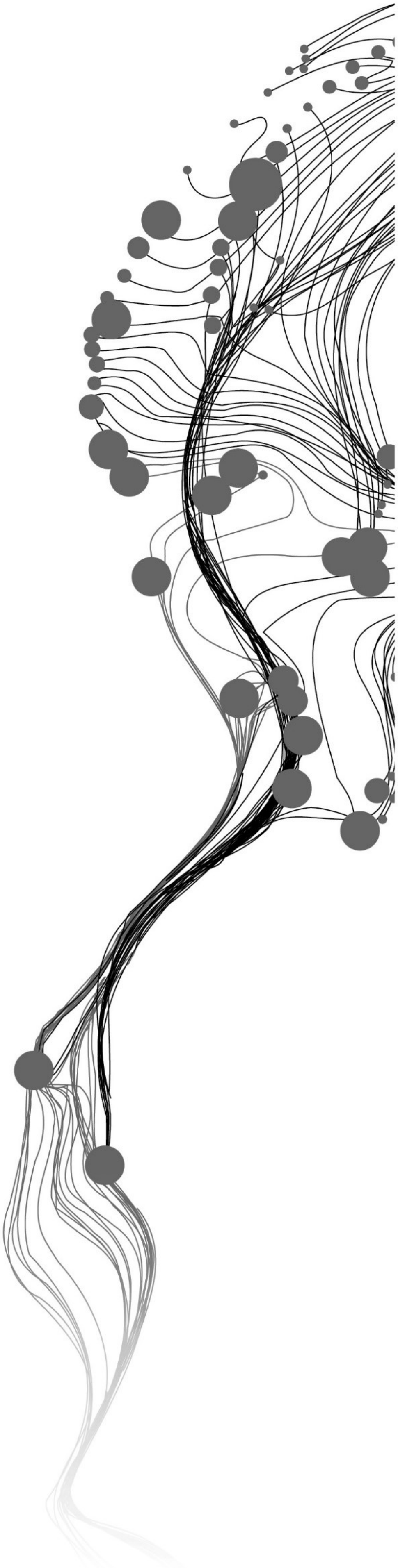
NATURE-BASED SOLUTIONS (NBS) AS AN URBAN FLOOD MITIGATION MEASURE: THE CASE OF GA EAST MUNICIPALITY, ACCRA, GHANA.

PRINCE ASARE
July, 2021

SUPERVISORS:
Dr. F. Atun Girgin
Prof. dr. K. Pfeffer



NATURE-BASED SOLUTIONS (NBS) AS AN URBAN FLOOD MITIGATION MEASURE: THE CASE OF GA EAST MUNICIPALITY, ACCRA, GHANA.

PRINCE ASARE
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SUPERVISORS:
Dr. F. Atun Girgin
Prof. dr. K. Pfeffer

THESIS ASSESSMENT BOARD:
Prof. dr. R. V. Sliuzas (Chair)
Dr. Angela Colucci (External Examiner, Politecnico di Milano)
Dr. F. Atun Girgin (1st Supervisor)
Prof. dr. K. Pfeffer (2nd Supervisor)

ABSTRACT

The rapid rate of urban expansion with its associated physical development in recent years sharply conflicts with the ecosystem and its services due to the natural landscape in most metropolitan regions of the world being transformed into the prevalence of hard surfaces. This hard surface development is very evident in the Ga East Municipality of Accra, Ghana. Hence, the rate with which these hard surfaces are increasing, coupled with climate change factors, has partly contributed to urban floods in the municipality. But attention has not been drawn to the impact of the decreasing natural and green environment on urban flood occurrences. As a result, flood mitigation strategies in Ghana are still geared towards the construction and desilting of drains and how proper solid waste management can help reduce the frequency and intensity of urban flood events. However, the flood mitigation strategies have not successfully resolved and mitigated urban floods in the country, including the Ga East Municipality. Studies have revealed that most cities in the western world have adapted "Nature-Based Solutions" (NBS) to restore the natural areas and ecosystem and reduce the environmental challenges linked with uncontrolled rapid urban expansion and hard surface development, including urban floods. The Ga East being one of the most affected Municipalities in Accra in terms of urban floods calls for a consideration of NBS measures as an alternative and complementary urban flood mitigation approach.

Hence, this study aims to explain the need for urban flood-related NBS measures. The study also identifies target areas where specified NBS measures, including green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements, can be implemented and how they can be integrated into spatial and flood mitigation schemes in the Ga East Municipality.

A case study approach was adopted for this research. In this context, a mixed-method approach specifically, quantitative, and qualitative methods were used to address different aspects of the research. Specifically, land cover change analysis and the SCS model were used to determine the relation between land cover changes and urban flood occurrences. Also, a Spatial Multi-criteria Analysis (SMCA) was applied to identify target areas where specific NBS measures can be implemented in the Ga East Municipality. Additionally, content and text analysis of spatial and flood management plans and key informant interviews were used to determine how the NBS measures can be part of the municipality's spatial development and flood management schemes.

The study revealed that the development of hard surfaces had increased the likelihood of urban flood happenings in specific areas in the Ga East Municipality, hence a need for NBS measures. Also, the study revealed that different areas in the municipality require specific NBS measures to ensure effective urban flood mitigation. Additionally, the study disclosed that the municipality's spatial plans and flood mitigation schemes reflect a possibility of NBS integration. Furthermore, the study also unveiled techniques of integrating the NBS measures as well as implementation barriers and facilitators in the Ghanaian flood management professionals' perspective. Therefore, for future research, it is recommended to empirically analyse and quantitatively determine how the specified NBS measures will reduce runoff depth and inundation volumes. Also, future research can also look at NBS integration from the perspective of the local people and inhabitants.

Keywords: Nature-Based Solutions, urban expansion, hard surface development, runoff and inundation, urban floods, urban flood management, spatial planning, NBS integration

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"I never dreamed about success. I worked for it." – Estee Lauder

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Abbreviations	**Details**
AHP	Analytic Hierarchy Process
BMP	Best Management Practice
CERGIS	Centre for Remote Sensing and Geographic Information System
CN	Curve Number
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
GAMA	Greater Accra Metropolitan Area
GARSDF	Greater Accra Regional Spatial Development Framework
GMS	Ghana Meteorological Services
HSD	Hydrological Service Department
LUSPA	Land Use and Spatial Planning Authority
NADMO	National Disaster Management Organisation
NBS	Nature-Based Solutions
NDMP	National Disaster Management Plan
NSDF	National Spatial Development Framework
PWC	Pairwise Comparison Matrix
RSDF	Regional Spatial Development Framework
SMCA	Spatial Multi-Criteria Analysis
SCS	Soil Conservation Service
TCPD	Town and Country Planning Department
USGS	United States Geological Services

1. INTRODUCTION

1.1. Background and justification

The rapid rate of urban expansion with its associated physical development in recent years sharply conflicts with the urban ecosystem and the services it provides. The conflict of physical development and ecosystem is due to the natural landscape in most metropolitan regions of the world being transformed into the prevalence of "hard surfaces" (Kabisch et al., 2016). It is now becoming increasingly noticeable that modern cities' growth has this hard surface development as the most prominent feature for the last two decades (Medrano, 2019). The nature of this hard surface development in cities across the globe has therefore led to the depletion of most natural areas (Li et al., 2019). The loss of natural areas coupled with climate change has contributed to numerous environmental problems, including urban floods (Lee et al., 2018).

According to Jha et al. (2011), urban flooding has been one of the most challenging issues in cities across the globe. It is attributed to the rate of urbanization and how cities are developing. Urban floods are being recorded every year in most urban centres, and the losses that come with them are always devastating (Stevens, 2012). Therefore, in the well-planned and developed countries, attention has been drawn to adopting innovative ways of addressing the urban flood menace, which recognizes the re-nurturing of most natural areas (Gustafsson & Platen, 2018).

In Africa, it has been found that the rate of urbanization in recent times is higher than in other places across the globe (Acheampong & Ibrahim, 2016). The urban expansion has led to the prevailing hard surface developments in major cities in the African continent (Simwanda, Ranagalage, Estoque, & Murayama, 2019). Urban floods on the African continent, have become a major challenge, and their impacts have been devastating, including loss of lives (Amoako, 2012). Studies have revealed that the West African sub-region has had the worst urban flood impacts on the continent (Amoako, 2012). Amoako (2012), therefore, highlighted that the record of urban floods in major West African cities, including Ghana, is strongly linked to the nature of physical development.

Uncontrolled rapid urban expansion has been observed in major metropolitan areas, including Accra and Kumasi (World Bank, 2015). The Greater Accra Metropolitan Area (GAMA), for instance, accommodates about 25% of Ghana's urban population (Ghana Statistical Service, 2014), which signifies there is high in-migration in the metropolitan area. This resulted in about a 35% increase in the area's physical expansion between 1985 and 2015 (Ministry of Environment, Science, Technology, and Innovation et al., 2017). Moreover, about 20% of GAMA's urban expansion has been observed in the Ga East Municipality (Amfo Otu, Omari, & Boakye Dede, 2012). The municipality's expansion comes with hard surface development, including roads, pavements, buildings, and other structures that require the displacement of the existing natural greenery environment and ecosystem (Addae & Oppelt, 2019). Kalantari et al. (2018) asserted that the continuous decrease in an area's natural green and soft surfaces minimizes the infiltration capacity of land surfaces. This loss leads to high surface water runoff and inundation. Also, the structures mentioned above are sometimes built in waterways, which shrinks and sometimes blocks the flow of rivers and water bodies (Amoako & Boamah, 2014).

As developments are spreading through the entire metropolitan area, including Ga East, developers put up structures that are not adequately checked. The enforcement of spatial plans in Ga East and Ghana has been a great challenge, retarding the quality of physical development (Acheampong & Ibrahim, 2016). In Ga East and the entire Accra, the lack of spatial plan enforcement has led to encroachment within the buffers of major rivers (Amoako & Boamah, 2014). Other waterways and wetland areas have also been filled up to construct buildings and other hard surface structures (Amoako & Boamah, 2014). Furthermore, spatial plan implementation does not drive developers to ensure the greenery characteristics of their developments (Addae & Oppelt, 2019). The increasing anomaly in hard surface development coupled with waste management issues has hugely affected the free flow of water through rivers, infiltration capacity, and water runoff on urban surfaces contributing to urban floods in the municipality (UNCT Humanitarian Support Unit, 2015). Examples of some flood scenes are displayed in Figure 1-1

Figure 1-1: Flood scene 1 in the Ga East Municipality (a) Flood scene 2 in the Ga East Municipality (b)
Source: (Amoako, 2020; Africa Feeds, 2020)

Additionally, the occurrence of urban floods in the municipality has drawn authorities' attention, and there are measures put in place to address them. Ghana's strategy to mitigate urban floods has traditionally relied on conventional engineering strategies. The strategies include dams, levees, storm drains, and walls to adapt to climate change and mitigate urban floods (Ahadzie & Proverbs, 2011), as is being done in some developed countries (Gustafsson & Platen, 2018). However, these practices have not always been successful in a sustainable way (Gustafsson & Platen, 2018). The unceasing loss of natural areas in the municipality and over-reliance on conventional urban flood mitigation strategies implies that authorities and society, in general, continue to underestimate the value that NBS can offer in addressing urban floods (Medrano, 2019).

In recent years, cities across the globe have adapted "Nature-Based Solutions" (NBS) as a response to the restoration of the natural areas and ecosystem and to reduce the environmental challenges linked with hard surface development (Medrano, 2019). The European Commission (2020) defines NBS as actions inspired, supported by, or copied from nature that are used to address a variety of social, economic, and environmental challenges sustainably. The need for NBS is attributed to the current Climate Change and urban expansion being a significant challenge for most cities in both developed and developing countries (Kabisch et al., 2016; Fritz, 2017). According to Kabisch et al. (2016), the concept of NBS is also associated with Ecosystem Services, Green Infrastructure, and Ecosystem-Based Adaptation.

Several studies have been done on NBS and its use across the globe. However, it is most appreciated by the western world and has been studied and applied in multiple ways (Walters, Cohen-Shacham, Maginnis, & Lamarque, 2016). For example, studies have been done on the usage of NBS in climate change adaptation and mitigation, which is highlighted in Kabisch et al. (2016) and Fritz (2017). Kabisch et al. (2016), for instance, found the introduction of green roofs and walls improved the urban biodiversity in some European and American cities. Improving flood risk management and resilience through the usage of NBS has also been researched and is evident in studies like Turhan & Gökçen Akkurt (2018) and Gustafsson & Platen

(2018). Turhan & Gökçen Akkurt (2018), for instance, revealed the use of NBS significantly reduced the urban risk associated with heat and air quality. Harnessing on urban flood mitigation, different approaches and measures have also been looked into globally (Bons, 2010). Africa and other developing areas present limited studies on NBS measures (Babí Almenar et al., 2021). Exceptions include a study that revealed the use of NBS could reduce heat and drought in some parts of Eastern Africa (Kalantari et al., 2018).

The use of engineering infrastructure solutions like dams, levees, storm drains, flood control pumping stations, walls, and others contributed to urban floods reduction, according to Soz, Watson, & Stanton-Geddes (2016); Heidari (2009). These engineering infrastructure solutions are well known in most parts of the world (Soz et al., 2016). Studies on urban flood mitigation in most developing and less developed countries, including Africa, are largely centered on some of the above-mentioned engineering solutions (Soz et al., 2016). Hence, urban flood mitigation studies in Ghana are also only linked to the desilting and construction of drains and other engineering infrastructure and proper waste management (Ahadzie & Proverbs 2011; Arntz, 2016).

1.2. Research problem

Studies, especially in the well-planned and developed world, have been conducted on the subject of NBS and how it can be used to reduce urban floods in cities (European Commission, 2015; Kabisch et al., 2016; Fritz, 2017). However, there are limited studies that focus on how flood-related NBS measures, in general, can be integrated into spatial plans to shape and guide the development of cities in mitigating urban floods.

In developing and less developed countries, studies on urban flood-related NBS measures are scarce. Urban flood mitigation in developing and less developed areas focuses on engineering infrastructure solutions and conventional mitigation measures (Soz et al., 2016). Being identified as the region most vulnerable to climate change and variability (IPCC, 2012), Africa has been battling severe urban flood challenges (Amoako, 2012). Hence, urban floods are prevalent in African cities like Mozambique, Zimbabwe, South Africa, Zambia, Namibia, Algeria, Uganda, and Ghana (Jha, Bloch, & Lamond, 2011).

In Ghana, there is limited attention to the impact of the decreasing natural and green environment on urban flood occurrences. Flood mitigation studies in Ghana are still geared towards constructing and desilting drains (Ahadzie & Proverbs, 2011) and how proper solid waste management can help reduce the frequency and intensity of urban flood events (Marinetti et al., 2016). Hence, there is limited study in Ghana to investigate the relation between the continuous increase in hard surfaces and urban flood happenings. How natural means or NBS can be integrated into spatial plans and urban flood mitigation schemes in Ghana has not been clearly studied either.

Flood mitigation strategies outlined by the Government of Ghana, which is inspired by the existing studies in the Ghanaian scope, have not successfully resolved and mitigated the urban floods in the country (Tengan & Aigbavboa, 2016). Therefore, research is required to investigate the impact of the continuous increase in hard surfaces on urban flood occurrences and how selected NBS measures can be introduced in flood mitigation schemes and spatial plans to reduce floods.

Therefore, this research will throw more light on *why* cities should consider NBS for flood mitigation, *where* the NBS can be applied in cities, *what* specific NBS would be best for different locations and *how* the NBS can be integrated into spatial plans flood mitigation schemes. In this light, the research will focus on how the continuous hard surface development in the Ga East Municipality, Accra, has affected urban flood occurrences. The study will also identify target areas where appropriate NBS measures such as green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements can be implemented and finally, how the NBS can be captured in flood mitigation schemes and spatial plans. This will contribute to the knowledge base concerning urban flood mitigation from the Ghanaian perspective. It will also inform spatial planners and institutions involved in urban flood management about alternative flood mitigation measures

1.3. Research objectives/ questions

1.3.1. General objective

This research aims to explain the need for NBS measures, identifying and analysing possible areas where they can be implemented and integrating them into spatial plans and flood mitigation schemes in the Ga East Municipality, Accra.

1.3.2. Specific objectives and questions

1 To determine the relationship between urban flood occurrences and land cover changes in 2015 and 2020 in the Ga East Municipality.
- How has the land cover in the Ga East Municipality changed from 2015 to 2020?
- What was the likelihood of urban floods occurrence in 2015 and 2020 in the Ga East Municipality in relation to rainfall records?
- Is there a relationship between land cover changes and urban flood occurrences?

2 To identify target areas in Ga East Municipality for implementing NBS measures.
- Which areas in the Ga East Municipality can be targeted for implementing NBS measures?
- What are the physical geography and land use characteristics of different NBS target areas?

3 To identify an appropriate NBS measure with the potential to reduce urban flood occurrences in the identified target areas in the Ga East Municipality.
- What NBS measures are appropriate for different target areas in Ga East Municipality to reduce urban flood occurrences?

4 To suggest possible ways of integrating NBS measures in spatial and flood mitigation plans.
- How do existing spatial and flood mitigation plans reflect the possibility of NBS integration?
- What are the views of urban flood management stakeholders on NBS integration?

1.4. Research hypotheses

The development of hard surfaces has increased the frequency and extent of urban floods in the Ga East Municipality. Different areas in the municipality require various NBS measures to mitigate urban floods.

1.5. Thesis structure

The study is presented in 6 chapters. Chapter 1 presents the introduction, which highlights the background to the study and justification, research problem, objectives, and questions. Chapter 2 provides the literature review of key concepts of the study, thus on Nature-Based Solutions, hard surface development, urban floods, urban flood management, and NBS integration in spatial planning. Chapter 3 also highlights the study area's description, research design and strategy, data collection and analysis, and ethical considerations. Chapter 4 presents the analysed data and answers to research questions, followed by chapter 5, which discusses, interprets, and explains the study findings and results. The study's conclusion and recommendation for future research are presented in the final chapter, chapter 6.

2. LITERATURE REVIEW

This section of the thesis briefly explains the key and related concepts regarding the impact of hard surface development on the occurrence of urban floods and the introduction of Nature-Based Solutions (NBS) as a mitigation measure. It also highlights and elaborate on the concept of spatial planning and flood management related practices in Ghana.

