do you feel any of your assets (house, apartment, vehicle, motorbike, etc.) is at risk of flooding because of the flash-floods? Read options.

[1] No, not at risk [2] Yes, at risk some minor damages [3] Yes, at risk of significant damages

X. MITIGATION

Q25. On a scale of 1 to 5, how important do you think the following reasons are in order to mitigate the problem of flash floods in Barranquilla?	Not important	Not very important	Don't know/ Neutral	Quite important	Extremely important
a. Reduce damage to homes	1	2	3	4	5
b. Reduce damage to vehicles	1	2	3	4	5
c. Reduce the possibility of personal injury/death	1	2	3	4	5
d. Improve vehicular mobility	1	2	3	4	5
e. Improve pedestrian mobility	1	2	3	4	5
f. Other (specify) _____	1	2	3	4	5

XI. PREPAREDNESS

Q26. How prepared are you for a coming flash-flood? Read.

1 Not prepared at all

2 Moderately prepared

3 Well prepared

Q27. Do you do any of the following to prepare for a flash flood? Read options. Circle all that apply.

1	Move items of sentimental value	11	Move myself and others to a safe place (e.g upstairs)
2	Move or protect costly items (e.g. fridge, furniture)	12	Prepare for loss of power (candles/torches)
3	Block doorways/airbricks	13	Move pets/livestock to a safe place
4	Put sandbags, flood-boards or blood gates in place	14	Move cars to a safe place
5	Switch off gas/electricity	15	Help neighbours
6	Block toilets	16	Evacuate emergency
7	Watch the water levels	17	Contact Emergency Services for assistance
8	Collect clothing, food, water, medication.	18	Other (Please specify)
9	Listen to TV/radio for more information		
10	Contact friends/family for advice		

XII. WORRY

Q28. How worried are you regarding the flash-floods during the rainy season? Read.

[1] Not worried at all [2] Moderately worried [3] Greatly worried

XIII. INSTITUTIONAL TRUST

Q29. How much confidence do you have in the local government to solve the problem of flash floods? Read.

[ ] No trust [ ] Very low [ ] Low [ ] Moderate [ ] High [ ] Very High

Q30. Rate your confidence in the following institutions for their ability to respond to emergencies caused by flash-floods.

Institution	No trust	Very low	low	Moderate	High	Very High
a. Fire Department	1	2	3	4	5	6
b. Civilian Defence Force	1	2	3	4	5	6
c. Colombian Red Cross	1	2	3	4	5	6
d. Police and Military Forces	1	2	3	4	5	6
e. Office of Attention and Prevention of Disasters	1	2	3	4	5	6

XIV. PREVIOUS KNOWLEDGE OF SUDS

Q31. Have you heard of any of the following strategies to mitigate the run-off that causes the flash floods? Read options.

Strategies	Yes	No
a. In-house tanks for collecting rainwater	1	2
b. Green roofs on homes and buildings	1	2
c. Rain Gardens	1	2
d. Porous Pavement	1	2
e. Grass Pavement	1	2
f. Green zones	1	2

XV. VALUING OF SUDS.

a) Depicting the environmental scenario

According to experts' assessments it is impossible to build a sewer system for rainfall water in Barranquilla. Therefore, local authorities will have to implement a Sustainable Urban Drainage System, whose first foundations are currently under way. This system is based on six strategies (**show images of each**):

- Tanks for collecting rainwater in homes;
- Green roofs on homes and buildings;
- Rain gardens;
- Porous pavement;
- Grass pavement; and
- Green zones.

According to recent studies by the World Bank in the next thirty years the city will be exposed to severe flooding because of increased rainfall due to climate change. If above-mentioned measures are not taken now, inhabitants will assume higher level of risks regarding their own life and their properties.

b) Payment question

We want to assess how much **you would be willing to pay** for the implementation of a Sustainable Urban Drainage System (interviewers must show the prop card to clarify the three scenarios) aimed at reducing the negative effects from flash floods.

We are going to show you a set of eight cards, each one with three alternatives. These alternatives have a cost, except the "Current situation", whose cost is always zero. The cost represents a monetary increase in the annual Land Tax. Please, choose the alternative in each of the following cards that you most prefer. Remember that whatever the alternative chosen your monetary contribution will be taken from your own family budget, unless you elect the "Current situation".