2.1. Hard surface development

The development of hard surfaces due to urban expansion is evident in most cities across the globe. The hard surfaces have replaced soils, natural vegetation, and waterways as human settlements expand (Kabisch et al., 2016). This type of development seals the natural coverage of an area like the natural soil and other green areas. It is considered a harsh substrate to vegetation due to the lack of rooting space, low moisture, and penetration availability (Lundholm, 2011). Examples of these hard surfaces include buildings, asphalt, and concrete roads, pavements, among others, that cover natural surfaces (Kalantari et al., 2018).

The prevalence of hard surface development in cities threatens natural surfaces and urban ecosystems, reducing, for example, the infiltration capacity of areas, making it difficult for water to penetrate through soils (Simwanda et al., 2019). Hence, it results in water-related hazards, including urban floods.

According to the European Union (2013), land take and soil sealing by hard surfaces have been a growing problem in many areas across the globe. In Europe, for instance, land cover surveys from 1990 to 2006 revealed a land take of about 1000km square per year. In Africa, urbanization is growing rapidly, and the development of hard surfaces is on the increase. These developments are generally unplanned, which is linked to the weak spatial planning system and its implementation in the region (Simwanda et al., 2019).

The prevalence of hard surface development also exists in Ghana and is increasing, especially in the capital region, Accra (Addae & Oppelt, 2019). Waterways, river buffers, and other green areas in major towns in the region have now been replaced with hard surfaces, affecting the free flow of water through rivers and the infiltration capacity of urban surfaces.

2.2. Urban floods

Urban flood, according to Sene (2013, p. 3), is defined as *"the submergence of usually dry area by a large amount of water that comes from sudden excessive rainfall, an overflowing river or lake, melting snow or exceptionally high tide."* Globally, urban floods are considered the most frequently occurring hazards that affect most urban areas (Stevens, 2012). The hazard has been a growing concern for both developed and developing areas because they cause damage to buildings, housing, properties, loss of lives, among others (Kalantari et al., 2018).

According to APFM (2012), urban floods result from climate and hydrological elements' confluence, aggravated by human factors. The climate elements include temperature conditions, rainfall frequency, and intensity, among others. The hydrological elements comprised soil type or moisture levels, the extent of impervious surfaces, the natural channelization of watercourses, groundwater levels, and water runoff conditions. The human factors include land-use change, maintenance of drainage infrastructure, and soil sealing associated activities emanating from hard surface development.

Concerning water movement in the urban environment, if the meteorological conditions like rainfall intensity are greater than the urban drainage infrastructure and surfaces' capacity, urban floods occur (Sene, 2013). As cities are developing, the continuous increase in hard surfaces decreases the urban surface's permeability or infiltration capacity, leading to higher surface runoff and inundation (APFM, 2012). Additionally, the increased sedimentation from an unprotected surface like bare soil and solid waste production that end up in rivers and other drainage infrastructure affect the free flow of water, which contribute to urban floods occurrences (APFM, 2012).

2.3. The concept of Nature-Based Solutions (NBS)

NBS is a concept defined by the European Commission (2020, p.3) as "*Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.*" The use of NBS as a term was introduced at the beginning of the 21st century. Some well-planned and developed countries adopted it a few years after its introduction (Stagakis, Somarakis, & Chrysoulakis, 2019). In the early stages of the use of NBS, the focus was on environmental management, biodiversity conservation, and other ecosystem-based initiatives.

Further research was also carried out on NBS, considering the social and economic dimensions (Stagakis et al., 2019). Currently, the subject of NBS has been widely accepted and pushed forward in most well-planned and developed countries, particularly in the European Union, and is being considered in the EU Research and Innovation Policy Agenda (Kabisch et al., 2016). The EU's NBS strategy is to promote synergies between societies, economies, and nature (European Commission, 2015).

The use of NBS makes it more possible to explore more novel solutions to most environmental challenges in society, including urban floods (Fritz, 2017). This means that it is very important for cities to maintain and enhance their natural capital as it can help prevent many challenges, including the menace of urban floods.

2.4. Urban flood-related NBS measures

NBS is often related to concepts like ecosystem services, blue and green infrastructure (Gehrels et al., 2016). Green infrastructure generally refers to projects that make use of vegetated design elements. Blue infrastructure technically also refers to infrastructure related to hydrological functions like surface water, urban stormwater systems, among others (Gehrels et al., 2016). Ruangpan et al. (2020) have also identified types of NBS, which include small and large-scale NBS. The small-scale NBS are applied in urban and local areas, specifically on buildings, streets, roofs, and other areas. Large-scale NBS, on the other hand, are usually applied in rural areas and river basins. Harnessing on the urban flood-related NBS measures, the European Commission (2015) and Ruangpan et al. (2020) highlighted some widely used measures in the well-planned and developed countries, which have effectively reduced urban floods in cities. These NBS measures will be the ones to be considered in this research and they include green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements.

2.4.1. Green roofs

Green roofs in recent times have become increasingly popular as more people have realized their benefits, including economic and environmental. Cities across the globe have now started using sky-high gardens on top of their residential and business buildings, providing urban areas with rooftop greenery and cleaner air and serving as solutions to most environmental problems (Ansglobal, 2019). A green roof is explained as a flat or sloped rooftop that supports vegetation on top of buildings to provide urban greening for buildings, people, or the environment while also acting as a stormwater management system (Magill et al., 2011). The implementation of Green roof technology has been successful in many forms in dealing with numerous urban challenges. Ansglobal (2019) and Magill et al. (2011) highlighted some benefits of green roofs, including reducing energy costs, ensuring cleaner air, temperature regulation, and flood reduction. Harnessing on flood reduction, the abundance of non-porous materials in most cities, a storm can create more than five times as much water runoff as it would in a rural area. In that regard, green roofs can retain up to 90% of the precipitation that falls on them, greatly reducing flooding in times of extreme weather. Examples of green roof designs are shown in Figure 2-1.

Figure 2-1: First example of a green roof (a), second example of a green roof (b)
Source: (Fremantle Roofing Services, 2020; Architecture & Design, 2016)

Designing green roofs is best applied in specific locations in an urban area (Magill et al., 2011). Green roofs are easily installed on areas that are horizontally and gently sloped; thus, the slope should be less than 10 degrees. It can also be possible to install green roofs on steeper areas as well. Green roofs can be installed in any climate since there is a possibility to use different vegetative materials. Moreover, installing a green roof in a corporate or an industrial building is much easier than in a home. However, they are suitable for all buildings (Magill et al., 2011).

2.4.2. Vegetated swales

According to Pennsylvania DEP (2006), a vegetated swale is also called a drainage swale or bioswale. It is a shallow stormwater channel densely planted with a variety of grasses, shrubs, and trees designed to filter, slow, and infiltrate stormwater runoff. They are an excellent alternative to conventional curb and gutter conveyance systems because they provide pre-treatment and distribute stormwater flows to subsequent Best Management Practices (BMPs) and major drains in urban areas. In general, vegetated swales Provide water quality treatment; remove suspended solids, heavy metals, trash. They also reduce peak discharge rate, reduce total runoff volume, infiltrate water into the ground, and improve site landscaping. Vegetated swales are sometimes used as pre-treatment approaches for other structural water BMPs, especially from roadway runoff. Ruangpan et al. (2020) highlighted that many cities across the globe have resorted to vegetated swales as a measure in dealing with urban floods. Figure 2-2 illustrates some examples of vegetated swales.

Figure 2-2: First example of a vegetated swale (a), second example of a vegetated swale (b)
Source: (Blanco Water Atlas, n.d.; Dott Architecture, 2010)

In designing vegetated swales, they are widely applicable to residential, commercial, industrial, and institutional sites and roadside or sometimes used as road medians (Bureau of Watershed Management, 2006). Swales work best in sandy loams that facilitate infiltration; very sandy soils may be prone to erosion under high runoff velocities. Also, vegetated swales may be impractical in areas with steep topography. That is, they are best applied in gentle and horizontal slope areas (Bureau of Watershed Management, 2006).

2.4.3. Rain Gardens

Bray et al. (2011) described a rain garden as a shallow depression, with absorbent yet free-draining soil covered with vegetation that can withstand occasional surface runoff and temporary flooding. Rain gardens are designed to reduce rainwater volume running off into drains from impervious areas and treat low-level pollution. Rain gardens usually can absorb all the rainwater that flows into them, but when they fill up following heavy storms, any excess water is redirected to the existing major drains. This type of NBS measure has also been used in most well-planned and developed areas as a flood reduction strategy (NRCS, 2005; Ruangpan et al., 2020). Illustrations of some rain garden designs are shown in Figure 2-3.

Figure 2-3: Example of a Rain Garden
Source: (Cancler, 2018)

According to Bray et al. (2011), rain gardens are mostly suitable for residential areas. However, they should be situated some distance from buildings or site boundaries. It is recommended that rain gardens are situated at least 3m (10 feet) from any building. Also, the location of the garden should slope away from existing buildings. Therefore, rain gardens are best situated on gentle slopes and high elevation areas. Slopes of more than about 12% are difficult to work with and may require retaining structures. Rain gardens may not be ideal for areas characterized by clayey soil. Also, a rain garden of any size may bring some benefits, but it should not be too small, as it may overflow too frequently and may become saturated and less effective in reducing runoff rates. Additionally, the location of rain gardens should not be close to areas very close to water bodies and areas of shallow water tables (National Resource Conservation Service, 2005).

2.4.4. Rainwater harvesting

Rainwater harvesting has been defined by IRICE (2006) as the technique of collection and storage of rainwater at the surface or in sub-surface aquifer before it is lost as surface runoff. It is also further explained as making optimum use of rainwater where it falls that conserves it and does not allow it to drain away and cause floods elsewhere. There are many benefits associated with the use of rainwater harvesting. The benefits include reducing flood hazards, promoting the adequacy of groundwater, reducing drought effects, and decreasing load on stormwater disposal systems, among others. Thereby, this approach has also been used in many developed areas as a flood control mechanism (Ruangpan et al., 2020). Illustrations of some rainwater harvesting designs are shown in Figure 2-4.

Figure 2-4: First example of a rainwater harvesting (a), second example of a rainwater harvesting (b)
Source: (Maximize Market Research, 2018; CustomMade, n.d.)

On the design of Rainwater harvesting, they can be used in residential homes, commercial, and other industrial facilities. It can be installed in a garden or basement of the building (KFC, 2014). However, the soil texture should be medium (Ammar et al., 2016; Water, 2006). KFC (2014) also highlighted that rainwater harvesting could be an innovative approach for being applied on a large neighbourhood scale. In this case, water is harvested from many homes and buildings in an urban neighbourhood or residential, commercial, or industrial area. Hence, they are beneficial and best situated in upstream or relatively highland areas (Hashim & Sayl, 2020) that are gently sloped (Ammar et al., 2016). Rainwater harvesting is also not ideal for areas very close to water bodies (Ibrahim et al., 2019). Another key aspect to consider is that rainwater harvesting should be additional to existing urban drainage infrastructure. Rainwater harvesting should not be a replacement for existing infrastructure. In that regard, rainwater harvesting should be applied to tackle rainwater falling on rooftops. Existing sewers can then be used also to tackle rainwater falling at the street surface.

2.4.5. Detention basins

A detention basin (or pond), as the name sounds, is used to gather and temporarily store rainwater while releasing a lesser amount with the intent of lowering the risk of flooding downstream areas (Lee et al., 2018). These kinds of basins could be large, excavated areas purposely designed at vantage locations in urban areas. They are designed to be entirely dry when not storing stormwater. In contrast, others have a permanent shallow pool of water with a capacity above the average water level to store stormwater. These basins capture and store additional runoff and have been one of the several tools used by most well-planned and developed areas to mitigate downstream flooding (Ruangpan et al., 2020). Illustrations of some detention basin designs are shown in Figure 2-5.

Figure 2-5: First example of a detention basin/pond (a), second example of a detention basin/pond
Source: (McCollum, n.d.; Stormwater Partners, n.d.)

Detention basins can generally be incorporated in residential, parking lots, parks, sports fields, and roadside areas. These areas should be characterized as downstream areas and areas close to rivers (Maine Department of Environmental Protection, 2016). However, detention basins are not ideal for sandy soil or gravel areas (Maine Department of Environmental Protection, 2016). Another important aspect about detention basins is that they can easily apply the concept of multiple uses so that detention facilities can provide open space, landscape amenities, habitat, and other functions.

2.4.6. Porous pavements

Porous pavements are also well known in some areas as permeable or pervious pavement. They are stormwater management facilities that are designed to permit stormwater to penetrate through void spaces. It can be used in place of conventional pavements for both pedestrian and vehicular traffic routes, without the need for any additional stormwater management feature such as a detention basin, rain garden, among others. These systems reduce runoff volumes that would otherwise be produced by impervious surfaces such as parking lots, roads, and sidewalks (Oregon Sea Grant, 2011). This approach has also been used in many urban areas as a flood control mechanism (Ruangpan et al., 2020). Illustrations of some porous pavement designs are shown in Figure 2-6.

Figure 2-6: First example of porous pavements (a), second example of porous pavements (b)
Source: (Block Rani, 2016; Grass Concrete Ltd, 2017)

Porous pavements have fewer location restrictions than many other stormwater facilities or NBS measures (Oregon Sea Grant, 2011). Hence, it can be used almost anywhere impervious pavements are used (Oregon Sea Grant, 2011). However, porous paving is most suitable for areas of light traffic loads like carparks, lanes, among others, and can either be applied in upstream and downstream areas (Thelen & Howe, 2011). Also, porous pavements do best in areas where soils have a moderate infiltration rate, like loamy and sandy loamy. If soils have low infiltration rates, they result in an unacceptably long infiltration time. In contrast, high infiltration rates may cause groundwater contamination (DPTI-South Australia, 2016).

2.5. The concept of Spatial planning

Spatial planning is essential for building cities and plays a prominent role in developing places and cities across the globe (Nadin, 2006). The concept focuses on the location of land uses and infrastructure, whether static or in movement, and the interrelations between activities and networks in an area (Healey, 2006). Spatial planning is mostly linked to land use planning, town planning, and physical planning (Acheampong, 2019). These terms are geared towards controlling the location of human activities and shaping and nurturing the form, intensity, and interlinkages between the activities (Acheampong, 2019).

In developing countries, the act of spatial planning is characterized by interest, assumptions, and methods inherited and imported from the well-planned and developed world, especially from Europe and North America (Okeke, 2015). Therefore, planning in most developing areas seeks to be focused on projected requirements that are manifested and distributed in space, covering residential, commercial, industrial, recreational, and other developmental areas (Acheampong, 2019). The motive of this tactic of planning is to ensure efficient use of land sustainably and to protect and preserve environmentally sensitive areas for the good of society (Okeke, 2015). However, studies conducted in most developing countries have revealed that the intentions and goals of land use and spatial plans have not been realized due to implementation challenges (Acheampong & Ibrahim, 2016; El-khamess, 2015). According to De Satgé & Watson (2018), the implementation challenge has brought about conflicting rationalities in cities' planning systems, leading to the loss of natural and green areas.

2.6. Spatial planning and NBS integration

The concept of NBS and spatial planning is explained by Grădinaru & Hersperger (2019) as the planning of an area by consolidating and promoting the development of green areas. Having the two concepts in a city's blueprint ensures coordination with other policies like Climate Change adaptation, water management, and flood mitigation (Grădinaru & Hersperger, 2019). Zwierzchowska et al. (2019) also highlighted that green and sustainable planning ensures physical development is always in line with green areas' growth. This feature of NBS and spatial planning existing in cities helps to reduce environmental-related challenges, including urban floods (Grădinaru & Hersperger, 2019). In the light of marrying spatial planning and NBS, UK Green Building Council, (2021); Sarabi et al. (2020); Kopsieker et al. (2021) made suggestions on six main principles and strategies of including NBS in spatial planning to ensure sustainable development of cities. The first strategy covers defining the ambition on the application of NBS in cities, thus, identifying the purpose of using NBS. The second strategy highlights assessing the possible impacts of the NBS thus, trying out the NBS to determine its functionality and quality. The third strategy also covers the maximization of multifunctionality, thus creating interconnection of the NBS and other practices. Cost-benefit and funding of the NBS also make up the fourth strategy. Furthermore, the fifth strategy hammers on creating a long term management plan for the NBS. The sixth and final strategy then highlights on collaboration, education and innovation.

2.7. Changing climate and rainfall patterns in Ghana

There is no doubt about the impact of climate change in most parts of the world; it has contributed to severe urban challenges in most cities across the globe. In Ghana, Climate Change has been manifested through rising temperatures, declining rainfall patterns but increased variability, rising sea levels, and high incidence of weather extremes (UNEP & UNDP, 2013).

Harnessing on the rainfall, UNEP & UNDP (2013) have stated that the pattern has been declining in the last three decades. Based on the past decline of the rainfall pattern, UNEP & UNDP (2013) estimated future decline of -3.1%, -12.3%, and -20.5% in 2020, 2050, and 2080 respectively for the coastal savannah zone, a climatic zone within which the Ga East Municipality, Accra is located. However, Amoako & Boamah (2014) highlighted the assertion that the rainfall pattern in the Accra Metropolitan Area has changed in terms of frequency and intensity, as captured from recent figures. With the rainfall frequency slightly reduced, as stated by UNEP & UNDP (2013), the rainfall intensity per rainy day has gone up on the average. This contributes to urban flood occurrences, especially in the peak *(June and October)* rainy periods.

2.8. Urban flood management in Ghana

The issue of urban floods has been one of the critical areas the Government of Ghana has been battling, and state interventions are usually carried out to address the menace (Ahadzie & Proverbs, 2011). A national disaster management plan was established by the Government of Ghana, which guides all-natural disasters, including urban floods in Ghana (Nansam-Aggrey, 2015).

According to Poku-Boansi et al. (2020), there is a wide range of institutional actors at the city, regional, national, and even international levels involved in ensuring effective flood prevention and management in Ghana. Therefore, Ghana's flood management system is structured into three levels, thus national, regional, and metropolitan/municipal/district. The overall flood management framework is highlighted in the Ghana National Disaster Management Plan, and it is designed and formulated at the national level by the National

Disaster Management Organisation (NADMO). Implementation of the management plan and other related activities are executed at the local or metropolitan/municipal/district level by the NADMO district offices, metropolitan/municipal/district assemblies, the Land Use and Spatial Planning Authority (LUSPA), Hydrological Service Department (HSD) district offices, among others. At the regional level, institutions involved harmonize and coordinate plans and activities at the metropolitan/municipal/district level.

There are four main stages in the management of disasters, which include Preparedness, Response, Recovery, and Mitigation/Prevention (Flanagan et al., 2020). Table 2-1 below describes the functions or roles of the various flood management institutions.

Table 2-1: Flood management institutions and their roles (Coloured cells represent flood mitigation institutions and roles)

Institution	Spatial level of operation	Laws backing for establishment and mandate	Functions towards flood management
National Disaster Management Organisation (NADMO)	National but have local offices at the municipal level	The institution was established by The National Disaster Management Organisation Act, 1996 (Act 517)	Preparation of national disaster management plan
			Community[1] sensitization on flooding
			Evacuation and provision of relief items to flood-affected victims
			Dissemination of community[1] flood warning information
			Coordination of flood management activities and institutions
			Coordinate local and international support for flood management
			Liaise with other institutions in the dredging and desilting of drains
District Assemblies (Ga East Municipal Assembly - GEMA)	At the municipal level responsible for the overall development of Accra	Established on a legal basis of Local Government Act, 1993, (Act 462)	Rehabilitation and restoration of infrastructure
			Provision of life support incentives and relief items for flood-affected victims
			Desilting and construction of drains
Land Use and Spatial Planning Authority (LUSPA), formerly Town and Country Planning Department (TCPD)	National but have local offices at the municipal level	Established on the legal basis of Land Use and Spatial Planning Act, 2016 (Act 925)	Land use planning and regulation to prevent floods especially along river bodies
			Demolition of buildings, properties and other structures built in waterways and other environmentally sensitive areas.

[1] Community = Neighbourhood

Environmental Protection Agency (EPA)	National but have local offices at the municipal level	Established on the legal basis of The Environmental Protection Agency Act, 1994, (Act 490)	Mapping of environmentally sensitive areas
			Prevention encroachment and developments close to rivers and on wetlands
Ghana Meteorological Agency (GMA)	National level	Ghana Meteorological Agency Act, 2004 (Act 682)	Weather monitoring and forecasting
			Analysing the impact of climate change variability
			Building Early Warning Systems and Mechanisms
Hydrological Services Department (HSD)	National level	-	Monitoring and evaluation of surface water bodies in respect of floods
			Designing, construction and maintenance of storm drains
Water Resource Commission	National level	Water Resource Commission Act, 1996 (Act 1996)	Managing and monitoring of river bodies and their buffers/ catchment
Centre for Remote Sensing and Geographic Information Systems (CERGIS)	National level	-	Mapping of flood-prone areas on a consultancy basis for public institutions, and researchers
Department of Urban Roads (DUR)	National but have local offices at the municipal level	Ghana Highway Authority Act, 1997 (Act 540)	Construction of storm drains in line with road construction
			Periodic maintenance of storm drains
Ghana Health Service / *Red Cross Ghana*	National but have local offices at the municipal level. *Red Cross operate at the national level*	Ghana Health Service Act 1996, (Act 525)	Provision of emergency response to injured people
			Provision counselling services for flood victims going through psychological trauma

United Nations Development Programme (UNDP), World Bank etc.	International level	-	Support NADMO in undertaking adaptation projects geared towards flood management
Community-Based Organisations (CBOs)	Community-level	-	Mobilization of community[1] for sensitization and participation in flood management projects in various communities[2].

Source: (Poku-Boansi et al., 2020)

Harnessing on the mitigation/prevention stage, which is the focus of this study, there is a wide range of plans, interventions, and projects to deal with Ghana's urban flood menace. Plans like metropolitan/municipal/district land use and structure plans prepared and implemented by the LUSPA or TCPD prevents developers from building in waterways and environmentally sensitive areas (TCPD, n.d.). Also, there is construction and maintenance of storm drains project carried out by the HSD and metropolitan/municipal/district assembly offices. There are also clearing, dredging, and desilting of rivers and drains activities, which are also done annually (Nansam-Aggrey, 2015). Furthermore, there are also resettlement projects to relocate slum dwellers living on rivers' banks (TCPD, n.d.). The above-mentioned plans, projects, and activities are mostly engineering inclined, and they are all geared towards mitigating urban floods in Ghana.

2.9. Spatial planning in Ghana

In Ghana, the Land Use and Spatial Planning Act, 2016 (Act 925) provides a mandate to the Land Use and Spatial Planning Authority (LUSPA) to see to the overall orderly spatial planning in the country. The spatial planning is done at three major levels thus has a three-tier planning system. The first is national and the regional. On the national, Act 925 gives mandate to LUSPA to prepare a National Spatial Development Framework (NSDF). The NSDF becomes part of a broad National Development plan that seeks to ensure the overall development of Ghana. The Regional LUSPA offices also come up with a Regional Spatial Development Framework (RSDF) that also seeks to control the development of land use areas in the region. This plan is inspired by the NSDF.

The second tier is the structure plan which is prepared in accordance with the RSDF by LUSPA metropolitan, municipal and District offices. The structure plan highlights the broad land use structure of a district.

The third tier is the local plans. This plan is prepared on community[1] basis. With this, the specific form of regulations and development of land is provided down to individual plot level. The local plan is the plan that normally provides the basis for the decision-making about building permits which developers submit to the district assembly to ask permission before any physical development happens. Figure 2-7 elaborate the structure of Ghana's spatial planning.

[2] Communities = Neighbourhoods

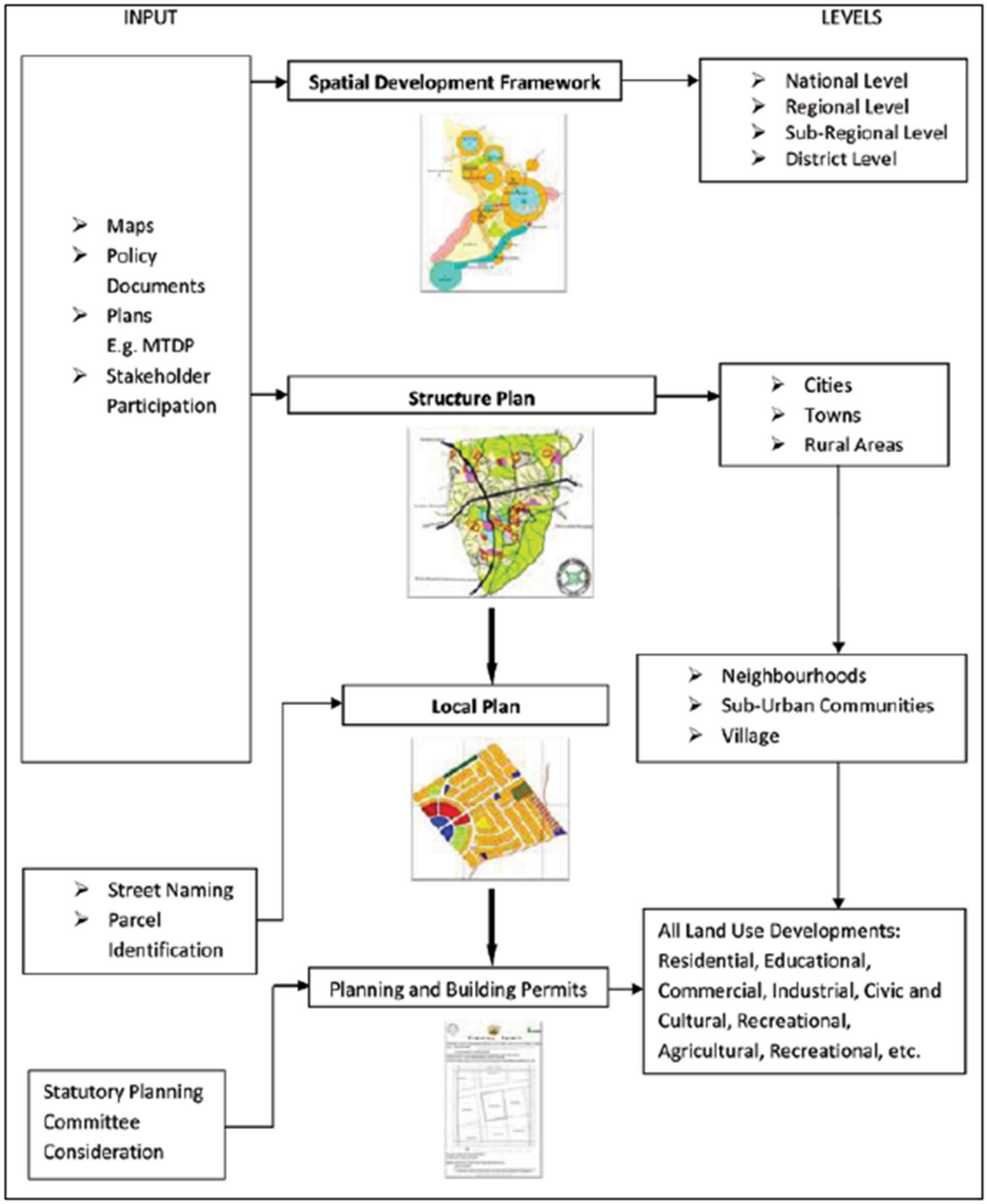


Figure 2-7: The three-tier spatial planning model in Ghana
Source: (TCPD, 2011)

2.10. Conceptual framework

This research's main concepts have been established and described in the introduction section and the literature review. Hence, the conceptual framework below illustrates the relationship between the different concepts underlying hard surface development and urban floods occurrences and the introduction of Nature-Based Solutions (NBS) as a mitigation measure. It also highlights the why, where, what, and how aspect of NBS.

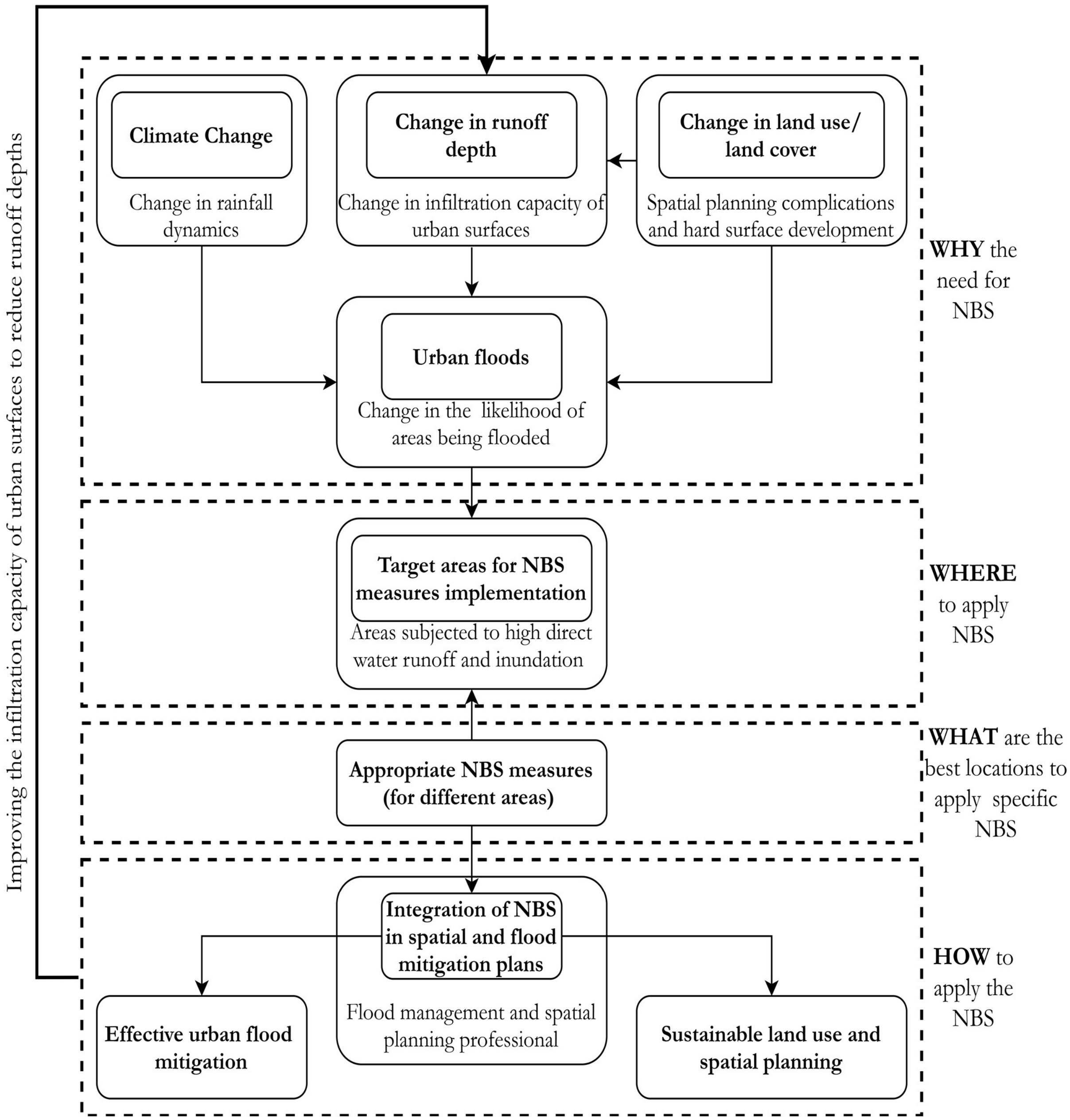


Figure 2-8: Conceptual framework

3. RESEARCH DESIGN AND METHODS

The aim of the research is to analyse the relationship between land cover changes and the potential urban flood areas in the Ga East Municipality. It also analyses identified possible areas where NBS measures can be implemented and how they can be integrated into spatial plans and flood mitigation schemes in the Ga East Municipality. This section, therefore, briefly explains the background of the study area and how the formulated research objective and questions were addressed as well as the data used.

3.1. Study area

Ga East Municipality is one of the 16 municipalities making up the Greater Accra Metropolitan Area (GAMA) (Ghana Statistical Service, 2014). The municipality was chosen as the study area for this research because, first, it is one of the fastest-growing areas in GAMA. The Ghana Statistical Service (2014) stipulated that; 71.1% living in the municipality are migrants from other regions of Ghana. The migrant composition in the municipality is the reason for about 20% of GAMA's expansion being observed in the Ga East municipality (Amfo Otu, Omari, & Boakye Dede 2012). The rapid urban expansion is characterized by residential, industrial, and commercial developments (Ackom, Adjei, & Odai, 2020). Secondly, many areas in the municipality have been experiencing flood events in the past decades. Areas in the municipality that were without flood records some years back are recently experiencing flood events negatively affecting a quite a number of inhabitants in the area (Ackom et al., 2020). Therefore, the nature with which urban development is carried out and the recent record of urban flood occurrences in the municipality calls for innovative strategies, including NBS.

The municipality is located in the northern part of the metropolitan area, covering 83.5 square km, with an estimated population of about 200,000 inhabitants (Ghana Statistical Service, 2014). The municipality is bounded by Accra central to the south, Ga West Municipality to the west, Adentan Municipality to the east, and Akwapim South District to the north (see Figure 3-1).

According to Ghana Statistical Service (2014), the municipality falls within the savannah ecological zone. The average temperature of the area ranges between 25.1°C (the coolest) in August and 28.4°C (the hottest) in March, with an overall 26.8°C average. The annual rainfall pattern is around 730 mm, which is the same for the GAMA area. There are two rainy seasons, which are also the same for the entire country, thus from April to July and September to November, with peak periods recorded in June and October. The municipal's relief is generally gentle and undulating in some parts, with heights ranging from 42 to 374 metres (Ghana Statistical Service, 2014). There are major rivers and seasonal streams that run through the municipality. They include the Odaw river, Sesemi, and Dakubi streams.

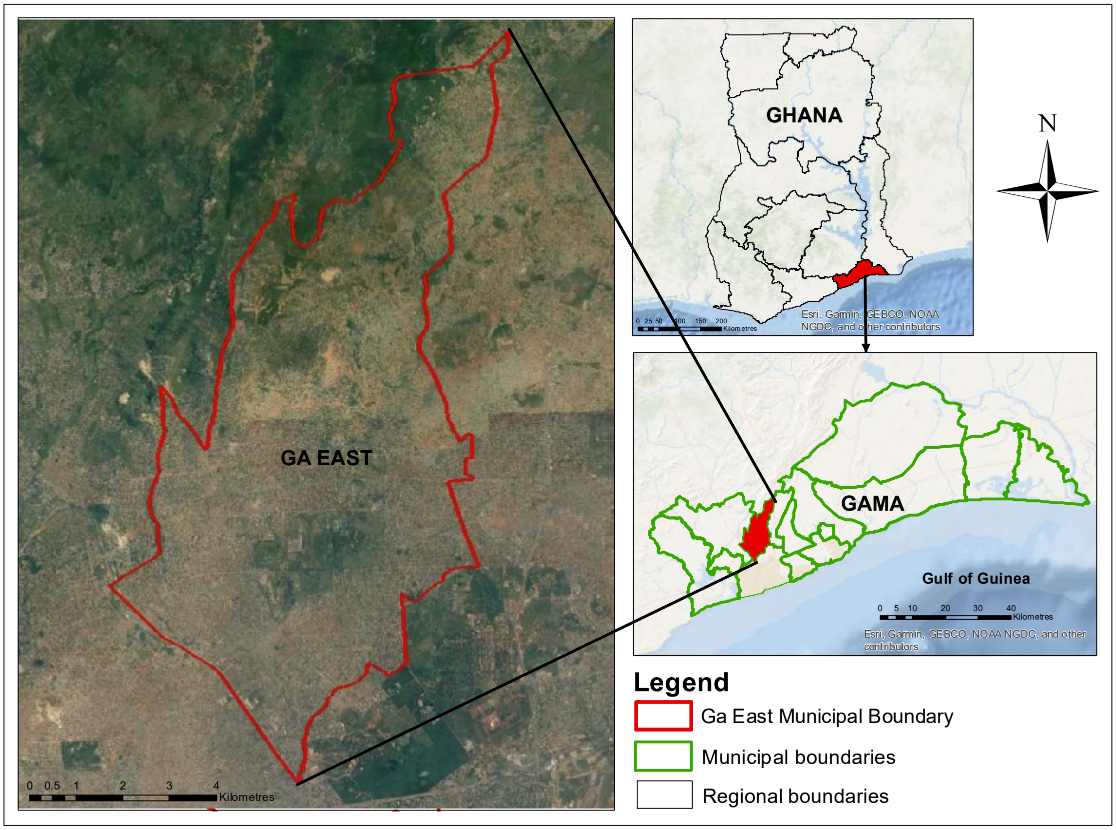


Figure 3-1: Contextual map of Ga East Municipality
Sources: (CERGIS-University of Ghana, ESRI, OSM)

3.2. Research design and approach

This research adopted a case study approach. This approach was adopted because it allows an in-depth exploration of real-life issues pertaining to a jurisdiction (Crowe et al., 2011), and in the case of this research, urban floods and NBS related matters were explored in the Ga East Municipality. In this context, a mixed-method approach was used to research different aspects of the case because it allows for a carefully designed combination of both quantitative and qualitative methods through triangulation. Drawing inferences from Heale & Forbes (2013), triangulation involves the use of more than one method in data collection and analysis for research to increase the confidence in the findings. Hence methods such as spatial, statistical and document analysis were used to come up with in-depth findings in this study. Additionally, Brannen (2018) takes on mixed methods to portray how the two approaches can complement each other in explaining a phenomenon, for example, understanding the why of quantitative associations. This research made use of the sequential technique, specifically QUAN+qual, as highlighted by (Bryman, 2012). This technique shows which method precedes the other in the research. The case sensitive also shows which approach is more prioritized, and the plus sign shows they are combined. Hence, this research focused more on quantitative (QUAN), which involves spatial and statistical analysis. On the other hand, the qualitative (qual) was used to review literature, other documents, and interviews to relate to the quantified findings of the research.