Q32. Which of these alternatives best suits your preferences towards the implementation of SUDS in Barranquilla? Show 10 cards in the written order.

Order	Card number	alternative chosen			Order	Card number	alternative chosen		
1		Actual (0)	-1	-2	6		Actual (0)	-1	-2
2		Actual (0)	-1	-2	7		Actual (0)	-1	-2
3		Actual (0)	-1	-2	8		Actual (0)	-1	-2
4		Actual (0)	-1	-2	9		Actual (0)	-1	-2
5		Actual (0)	-1	-2	10		Actual (0)	-1	-2

XVI. WILLINGNESS TO IMPLEMENT IN-HOUSE SUDS MEASURES

Q33. Would you resort to any of these three strategies in your home to help in reducing the run-off that causes the flash-floods? Show images.

Strategies	Yes	No	Unsure
a. In-house tanks for collecting rainwater	1	2	0
b. Green roofs on homes and buildings	1	2	0
c. Rain Gardens	1	2	0

XVII. SUDS vs BUILT ENVIRONMENT

Q34. Which of the following options do you think would be most effective for reducing the negative effects from flash-floods? (Please rate the following options on a scale from 1 least effective to 3 most effective)

a. Only channeling the main flash-floods	
b. Only the implementation of the six (6) SUDS strategies	
c. Channeling the main flash-floods plus the six SUDS strategies	

XVIII. QUALITY OF LIFE

Q35. Thinking about the good and bad things in your life, which of these best describes your life as a whole?

[1] Very Bad [2] Bad [3] Neutral [4] Good [5] Very good [6] Exceptional

Q36. How is your health in general? Would you say that it is…?

[1] Very bad [2] Bad [3] Fair [4] Good [5] Very good [6] Exceptional

Q37. Would you say that…

[1] Neighbours never care about each other in this area

[2] Neighbours rarely care about each other in this area

[3] Neighbours sometimes care about each other in this area

[4] Neighbours almost always care about each other in this area

[5] Neighbours always care about each other in this area

Q38. How often do you speak with your neighbours? Please select the option that most closely applies to your case.

[1] Every day
[2] A few times per week
[3] About once a week
[4] A few times per month
[5] About once a month
[6] 3-6 times per year
[7] About twice per year
[8] About once per year
[9] Less than once per year

Q39. How safe do you feel walking alone in your neighbourhood late at night? Read. Circle.

Very unsafe [1] A bit unsafe [2] Very safe [5]

Fairly safe [3] Safe [4]

Q40. Overall, how satisfied or dissatisfied are you with the area where you live?

[1] Very dissatisfied [2] Dissatisfied [3] Neither satisfied nor dissatisfied [4] Satisfied [5] Very satisfied

XIX. HOUSEHOLD SOCIO-DEMOGRAPHIC PROFILE

Q41. How many people make up (live in) your home?

Q42. From these people, how many are:

a. Children (under 5 years): ___

b. Children (between 5 and 12 years): ___

c. Teenagers (between 13 and 18 years): ___

d. Adolescents (between 19 and 25 years):

e. Adults (between 26 and 59 years): ___

f. Seniors (between 60 years and more): ___

Q43. From these people, how many work:

Q44. Civil status?

[1] Single
[2] Married
[3] Divorced
[4] Widowed
[5] In a relationship but not married
[6] Other (specify) _____

Q45. What is your highest level of education?

[1] Elementary school
[2] High school
[3] Technical
[4] Technological
[5] College diploma
[6] Specialization
[7] Master's degree
[8] PhD degree, Post-doc
[9] Other (specify) _____

XXXVII. POLITICAL VIEWS

Q46. Are you interested in politics?

[1] YES

[2] NO

(If the answer is No, skip to Q71)

Q47. Which political party do you identify with?

[1] Partido de la U

[2] Partido Conservador

[3] Partido Cambio Radical

[4] Polo Democrático Alternativo

[5] Partido Opción Ciudadana

[6] Partido Liberal

[7] Alianza Verde

[8] (MIRA)

[9] Other

specify_____

XXXVIII. ENVIRONMENTAL ENGAGEMENT

Q48. Do you belong to (or support) an environmental organization?

[1] YES [2] NO

XXXIX. ORIGIN

Q49. Were you born in Barranquilla?

[1] YES [2] NO

XL. JOB PROFILE

Q50. What is your current work status?