3.3. Data sources and collection

To achieve the research objectives, both primary and secondary data were used. Primary data were collected on the opinions of flood management stakeholders, spatial planning institutions, and other professionals on

NBS integration. This was obtained through semi-structured interviews done both online and face to face. The secondary data used include satellite (Landsat) images (2020), 2015 land cover map from Addae & Oppelt (2019), historical flood data (number of flood events from 2015 to 2020), precipitation amounts (2015 to 2020), location of rivers/water bodies, soil map, Digital Elevation Model (DEM), spatial plans documents, flood management documents and literature on the selected NBS measures for this research. These data were obtained from government and research institutions as well as online platforms. A summary of the data used and their sources are shown in Table 3-1. The data description is given in detail in the analysis section where the data was used and applied.

Table 3-1: Summary of data used for the research

Data type used	Data format	Year	Data source
Landsat image	Raster	2020	USGS - Earth Explorer
Land cover map	Raster	2015	(Addae & Oppelt, 2019)
Historical flood data - number of flood events	Excel	2015 - 2020	NADMO
Meteorological data (rainfall)	Excel	1990 - 2020	Ghana Meteorological Services (GSM)
Soil texture map	Raster	2019	CERSGIS, University of Ghana
Digital Elevation Model (DEM)	Raster	2019	CERSGIS, University of Ghana
Location of rivers/ water bodies	Vector	2019	CERSGIS, University of Ghana
Transcribed interviews	Text	Field	Selected key informants
Spatial plan documents	Text	-	Ga East Municipality
Flood management plan document	Text	-	NADMO
Literature on selected NBS measures	Reports and journals,	2010 or newer	Scopus, Web of science, Google scholar etc.

3.3.1. Sampling technique of key informants

For the research's last objective, semi-structured interviews were conducted to obtain the opinions of spatial planning and flood mitigation institutions among other professionals on how specified NBS measures adapted for this research can be integrated into spatial and flood mitigation schemes. Hence, purposive sampling was used to select the key informants that are professionals involved in the management of urban floods and spatial planning in the Ga East municipality. The approached key informants included either planners, engineers, or technical officers working in flood management institutions.

3.3.2. Semi-structured interviews

Semi-structured interviews, as described by Rahman (2019), could bring a lot of insights into a particular subject. Hence it was employed to interview key professionals in the management of floods in Accra and Ghana as a whole. This type of interview was used because it helps in extracting targeted and relevant responses and views from respondents on a subject and geographical area (Rahman, 2019). Due to the professional background, approached interviewees could provide concrete suggestions on how NBS measures can be made part of the spatial planning and flood mitigation schemes in Accra, specifically the Ga East Municipality. Therefore, interviews covered the key informant's institution and role, their general knowledge on urban floods and NBS, including integration strategies and the possible challenges in the integration process.

In total, ten interviews were conducted with key informants from the institutions listed in table 3-2. Prior to the interview process, key informants were contacted by e-mail, describing the research's general idea and the purpose of the interviews. Some of the key informants were therefore invited to take part in an online interview (on the zoom platform). Other key informants' interviews were held face to face with the help of a field assistant due to internet limitations.

Table 3-2: Institutions of key informants

Key informant ID	Institution	Number of interviewees	Date of interviews
Municipal level			
1	Ga East Town and Country Planning Department (TCPD)	1	5th February 2021
2	Ga East Municipal Works Department	1	18th February 2021
3	Ga East Parks and Gardens Unit	1	18th February 2021
4	Ga East NADMO Office	1	16th February 2021
5	Ga East Department of Urban Roads (DUR)	1	24th February 2021
6	Ga East Environmental Protection Agency (EPA)	1	16th March 2021
National level			
7	TCPD Head Office – Now Land Use and Spatial Planning Authority (LUSPA)	1	23rd February 2021
8	NADMO Head Office	1	26th February 2021
9	Department of Urban Roads (DUR) Head Office	1	3rd March 2021
10	Hydrological Service Department (HSD) Head Office	1	25th February 2021

3.4. Data Analysis and software tools

To achieve the overall objective for the study, different methods were applied under each specific objective. To answer the first objective, spatial analysis, specifically, land cover change analysis was used to determine the increasing hard surfaces in the study area. A Soil Conservation Service (SCS) model approach was also used to determine the runoff depth and flood likelihood areas, and an overlay analysis was made to establish the relationship between land cover changes and urban flood occurrence. For the second objective, spatial multicriteria analysis was employed to identify target areas for NBS implementation, while comparative analysis served to determine appropriate NBS measures best for different target areas to answer objective three. The fourth objective was achieved using content and text analysis to determine possible ways to integrate the specified NBS measures into spatial plans and flood mitigation schemes. Table 3-3 and Figure 3-2 present the research matrix and a generic method flowchart respectively for the study.

Table 3-3: Research matrix

Research question	Method of analysis	Data	Software/ tools
Specific objective 2: To determine the relationship between urban flood occurrences and land cover changes in 2015 and 2020 in the Ga East Municipality.			
How has the land cover in the Ga East Municipality changed from 2015 to 2020?	Land cover change analysis (pixel based image analysis)	Landsat images (2020), landcover map 2015 from	ERDAS Imagine, ArcGIS 10.7
What was the likelihood of urban floods occurrence in 2015 and 2020 in the Ga East Municipality in relation to rainfall records?	SCS Model, overlay	Soil map, DEM, and rainfall data	ArcGIS 10.7
Is there a relationship between land cover changes and urban flood occurrences?	Overlay analysis	Land cover change analysis results flood likelihood results	ArcGIS 10.7
Specific objective 2: To identify target areas in Ga East Municipality for implementing NBS measures.			
Which areas in Ga East Municipality can be targeted for implementing NBS measures?	Spatial multi-criteria analysis	DEM, soil map, location of rivers *(CERSGIS),* land cover results	ArcGIS 10.7
What are the physical geography and land use characteristics of different NBS target areas?	Overlay analysis	Multi-criteria results	ArcGIS 10.7
Specific objective 3: To identify an appropriate NBS measure with the potential to reduce urban flood occurrences in the identified target areas in the Ga East Municipality.			
What NBS measures are appropriate for different target areas in Ga East Municipality to reduce urban flood occurrences?	Comparative analysis (matrix) of target areas and NBS measures design conditions	Objective 2 results, underlined NBS measures literature	Excel/ SPSS
Specific objective 4: To suggest possible ways of integrating NBS measures in spatial and flood mitigation plans.			

How do existing spatial and flood mitigation plans reflect a possibility of NBS integration?	Document review (content analysis)	Flood management plan document, spatial plan documents	Microsoft word, Atlas.ti
What are the views of urban flood management stakeholders on NBS integration?	Qualitative (text) analysis	Transcribed key informant interviews	Voice recorder, Microsoft word Atlas.ti

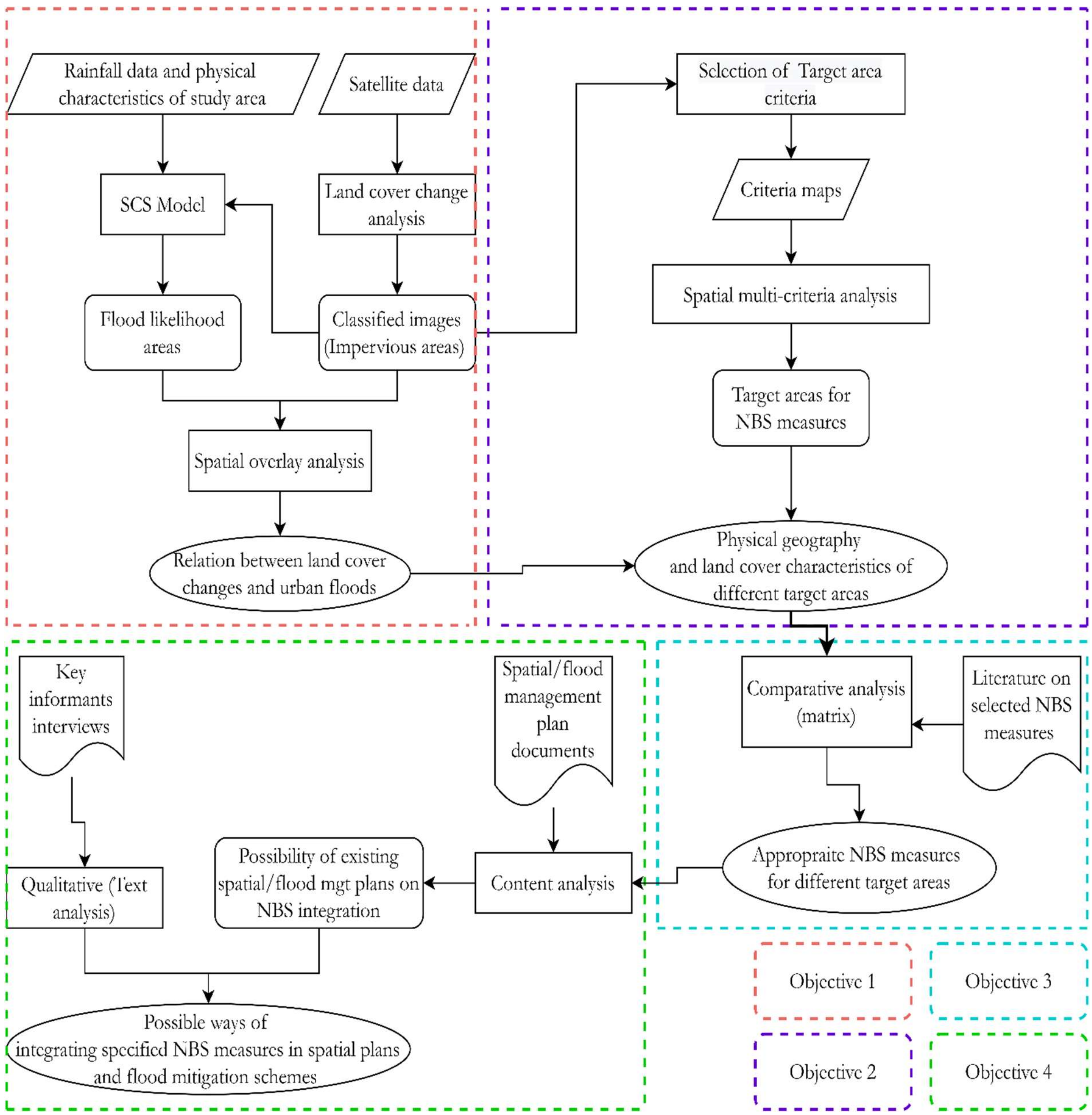


Figure 3-2: Methodological framework of the study

3.4.1. Objective 1: To determine the relationship between urban flood occurrences and land cover changes in 2015 and 2020 in the Ga East Municipality.

3.4.1.1. Land cover change analysis

The land cover change analysis was done using Landsat 8 OLI image for the year 2020 obtained from United States Geological Survey (USGS) online portal and 2015 land cover map for the Greater Accra Metropolitan area obtained from a secondary source (Addae & Oppelt, 2019). The 2015 land cover map from Addae & Oppelt (2019) was used to help save time in conducting two pixel-based image classifications. Hence, the image classification was done for only 2020. For the 2020 Landsat image, an image taken between the month of December and early February, which marks the dry season period in Ghana, was downloaded. This was to make sure the image was with fewer clouds to avoid differences in land covers' reflectance. Table 3-4 below shows the properties of the 2020 Landsat image used.

Table 3-4: Characteristics and properties of the 2020 Landsat image used

Acquisition date	Path/Row	Landsat	Sensor	Spatial resolution	Number of Bands
02/01/2020	193/056	Landsat 8	OLI - TIRS	30 m	11

Image processing

The 2020 Landsat image downloaded contained different band images which needed to be stacked. This process helped in combining the different bands into one single multispectral image. A sub-setting was done afterwards to delineate and carve out the study area for further processing (see Figure 3-3). This was done because the Landsat image covered a larger area not needed for this study. Afterwards, the image was projected into the Universal Transversal Mercator (UTM) zone 30N.

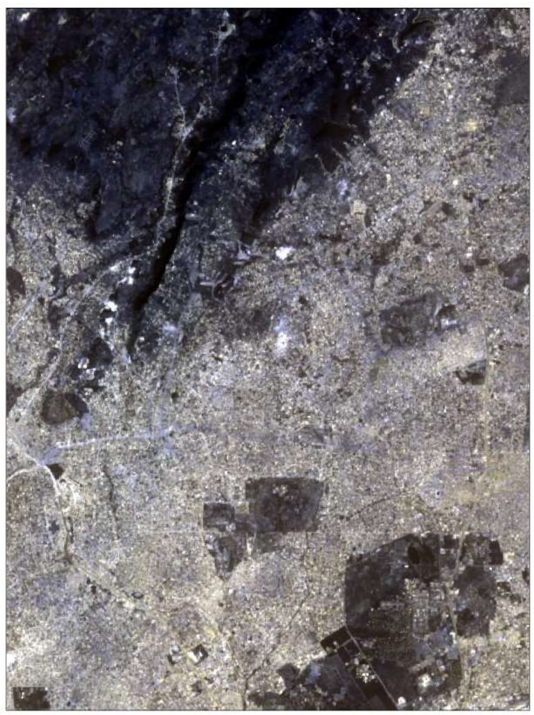


Figure 3-3: Stacked Landsat 8 OLI 2020
Source: USGS

Image classification

Since the 2015 landcover map was obtained from Addae & Oppelt (2019) studies, its methodological approach was employed in conducting the image classification. Hence a supervised classification, specifically, maximum likelihood algorithm was used. This type of classification categorizes image pixels into classes taking into consideration the spectral properties of the pixels. In this regard, 50 training samples were gathered for each identified landcover type by creating polygons around the landcover type features.

The polygons were created randomly to cover all sections of the study area and to also capture the spectral variability under each landcover type. The collection of the training samples was done with the help of Google Earth and the researcher's familiarity with the study area. The training samples were further converted into Region of Interest (ROI), which were used as signature files to conduct the maximum likelihood supervised classification. The supervised image classification was therefore executed in ERDAS Imagine.

The image for the study area was classified into four major land cover types, including bare land, forest, grassland, and built-up. Table 3-5 below briefly describes the land covers as adapted from Addae & Oppelt (2019).

Table 3-5: Description of land cover types

land cover	Description
Bare land	Exposed soil areas and exposed rocks
Forest	Forest reserve, evergreen, and deciduous forest land
Grassland	Shrubs and bush areas, lawns, scattered trees
Built-up	Buildings, transportation facilities (roads, pavements), industrial and commercial structures

Source: (Addae & Oppelt, 2019)

Water was absent from the land cover classes because of the nature of rivers and waterways in the study area. The rivers running through the municipality are of width about 6 meters, making it difficult to identify with a Landsat image having a resolution of 30 meters.

Accuracy Assessment of Image classification

The 2015 land cover results obtained from (Addae & Oppelt, 2019) had an accuracy of 81%. For 2020, an accuracy assessment was done for the land cover result by using 150 Ground Control Points (GCP) randomly generated from Google Earth, trained, and used as reference data to check the accuracy of the classified map.

Determining Land cover changes

The changes in the various land cover types from 2015 to 2020 were also determined and analysed. Therefore, the change in different land covers was calculated using the Raster calculator tool in ArcGIS. In calculating the percentage change and the rate of change in land use, equation one and two were adapted from (Meshesha, Tripathi, & Khare, 2016) and used.

Equation one ______ $\triangle A(\%) = \frac{At_2 - At_1}{At_1} \times 100$

Where $\triangle A(\%)$ = percentage change in an area of land cover between the years, At_1 = area of land cover type for the initial year (2015), and At_2 is an area of land cover type for the later year (2020).

Equation two ______ $\triangle R = \frac{At_2 - At_1}{W}$

Where $\triangle R$ = rate of change, and W = time interval between At_1 and At_2 in years.

3.4.1.2. SCS model and flood likelihood areas (relating possible flood occurrence to rainfall)

In determining the pattern of urban floods occurrence in relation to rainfall amounts in the municipality, an SCS model was used to first determine the runoff depth of the study area. The runoff depth, together with a determined drainage density for various areas in the municipality, was used to determine the likelihood of areas being flooded in 2015 and 2020. In this context, the entire municipality was considered as a catchment area since the drainage network and flow, as shown in Figure 3-4, covers almost every part of the municipality.

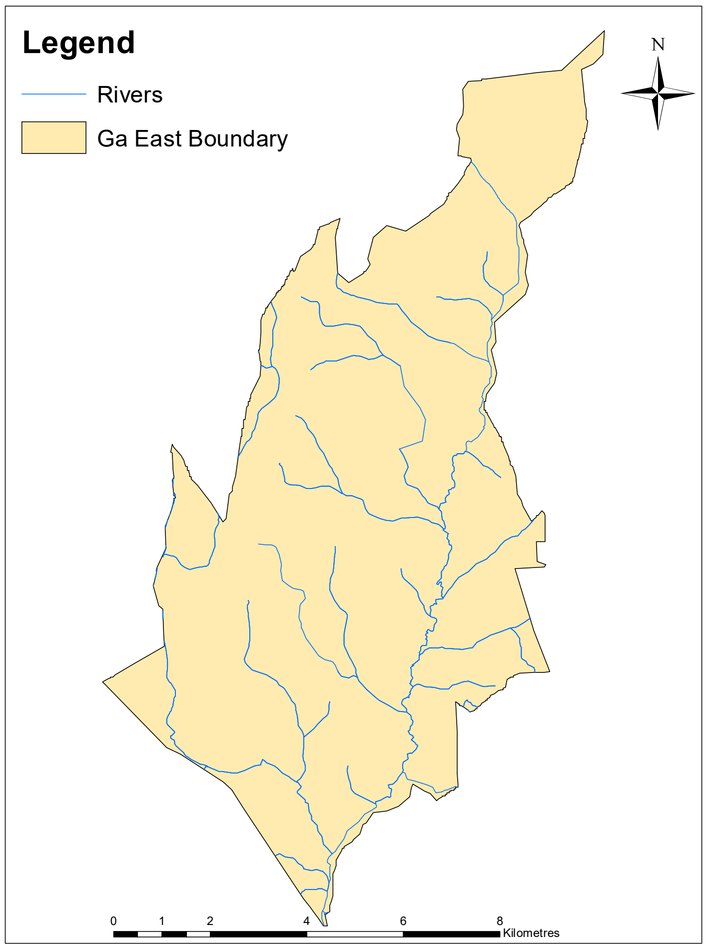


Figure 3-4: River network map

The SCS model

The SCS model is a runoff forecast and water resource evaluation model that was developed by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) (Shrestha, 2018). The model is widely used in calculating the runoff depth of an area (Abdi & Meddi, 2020). Thus, it uses an empirical equation in predicting runoff from rainfall basing on parameters like soil, land use, and vegetation. According to Shiqiang Du et al. (2019), areas of higher runoff depth have a high probability of experiencing urban floods. Therefore, the model can be used to explain the nature of flood happenings both in the past and present state (Shiqiang Du et al., 2019). Hence, the SCS model was adapted for this study to determine the runoff depth of areas in the municipality and further ascertain areas that were likely to be flooded for 2015 and 2020 taking into consideration a single rainfall event in the absence of historical flood maps. Since most of the data obtained had a resolution of 30m, the runoff depth was calculated using a spatial unit of

30m by 30m. Hence, all data used were resampled to have a spatial resolution of 30m. The data used in the SCS model included 2015 and 2020 land cover as shown in Figure 4-1, soil texture and Digital Elevation Model (DEM) shown in Figure 3-5, and rainfall records for the municipality.

It was therefore assumed that the average daily amount of rainfall in peak periods is the same average rainfall amount recorded per single rainfall event for the respective years. It was also assumed that the recorded rainfall amounts were the same for each spatial unit.

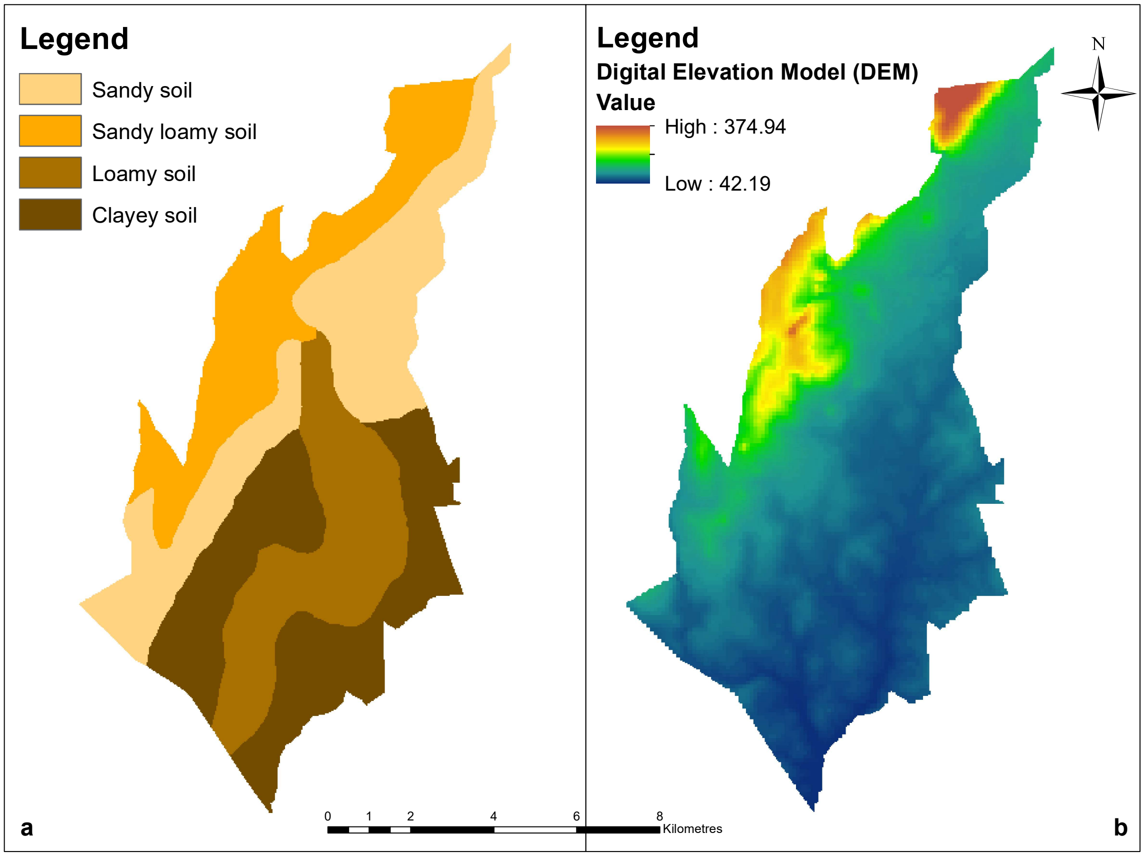


Figure 3-5: Soil texture (a) and DEM (b) map

The formula for the SCS model, as presented in Shiqiang Du et al. (2019), shown in equation three was used in calculating the runoff depth of the study area.

Equation three ______ $Q = \frac{(P-Ia)^2}{P+S-Ia}$

Where Q is the runoff depth (mm), P is the rainfall amount per single event (mm), Ia is the initial abstraction of rainfall in (mm) which is 0.2*S. where S also signifies the land's capacity to retain stormwater (infiltration) which is calculated using equation four below.

Equation four ______ $S = \frac{25400}{CN} - 254$

Where S is the Storage or infiltration for the various areas in the study area and CN is the curve number for the various areas in the study area.

Determining the Curve Number (CN)

Using the CN lookup table (standardized values highlighted by NRCS 1986 for different soil groups and land cover used in determining the curve number of an area), as shown in table 3-6, the curve number of every spatial unit in the study area was determined. This was done using the generate CN Grid tool in Arc Hydro taking into consideration the DEM, an intersect of land cover and soil maps, and CN lookup table as presented in Table 3-6.

Table 3-6: CN lookup table adapted in determining the CN grid for the study area

Land use	Soil group A	Soil group B	Soil group C	Soil group D
Bare land	77	86	91	94
Built-up	61	75	83	87
Forest	37	60	73	80
Grassland	49	69	79	84

Source: (NRCS 1986)

The determined curve numbers for areas in the municipality were then used in calculating the storage or infiltration per each spatial unit in the study area.

The storage was afterward factored in equation 3 to calculate the runoff depth in mm per spatial unit in the municipality. This calculation was done for both 2015 and 2020. The calculated runoff depth (mm) for the study area in the respective years thus 2015 and 2020 was further categorized into five (very high, high, moderate, low, and very low) runoff depth areas. The runoff depth was further used together with drainage density to determine the likelihood of areas being flooded in the municipality.

Drainage density

According to (Carlston, 1963; Cotton, 1964; Pallard, Castellarin, & Montanari, 2008), drainage density refers to the division of all rivers' total length in a drainage basin by the total area of the basin. It is the measure of how poor and well a watershed is drained through waterways and river channels. Therefore, higher drainage density in areas is an indication that there are many tributaries meeting a river channel. This will consequently cause a large volume of water moving into the river point at the same time. Hence, (Carlston, 1963; Pallard et al., 2008) discussed that high drainage density areas cause large volumes of water in rivers to increase rapidly whenever there is a heavy storm, causing rivers to overflow. Consequently, high drainage density areas are also considered to be greater flood risk areas.

The drainage density was determined by using DEM manipulation, flow direction, flow accumulation, stream definition, and line density spatial analyst tools in ArcGIS as adapted by (Dragičević, Karleuša, & Ožanić, 2018; Dahan & Al-Komaim, 2017)

Determining the likelihood of areas being flooded

The runoff depth was related to the study area's drainage density to determine the likelihood of areas being flooded for the respective years (2015 and 2020).

Assumptions in determining the likelihood of areas being flooded

- The drainage movement is only restricted to the study area, and the flow of water from areas outside the municipality is insignificant.
- An area of higher runoff depth and higher drainage density will be a higher likelihood of the area being flooded.

Both the runoff depth and the drainage density maps were reclassified from 1 to 5, with 1 being a low runoff depth or low drainage density and 5 being a high runoff depth or high drainage density. Giving both the runoff depth and drainage density equal importance, the raster calculator was used to merge the two maps to generate the flood likelihood areas in 2015 and 2020.

The flood likelihood areas' results were compared with the location of the frequent flood areas as indicated by flood management professionals (key informants) in the municipality and relating the number of flood events recorded in the municipality for 2015 and 2020.

3.4.1.3. Relation between land cover and flood likelihood change areas

In analysing the land cover and flood likelihood change areas, an overlay analysis was conducted using the land cover change areas' results and the results of the flood likelihood change areas. Hence, the results depicting change areas from other land covers to built-up as well as the flood likelihood change areas were overlayed using the intersect tool in ArcGIS. This relation was established to reveal that urban expansion and the development of hard surfaces in the Ga East Municipality have influenced the occurrence of urban flood events and justify the need to implement urban flood-related NBS measures in some areas in the municipality. Figure 3-6 below is the method flowchart for the first objective.

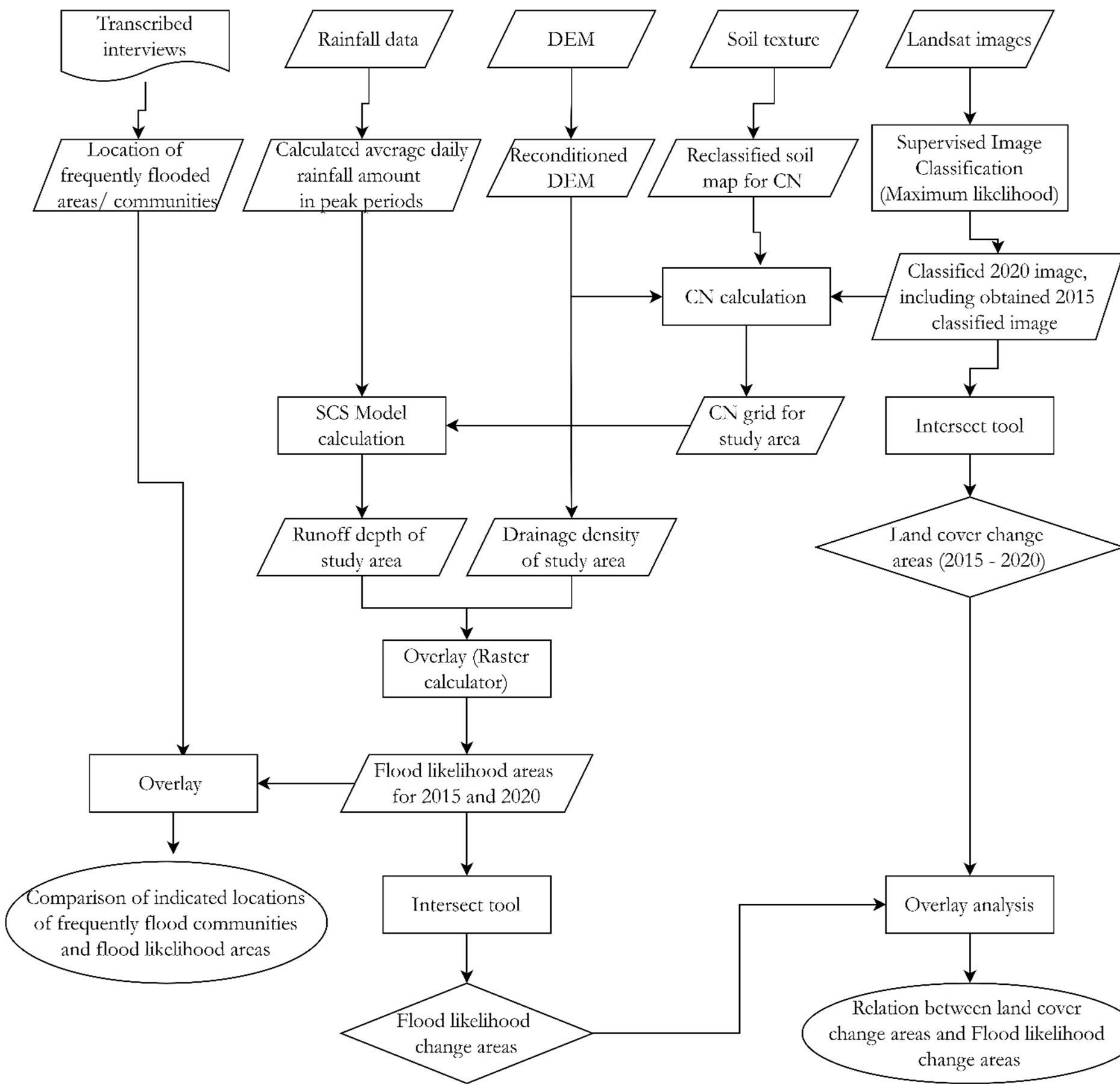


Figure 3-6: Method flowchart for the first objective

3.4.2. Objective 2: To identify target areas in Ga East Municipality for implementing NBS measures.

3.4.2.1. Spatial multicriteria analysis

A spatial multi-criteria analysis was done for the second objective to identify different target areas where NBS measures can be implemented. This method was used because it is able to combine and transform, for instance, different geographical data into a resultant or decision output (Boggia et al., 2018). The target areas in relation to this research are defined by spatial elements or factors subjected to surface runoffs and inundation. In that regard, a target Area Index was developed and calculated to identify and differentiate target areas to implement the urban flood-related NBS measures adapted for this study. The index was calculated in three steps: (1) standardization of criteria maps, (2) determination of weights for the criteria, and (3) final target area index calculation.

Criteria selection

The criteria used in identifying target areas for NBS implementation were based on the spatial elements and factors that are subject to surface runoffs and inundation. With this, criteria or factors mentioned in the existing literature and previous research on surface runoffs and inundation were used. Based on a search in Scopus using the keywords "surface runoff" and "inundation," four (4) studies were identified. The studies include: (Dash & Sar, 2020; Nardi, Annis, & Biscarini, 2018; Park, Lee, Lee, & Ha, 2014; Zhou, Shi, Du, & Fan, 2013). These studies basically focus on the physical and meteorological characteristics that cause changes in runoff and inundation in cities. Considering these studies, nine criteria were identified to be used. These nine criteria included the ratio of impervious surfaces, wetlands or areas close to rivers, slope, soil texture, elevation, ground water depth, existing drains capacity, temperature, wind and humidity. However, the nine criteria were reduced to five upon checks for data availability. No data were obtained for the ground water depth, temperature, existing drains capacity, and wind and humidity. Hence a total of five criteria were finally chosen to identify target areas that are relatively worse and better off in terms of runoff and inundation, thus areas in need of NBS implementation. The worse off and the better off areas in terms of runoff and inundation will be targeted to implement different NBS measures to minimize the rate of urban flood occurrence. The criteria include the ratio of impervious areas or land cover (see Figure 3-7a), Areas close to rivers (see Figure 3-7b), soil texture (see Figure 3-7c), elevation (see Figure 3-7d), and slope (see Figure 3-7e). Table 3-7: Description of selected criteria and their justification is presented in Table 3-7 .

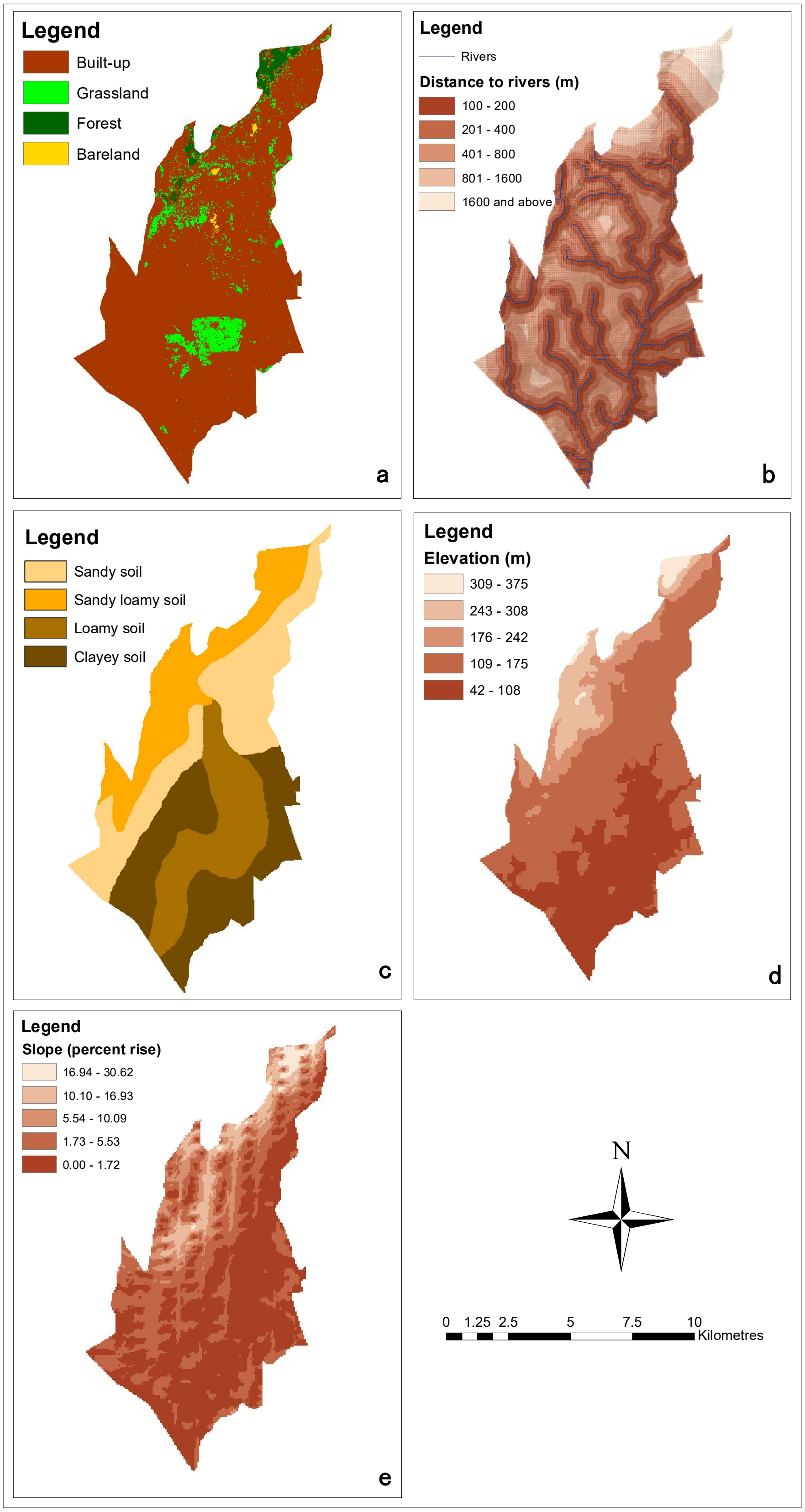


Figure 3-7: Impervious areas-land cover (a), Areas close to rivers (b), soil texture (c), elevation (d), and slope (e)