1. In employment full-time
2. In employment part-time
3. Retired
4. Home domestic duties
5. Not in employment
6. Unable to work due to permanent illness/disability
7. Other

Q51. Do you work for the Government?

YES [1] NO [2]

Q52. Are you an independent worker?

YES [1] NO [2]

Q53. Do you drive any vehicle (private car, taxi, motorbike, bus)?

YES [1] NO [2]

Q54. Do you own any vehicle (private car, taxi, motorbike, bus)?

YES [1] NO [2]

Q55. In which of the following intervals is your household's monthly income?

1. Less than $500,000
2. $500,000- $ 737,717 (legal minimum wage)
3. $737,717 - $ 1,000,000
4. $1,000,000 - $ 2,000,000
5. $2,000,000 - $ 3,000,000
6. $3,000,000 - $ 4,000,000
7. $4,000,000 - $ 5,000,000
8. More than $5,000,000

Source: author's elaboration

Appendix K (Chapter 4), Pictures of SuDS strategies

Green roofs

Rain gardens

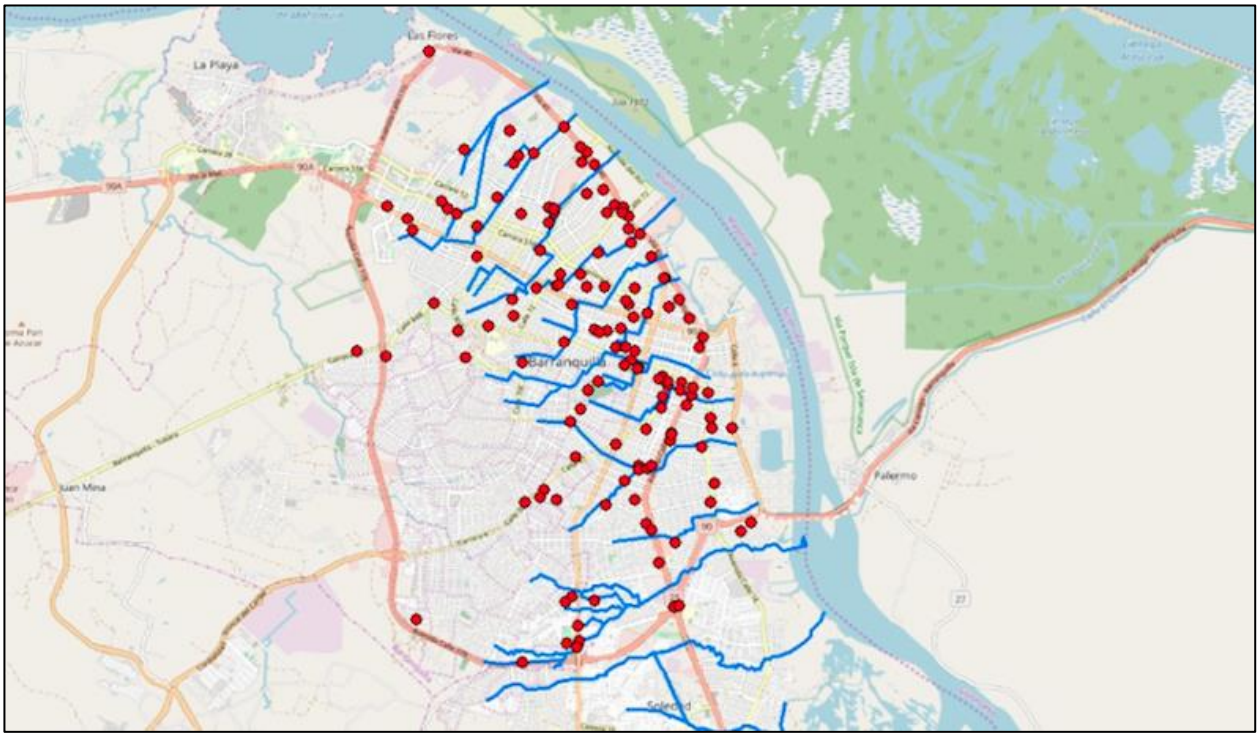
Green zones

Porous pavement

Rainwater tank

Source: author's elaboration

Appendix L (Chapter 5), Spatial distribution of open-air dumps and flash-floods



Source: author's elaboration