Table 3-7: Description of selected criteria

Criteria	Description and justification
Ratio of impervious areas (land cover)	Impervious areas in the context of this research are described as areas in the municipality that have been covered with hard surfaces including roads, pavements, building etc. Because these areas are sealed, the probability of water penetrating if there is heavy storm is low (Lee, Lee, Kim, & Lee, 2018). Hence, built-up land cover areas for instance are worse off in terms of surface runoff and inundation and will therefore need specific NBS interventions that will be effective to minimize urban floods.
Closeness (distance) to rivers and waterways	This criterion focuses on the closeness of the area to rivers and waterways in the municipality. Areas that are very close to rivers and waterways, for instance, have the high probability of being flooded anytime there is a heavy storm (Rubarenzya Meire, & Willems, 2009), and they are worse off in terms of inundation. This is because these areas mostly experience river overflows and inundation. Therefore, such areas will also be ideal areas to be targeted to implement specific NBS measures to help reduce the rate of urban flood occurrences.
Soil texture	This criterion also focuses on the texture of soils, thus, the size and structure of the soil particles (Martín, Pachepsky, García-Gutiérrez, & Reyes, 2018). There is a higher infiltration capacity in larger soil particle than in smaller particles. Therefore, areas characterised with tiny soil particles like clay soils are likely to be flooded when there is a heavy storm if the slope and other parameters are not favourable (Amoako, 2012). Therefore, areas with soils of fine texture are worse off in terms of surface runoff and inundation and may also require specific NBS interventions.
Elevation	This criterion also highlights the lowland and the highland areas. Floods according to several studies, mostly affect lowland areas. Therefore, areas characterised as lowland are worse off in terms of runoff and inundation. Since water normally moves from highland areas and accumulate at lowland areas (Manfreda, Di Leo, & Sole, 2011), specific NBS measures should be applied in different elevation areas to help in the mitigation of urban floods.
Slope	This criterion also describes the steepness of landforms in an area. The steepness of a slope determines the water carrying capacity, and normally, water flows quickly on steeper areas and tends to accumulate or be stagnant on relatively gentle and flat areas (Zhang et al., 2019). Hence, flat sloped areas are worse off in terms of inundation. Therefore, in the context of this study, steep, gentle, and flat slope areas will require different NBS measures to help mitigate urban floods.

Standardization of criteria

The selected criteria maps were reclassified into up to five classes (see Table 3-8). The reclassification was done to clearly delineate the variations in each criterion in terms of "worse off" and "better off" conditions to runoff and inundation. The classes were further standardized to ensure an accurate comparison of the criteria. In this regard, a rescaling approach was used for the standardization. Also, pixels in the criteria maps (30m by 30m) were considered as the spatial units for this analysis. This rescaling decomposes the reclassified criteria values into identical ranges, and for this research, a range between 0 and 1 was used, with values nearing 0 being better off areas in terms of runoff and inundation and values nearing 1 being worse off areas in terms of runoff and inundation. The rescaling formula used by Cutter, Burton, & Emrich (2010) was also adapted for this study, and it is presented below.

Equation five

$$\frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where Xi is the criteria value, Xmin is the minimum criteria value, and Xmax is the maximum criteria value.

Table 3-8: Classified criteria values before standardization

Criteria	Original value/ description	Classified value
Ratio of impervious surface (Landcover)	Forest	1
	Grassland	1
	Bare land	2
	Built-up	4
Closeness (distance) to rivers and waterways	0 - 200	5
	201 - 400	4
	401 - 800	3
	801 - 1600	2
	1601 Above	1
Soil texture	Sandy	1
	Sandy loamy	2
	Loamy	3
	Clay	4
Elevation	42 - 108	5
	109 - 175	4
	176 - 242	3
	243 - 308	2
	309 - 375	1
Slope (Percentage rise)	0.00 – 1.72	5
	1.73 – 5.53	4
	5.54 – 10.09	3
	10.10 – 16.93	2
	16.94 Above	1

Determining weight for the criteria

The selected criteria used in identifying different target areas (based on areas subjected to direct runoff and inundation) for NBS implementation are not equally important. Hence different weights were assigned to each selected criterion. The weights were calculated using the Pairwise Comparison matrix (PWC) of the Analytical Hierarchy Process (AHP) as applied by Jalao (2013). For this study, the PWC was calculated based on the opinion of planners, engineers, and technical officers working in flood management institutions on how important each criterion is in terms of identifying areas that are subject to runoff and inundation happenings. This method of weighting was applied because it provides a consistent and efficient approach in determining the importance of multiple options, reduces bias in decision making (Ramík, 2017), and also accurately assigns a fair share of weight ranging from 0 to 1. The average ranks in relation to the criteria were extracted from the interviews held with these professionals where they were asked to give a range of 1 to 5 on the importance of each criterion, with 1 being less important and 5 being more important. The average range given by the flood management professionals for each criterion was calculated and used for the PWC in determining the final weights of each criterion. Table 3-9 below, therefore, presents the average rank per each criterion importance as specified by the professionals.

Table 3-9: Average criteria importance rank per flood management professionals

Criteria	Average rank of importance
High ratio of impervious areas (land cover)	3
Closeness to rivers and waterways	3
Soil texture	1.4
Elevation	4.2
Slope	4.6

The Pairwise Comparison matrix was completed using the average rank of criteria importance as specified by the flood management professionals. The criteria were therefore evaluated against each other in terms of their relative importance. Using the Pairwise Comparison matrix, each value in the matrix was divided by the sum of its column. The new values in the matrix were used to determine the final weight of each criterion. This was done by calculating the mean of each row which is the final weight for each criterion which adds up to 1. Table 3-10 below presents the pairwise comparison matrix and the final determined weight.

Table 3-10: Pairwise Comparison matrix based on flood management professional's opinion

Criteria	Impervious areas (land cover)	Closeness to rivers	Soil texture	Elevation	Slope	Final weight	Rank
Impervious areas (land cover)	1	1	3	0.75	0.60	0.19	w_3
Closeness to rivers	1	1	3	0.75	0.60	0.19	w_3
Soil texture	0.33	0.33	1	0.25	0.20	0.06	w_5
Elevation	1.33	1.33	4	1	0.80	0.25	w_2
Slope	1.67	1.67	5	1.25	1	0.31	w_1

Target Area Index calculation

The five selected criteria maps were used in calculating the target area index for the NBS implementation. In this regard, the standardized maps of the selected criteria were combined using the raster calculator tool in ArcGIS 10.8. The determined weights were multiplied by the respective criteria to generate the final target area index ranging from 0 to 1. The equation as entered in the raster calculator tool is displayed below.

$$\text{Target Area Index} = (\text{Land cover} * w_3) + (\text{Closeness to rivers} * w_3) + (\text{Soil texture} * w_5) + (\text{Elevation} * w_2) + (\text{slope} * w_1)$$

Where w is the determined weight of the criterion.

The results of the index were further categorised into five classes using equal interval, namely target area type 1, target area type 2, target area type 3, target area type 4 and target area type 5. The equal interval was used to ensure an easy understanding and interpretation of results (Zimmer, 2011). Additionally, the individual physical geographical elements and the land use/ land cover characteristics of each target area type was afterwards outlined for further analysis.

Validation of Target area map result

The results of the target areas were validated using information obtained from the flood management professionals with respect to areas and communities[2] that are mostly flooded (worse off areas in terms of runoff and inundation) in the municipality. Figure 3-8 below is the method flowchart for the SMCA.

Additionally, the result of the SMCA was related to the flood likelihood areas to inform the specific NBS measures that will be beneficial to the very high flood likelihood areas and communities[2].

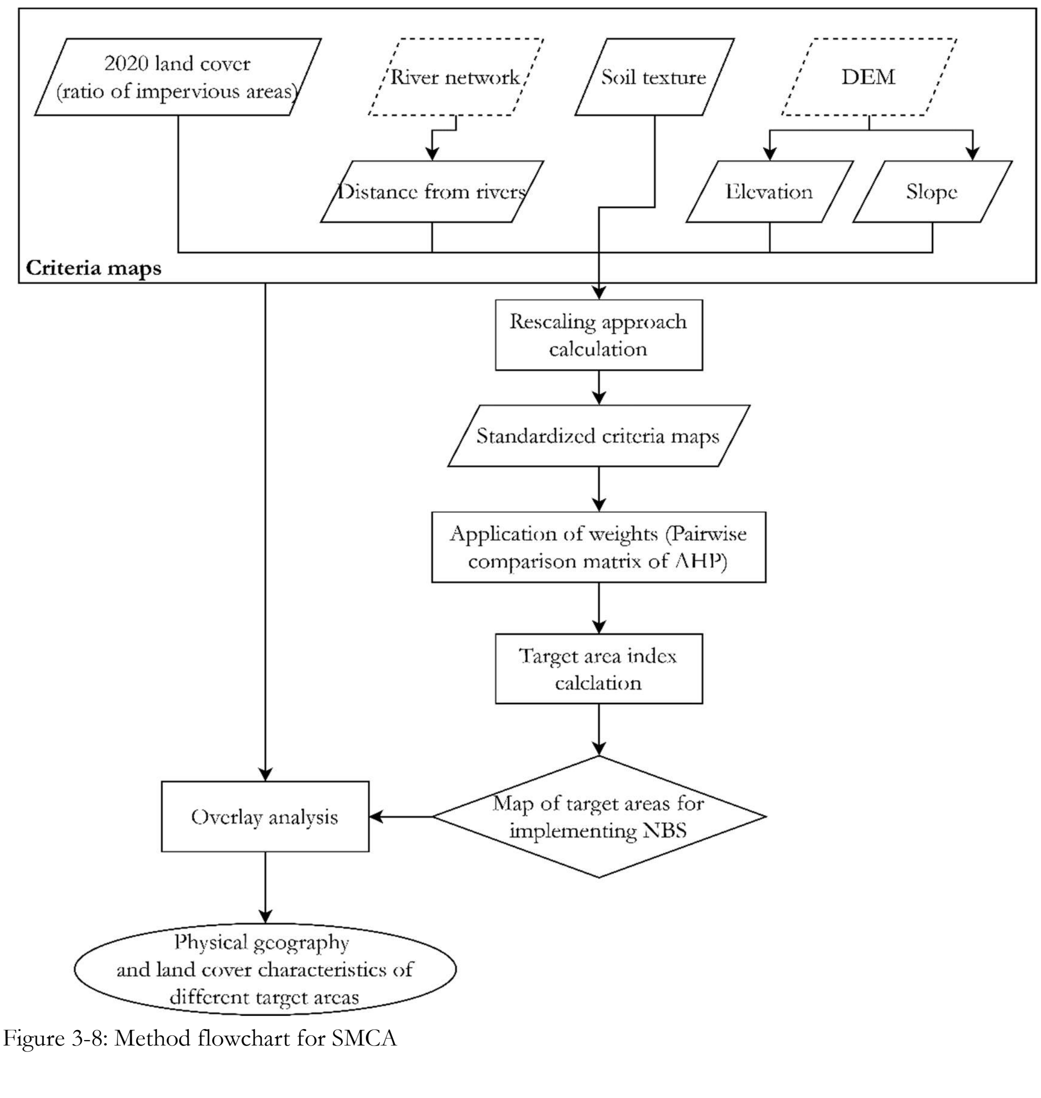


Figure 3-8: Method flowchart for SMCA

3.4.3. Objective 3: To identify an appropriate NBS measure with the potential to reduce urban flood occurrences in the identified target areas in the Ga East Municipality.

3.4.3.1. Comparative analysis

A qualitative comparative analysis was used to identify the appropriate NBS measure (green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements) that is best for different target areas. This method has been used in several studies in explaining, for example, why some interventions work and others do not work in cities (Simister, 2017). Also, this analysis ensures the possibilities in matching features of different phenomena (Pickvance, 2005). Hence it was employed to know which NBS measure will work well in the different target areas identified.

Therefore, the land use and physical geographical characteristics of the identified target area types were compared to the design conditions of the specified areas to determine which measure is best for which target area. A matrix table was then developed using the two sets of characteristics.

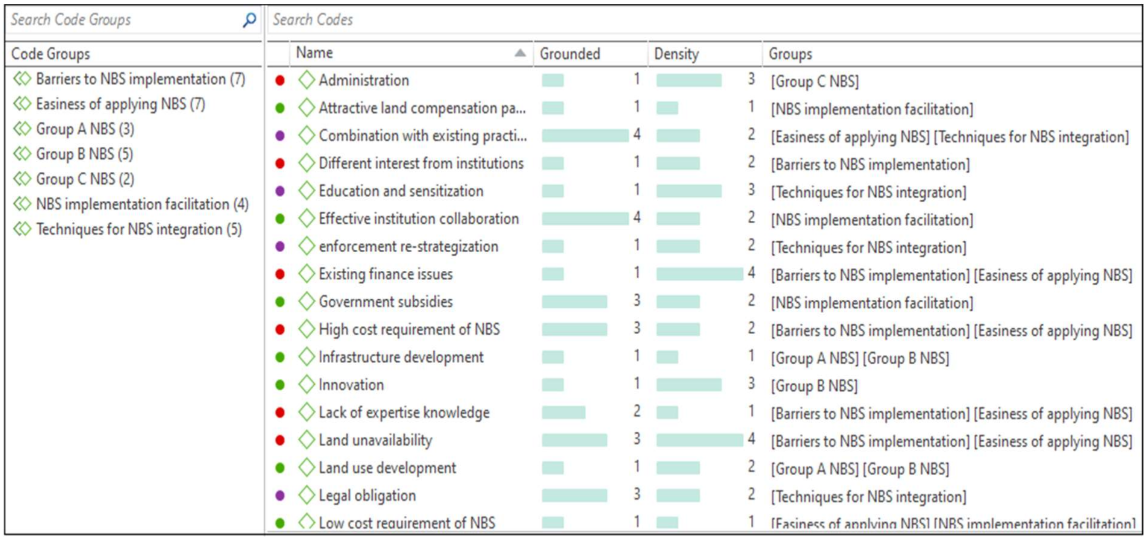
3.4.4. Objective 4: To indicate possible ways of integrating NBS measures in spatial and flood mitigation plans.

3.4.4.1. Content and text analysis

Content analysis is one of the most used tools in a variety of research. It is used for both quantitative and qualitative analysis (White & Marsh, 2006). However, this study employed the content analysis qualitatively to explore how the existing spatial plan for Accra reflects a possibility of NBS integration and interpret the views of flood management professionals on the integration of the NBS in the city, specifically the Ga East Municipality. This approach was used because it goes beyond just counting, for example, the keywords or extracting the objective in a document to examine its meaning or pattern but also helps better interpret the subject matter of a study linking it to reality (White & Marsh, 2006). In this context, this approach will help explain how the specified NBS measures can be integrated into spatial planning and flood mitigation in diverse ways.

The Spatial Development Framework document for the GAMA as well as the Zoning Guidelines and Planning Standards document, which covers the Ga East Municipality, were first analysed. An operational definition for NBS was used to identify NBS related content in the spatial document. For this analysis, the study assumed and defined NBS as a stated principle in the plan that ensures and encourages activities to increase, promote and preserve natural areas in the city. This definition was therefore applied in coding the principles and key statements in the spatial plan into three groups; Group A, B, and C. Group A covering elements and principles in the plan that seeks to preserve and protect green areas, including environmentally sensitive areas. Group B also covers statements and principles that are related and tend to create green-related areas, including gardens, parks, etc. Also, Group C refers to specifications that are unrelated to the protection of natural areas and the promotion of the development of green areas. This was done using Atlas.ti (see Figure 3-9 and Appendix 13).

Additionally, the Atlas.ti was also used to analyse the transcribed interviews. The transcribed documents were uploaded into the Atlas.ti, and they were grouped according to the key informant institutions. And the key informants were given IDs as well. The transcribed documents were coded (open) to extract information about the key informant's ideology and views pertaining to the integration of the specified NBS measures in flood mitigation schemes and spatial development of the Ga East municipality. According to Bryman (2012), an open way of coding interviews aids researchers to be open-minded in generating many ideas and making meanings from the interviews. Hence, the transcribed documents were broken down to cover themes on the techniques that can be adopted to integrate the NBS measures in spatial and flood mitigation schemes, factors that could facilitate and hinder the NBS measure's implementation as well as how key informants see the easiness in implementing the specified NBS measures. Figure 3-9 below shows the themes and codes generated in Atlas.ti, and the linkages between the themes and codes are displayed in Appendix 13.



Name	Grounded	Density	Groups
Administration	1	3	[Group C NBS]
Attractive land compensation pa...	1	1	[NBS implementation facilitation]
Combination with existing practi...	4	2	[Easiness of applying NBS] [Techniques for NBS integration]
Different interest from institutions	1	2	[Barriers to NBS implementation]
Education and sensitization	1	3	[Techniques for NBS integration]
Effective institution collaboration	4	2	[NBS implementation facilitation]
enforcement re-strategization	1	2	[Techniques for NBS integration]
Existing finance issues	1	4	[Barriers to NBS implementation] [Easiness of applying NBS]
Government subsidies	3	2	[NBS implementation facilitation]
High cost requirement of NBS	3	2	[Barriers to NBS implementation] [Easiness of applying NBS]
Infrastructure development	1	1	[Group A NBS] [Group B NBS]
Innovation	1	3	[Group B NBS]
Lack of expertise knowledge	2	1	[Barriers to NBS implementation] [Easiness of applying NBS]
Land unavailability	3	4	[Barriers to NBS implementation] [Easiness of applying NBS]
Land use development	1	2	[Group A NBS] [Group B NBS]
Legal obligation	3	2	[Techniques for NBS integration]
Low cost requirement of NBS	1	1	[Easiness of applying NBS] [NBS implementation facilitation]

Figure 3-9: Themes and codes generated using Atlas.ti software

3.5. Ethical considerations

Ethics in research does not only guide data usage or rights of participants involved but ensures sanity in the research (McKenna & Gray, 2018). In view of this, a written introductory document was obtained from the University of Twente, Faculty ITC, concerning the research. The introductory document was presented to all relevant stakeholders and respondents before interviews were carried out. Also, prior to interviews, explanations for the data collection/ views were given to the respective key informants and institutions. Furthermore, interviewees' consent was sought on their involvement in the research and disclosed to them; all gathered information will only be used for academic purposes. All other ethical protocols were observed during interview sessions, including Covid 19 measures outlined by the Government of Ghana especially for the face to face interviews. Also, all interviewees' profiles were anonymously treated to ensure their privacy rights were duly observed. Prior notice for interview meeting times both online and face to face was discussed and agreed upon before the interview sessions. All other ethical issues concerning this research were taken into consideration and observed.

4. RESULTS

This part of the research explains the findings and the outcome of the applied methods with regards to the main objectives of the research. Hence, elaborations and interpretations are given to results obtained in relation to how landcover changes have been influencing urban floods in the municipality. Also, elaborations and interpretation were given to the SMCA and the NBS target area types as well as the comparative analysis and the content analysis of the spatial/ flood management plans and the views of the flood management professionals.

4.1. Objective 1: To determine the relationship between urban flood occurrences and land cover changes in 2015 and 2020 in the Ga East Municipality.

4.1.1. Land cover in 2015 and 2020

The Ga East Municipality is one of the most urbanising areas in GAMA that has experienced a significant change within a period of 5 years based on the land cover image obtained for 2015 and the image classification results for 2020. As mentioned earlier, the 2015 classification obtained from Addae & Oppelt (2019) had an accuracy of 81%. The 2020 results obtained from the image classification had an accuracy of 86.75%, with a kappa value of 0.74 (see Appendix 4).

The statistics per the results obtained reveal that the built-up areas in the municipality had seen a significant increase between the five-year period. Figure 4-1 presents the spatial distribution of the two land cover maps in the Ga East Municipality in 2015 and 2020. The maps have four land cover types which include bare land, built-up, forest, and grassland. Per the statistics shown in Figure 4-2, the built-up coverage of the municipality increased from 68.3 km² representing 81.75% in 2015, to 75.35 km² representing 90.16% of the total land area in the municipality. The coverage of other land covers, however, decreased between the years. Also, grassland cover decreased from a 12.7% coverage in 2015 to 7.24% coverage in 2020. Additionally, there are also differences in the forest and bare land areas with total coverage of 5.51% in 2015 decreasing to 2.60% in 2020.

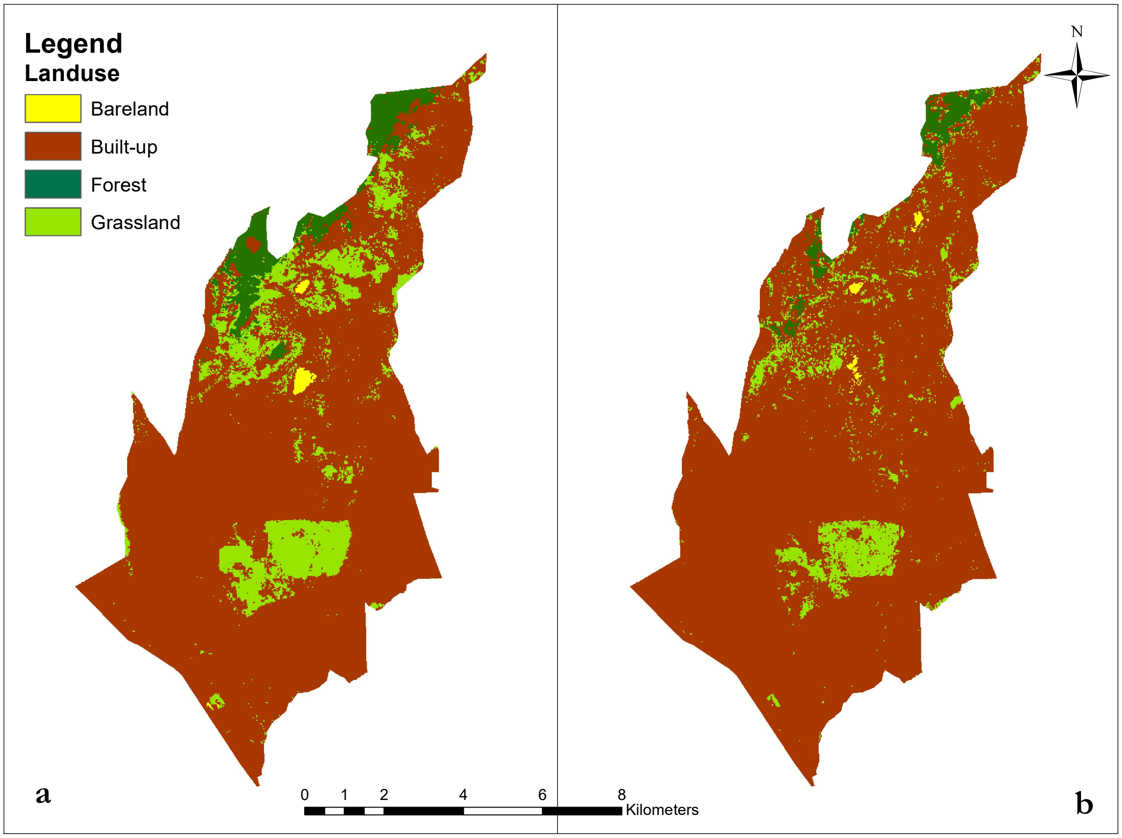


Figure 4-1: 2015 landcover map (a) and 2020 landcover map (b) of Ga East Municipality

The land cover change analysis, therefore, shows the total land area in the municipality is gradually being covered with hard surfaces with about 9 km^2 of green areas (forest and grassland) left, which represent 9.53% of the total land.

The significant land cover changes seen between the five-year period are attributed to the strategic location and transportation linkage of the municipality to Accra central and other business centres such as Madina and Achimota. Because the municipality is close to the above mentioned locations, it has become more attractive and convenient, influencing people to stay in the municipality (Ghana Statistical Service, 2014). The municipality being one of the attractive areas in the metropolitan has also influenced numerous estate companies to set up gated residential communities[2]. Aside the establishment of estates, there are individuals also putting up their residential developments, especially at the peripheries of the municipality (Ackom et al., 2020).

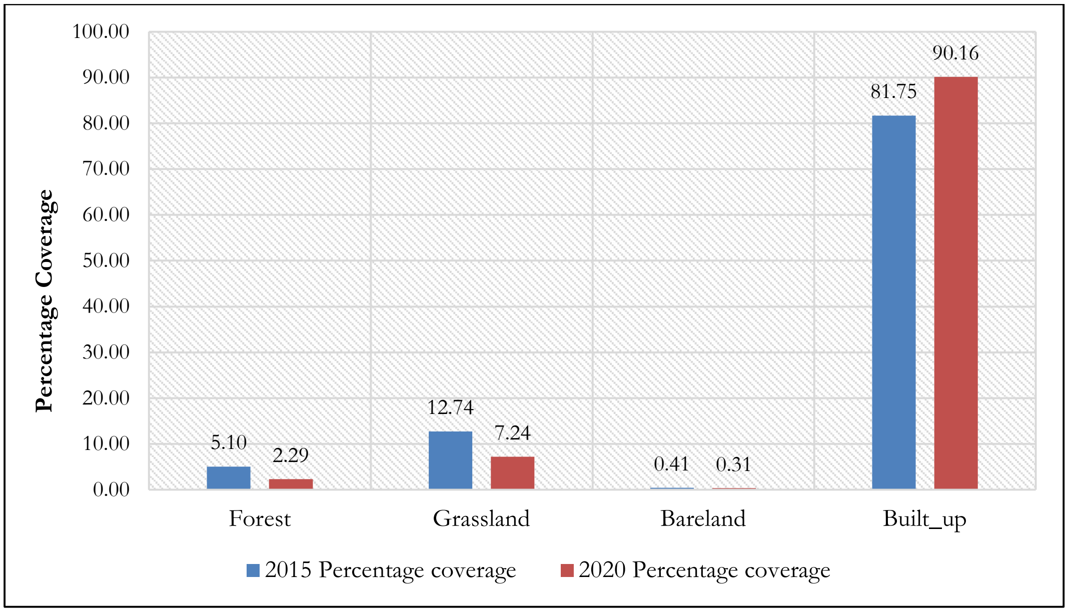


Figure 4-2: Landcover coverage from 2015 to 2020

4.1.1.1. The land cover change from 2015 to 2020

The land cover change analysis revealed variations in the change between different land covers from 2015 to 2020. Figure 4-3 presents how different land covers increased and decreased within the five-year period. The statistics show that bare land had the least total land area change, which is attributed to its small coverage in 2015, which was only 0.08km² changed. Built-up landcover, on the other hand, experienced the biggest change where there was a change of about 7.03 km² of land. As explained earlier, forest and grassland areas also changed where there was a decrease in the land area by 2.35 km² and 4.60 km² between 2015 and 2020, respectively.

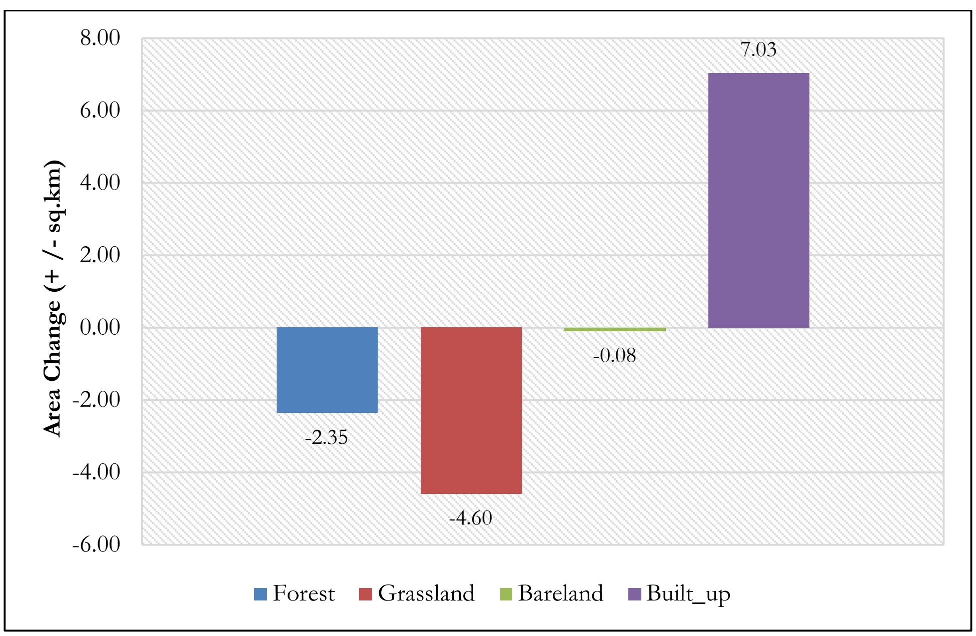


Figure 4-3: Land cover change overview in the Ga East Municipality from 2015 and 2020

Further statistics, as shown in Figure 4-4 also revealed that a significant land cover change happened between grassland and built-up, where a total of 6.57km² of grassland was transformed. On the other hand, a significant share of 1.74km² of built-up areas was also transformed into grassland between the period. The transformation from built-up to grassland could be due to demolishing and evacuation of unauthorized structures, as highlighted by (Acheampong & Ibrahim, 2016). Another significant landcover change was seen between forest and built-up areas, with about 2.37km² of forest areas converted to built-up.

Focusing on the increase in built-up areas, there was a percentage of 8.88 increase from 2015 to 2020, of which constituted about 55%, 43% and 24% of bare land, forest, and grassland areas respectively in 2015. Further analysis also shows that per the built-up area increase in the five-year period, there is an increasing annual rate of 1.4km². Figure 4-5, therefore, shows areas in the municipality where there was a change to built-up within the five-year period.

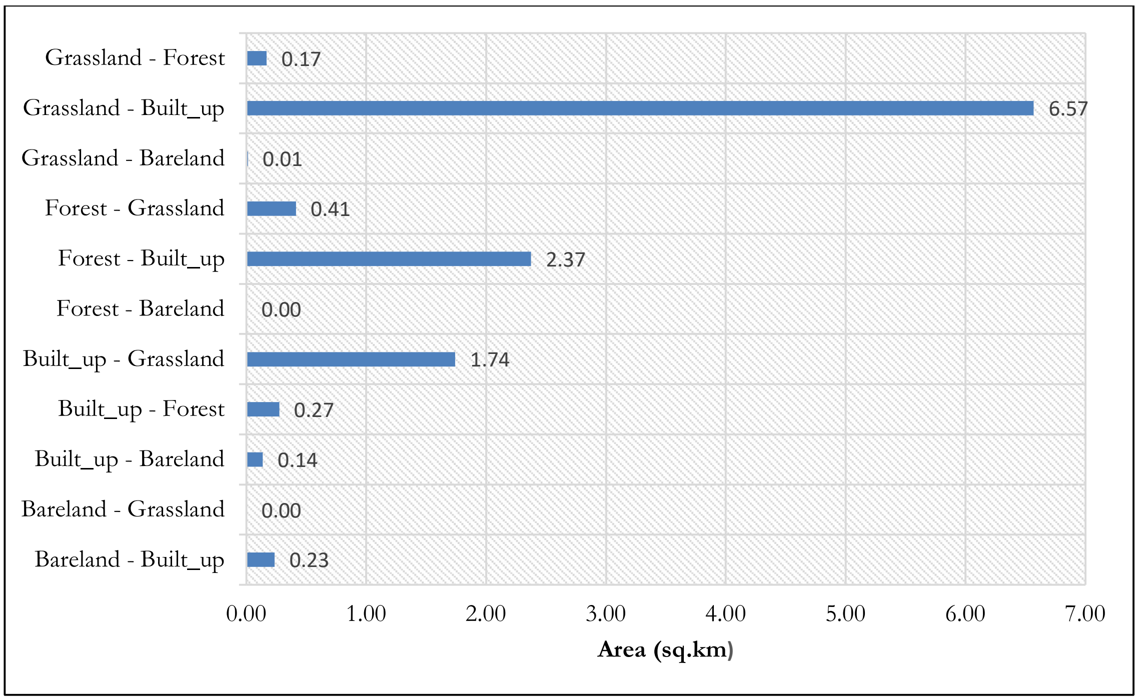


Figure 4-4: Change between different land covers 2015 – 2020

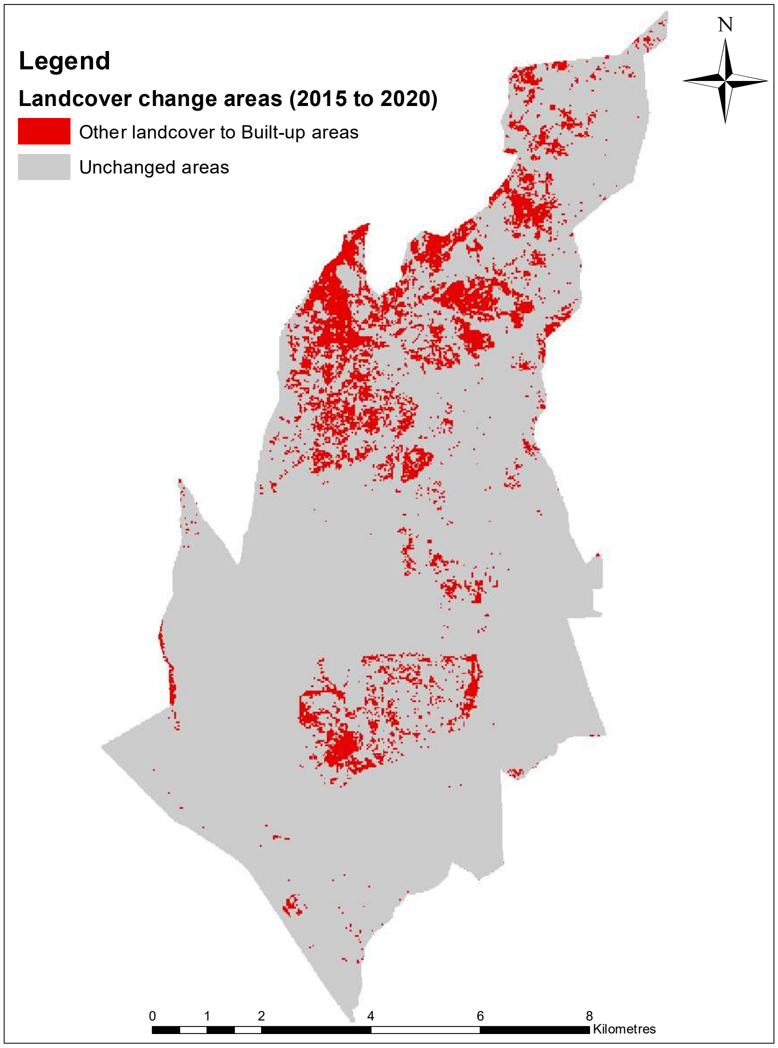


Figure 4-5: Land cover change to built-up areas (2015 – 2020)

4.1.2. The nature of urban floods in relation to rainfall records

4.1.2.1. The SCS runoff depth calculation

Based on the SCS model, the runoff depth per each spatial unit in the study area was calculated taking into consideration the average daily rainfall in peak periods, the storage (infiltration), which was based on the Curve Number (CN) per each spatial unit. The SCS model basically explains what happens to rain when it hits the ground. After the rain hitting the ground, it may either be retained or infiltrate or flow overland to other areas. The subsequent sections will therefore explain the results of runoff depth calculation in the municipality.

Rainfall

Analysis from the rainfall records from 2015 to 2020 buttress the assertion highlighted in several studies on the rainfall pattern in the municipality as there was a decline in rainfall amount from 2015 to 2020. Also, the rainfall amounts recorded in peak periods (months of June and October) for the specified years have seen a decrease from 2015 to 2018 and increased from 2018 to 2020. In general, the average daily rainfall amounts (calculated by dividing the total rainfall amounts in the peak periods by the number of days it actually rained) in peak periods in 2015 were higher than in 2020 with 21.11mm and 18.48mm respectively (see Figure 4-6). This average daily rainfall amount in peak periods was assumed to be a record of a single rainfall event in the respective years for this study.

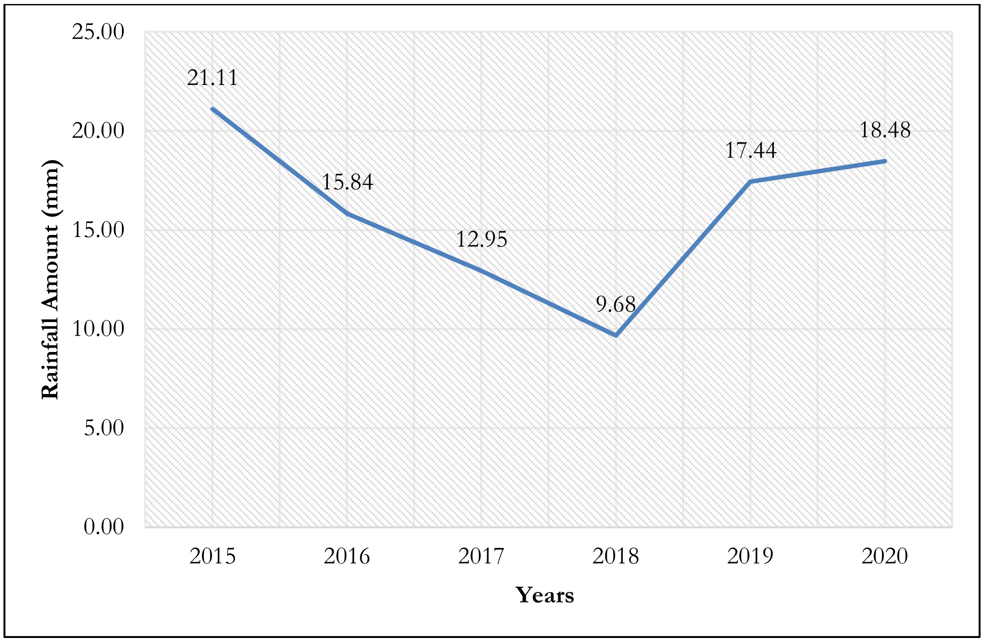


Figure 4-6: Average daily rainfall amounts in peak periods

Storage

The curve number (CN) per each spatial unit in the municipality for 2015 and 2020, which ranged from 37 to 91 (see Appendix 6), was used to determine the rainfall storage capacity of areas in the respective years. The results of the storage in 2015 and 2020 per each spatial unit ranged from 0.98mm to 17.03mm (see Appendix 7). These storage values signify the amount of rainfall that could be retained or infiltrated per each spatial unit for a single rainfall event.

Harnessing on the results of the initial abstraction, it was denoted by 20% of storage and explained the amount of rainfall that will infiltrate or evaporate prior to runoff. In that regard, the values of 2015 per each spatial unit ranged from 0.18mm to 3.41mm, and that of 2020 ranged from 0.13mm to 3.22mm. The results of the initial abstraction were also factored in the calculation of the runoff depth.

Runoff depth

The runoff depth of each spatial unit within the municipality was therefore calculated using the results of the average daily rainfall in peak periods (see Figure 4-6), storage (see Appendix 7), and initial abstraction. Figure 4-7, therefore, presents the runoff depth in mm per spatial unit in the municipality. The map shows that there are some changes in runoff depth between the five-year period. Such areas included Abokobi and Akokome. Also, areas around Atomic Down and Transition are portrayed to have lower runoff due to the existence of preserved farmlands own by the Ghana Atomic Energy Commission. In general, there were higher runoff depth values in 2020 than in 2015 as areas were transformed from relatively lower to a higher runoff depth due to land cover changes. Even though the average daily rainfall amounts in the peaks for 2015 were higher than that of 2020.

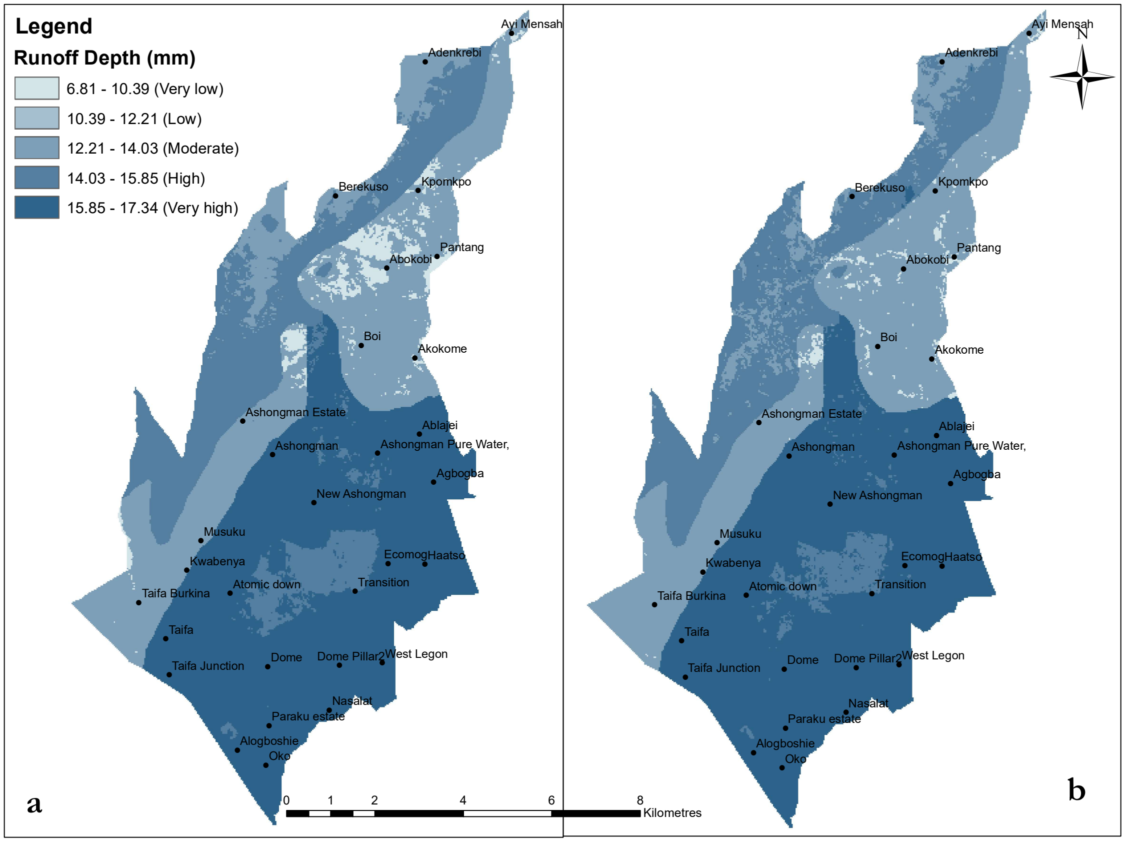


Figure 4-7: 2015 runoff depth (a) and 2020 runoff depth (b)

4.1.2.2. Drainage density of the municipality

The drainage density, as displayed in Figure 4-8, was determined with the DEM of the municipality using the Arc hydro tools as mentioned in section 3.4.1.2. The spatial unit of analysis for the drainage density was also 30m by 30m. The map shows areas in the municipality with relatively larger (100) and lower (1.51) drainage densities. The higher drainage density areas with values equal to or nearing 100 in the map signify the higher probability of these areas experiencing river overflows anytime there is a heavy storm due to the incoming flows from other parts of the municipality. Therefore, depending on the runoff situation per each spatial unit, an area could easily be flooded if the drainage density is also high (Carlston, 1963; Pallard et al., 2008). These drainage density values together with the runoff depth values of each spatial unit in the municipality were used to identify the probable areas that were flooded in 2015 and 2020.

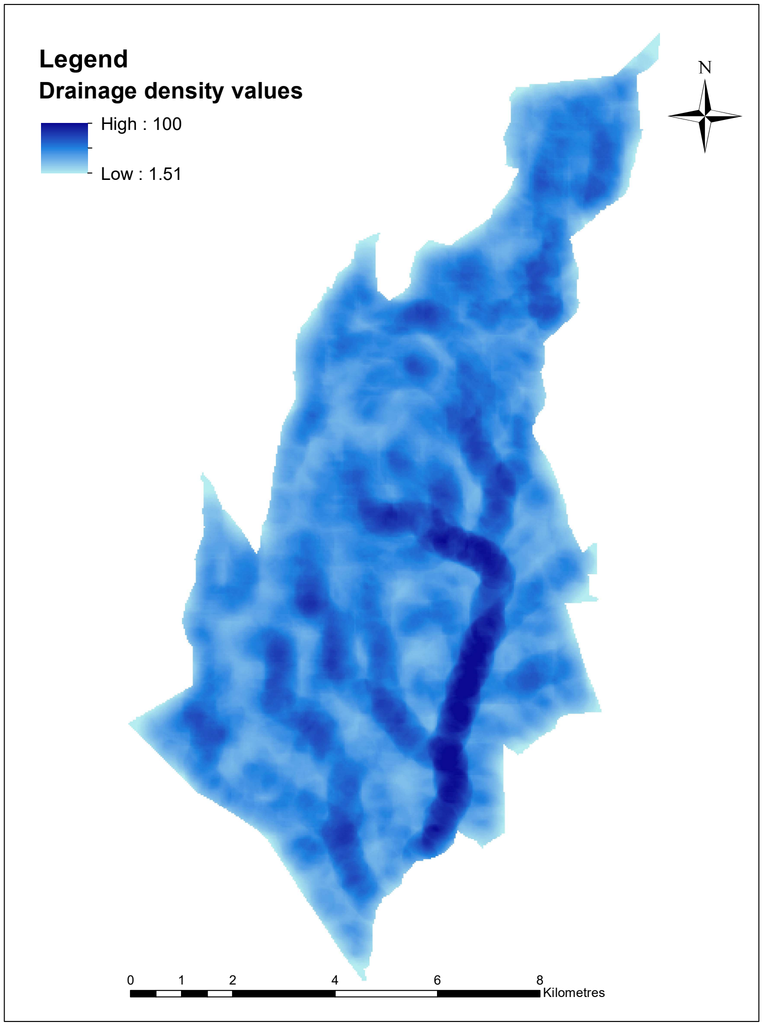


Figure 4-8: Drainage density map of Ga East Municipality

4.1.2.3. Likelihood of areas being flooded

The results of the likelihood of areas being flooded ranged from 2 to 10, with values nearing 2 means a low likelihood of the area being flooded and values nearing 10 signifying a high likelihood of the area being flooded (see Figure 4-9). The values were further categorized into five (very high, high, moderate, low, and very low) flood likelihood using natural breaks to give a fair delineation of the various flood likelihood levels areas.

Statistics of the likelihood of areas being flooded, as presented in Table 4-1, indicate an increase in the very high flood likelihood areas from 14.01% to 14.67% coverage in 2015 and 2020, respectively. Hence, there was a conversion of about 0.66% of relatively lower flood likelihood areas, making up close to 0.95km² in 2015, to a very high flood likelihood area in 2020 (see Figure 4-9). Additionally, Figure 4-10 shows the areas that changed from relatively lower to very high flood likelihood areas. This signifies a possibility of more areas flooded in 2020 compared to 2015, even though there were fewer rainfall amounts recorded in 2020 than in 2015.

Comparing likelihood flood areas with the indicated flood communities[2] indicated by key informants, 8 out of the 12 communities[2] indicated by flood management professionals fell within the very high flood likelihood areas in 2020 (see Appendix 9). Also, the coverage of the very high flood likelihood areas in 2015 was smaller than the coverage in 2020, which is in line with the number of flood events recorded by NADMO for the two periods (see Appendix 5).

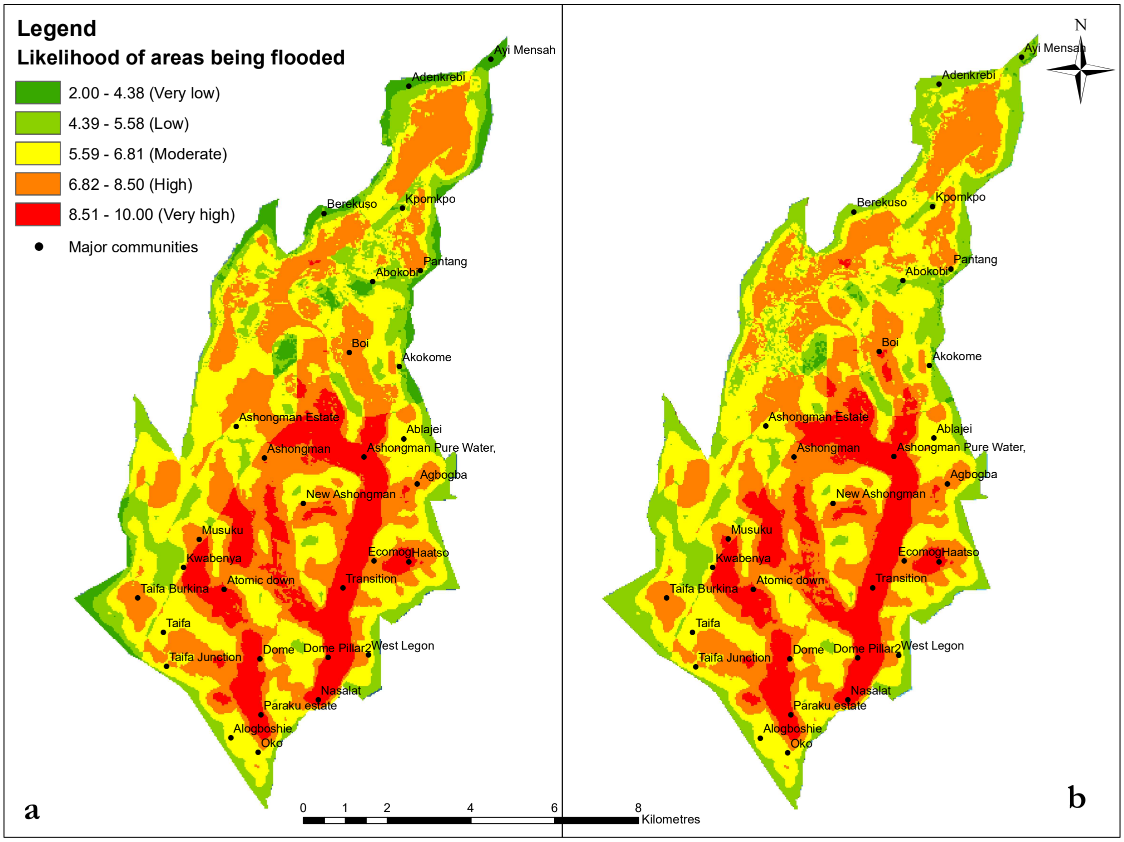


Figure 4-9: Likelihood of areas being flooded in 2015 (a) and Likelihood of areas being flooded in 2020 (b)

Table 4-1: Likelihood of areas being flooded statistics

Flood likelihood level	**Area km² (2015)**	**Percentage coverage**	**Area km² (2020)**	**Percentage coverage**
Very low	3.78	4.54	0.37	0.45
Low	11.79	14.15	14.21	17.06
Moderate	29.07	34.89	29.62	35.56
High	26.99	32.40	26.87	32.26
Very high	11.67	14.01	12.22	14.67

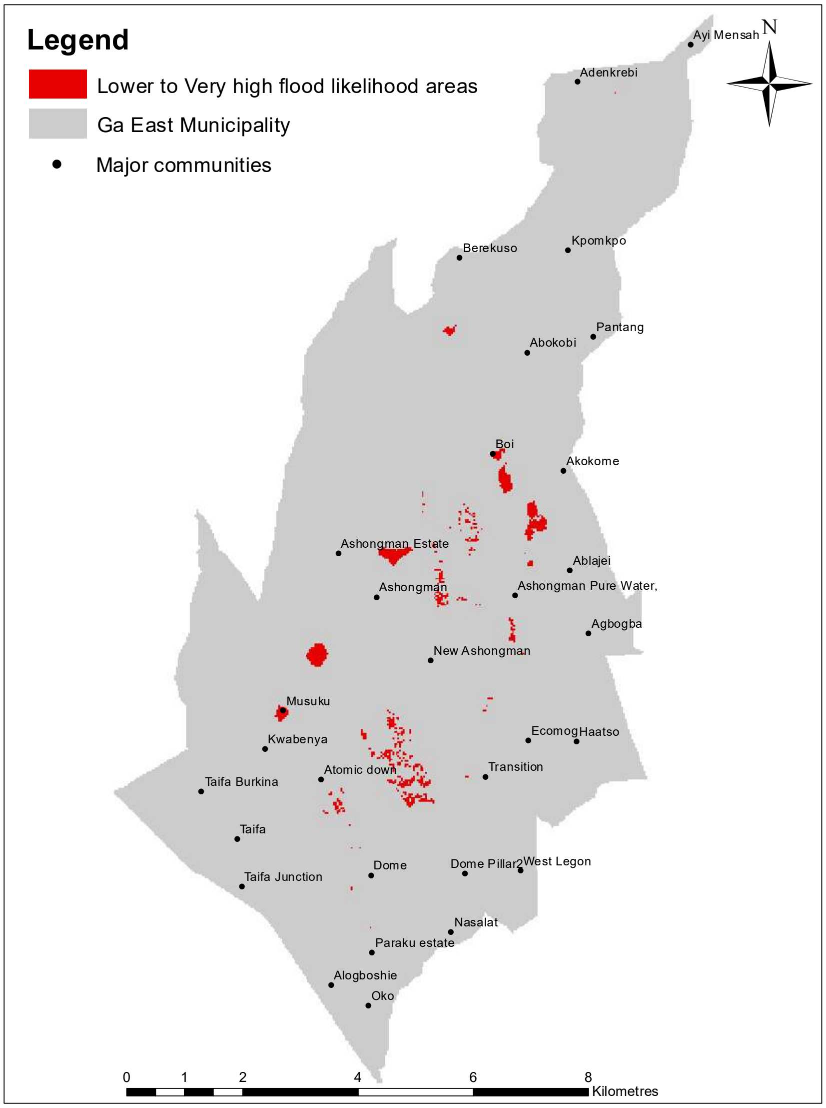


Figure 4-10: Areas transformed from a lower to a very high flood likelihood area

As presented in Figure 4-9, communities[2] that came out as very high likelihood to be flooded in 2020 included Taifa Burkina, Atomic Down area, Musuku, Haatso, Paraku estate, Nasalat, Ashongman pure water area, Transition area, and Boi. Figure 4-10 also shows areas that transformed from a relatively lower flood likelihood area in 2015 to a very high flood likelihood area in 2020. This means that these areas were possibly not experiencing flood events in 2015. Such communities[2] included Musuku and Boi. The two communities[2] were also part of the frequently flood communities[2] as mentioned by the key informants.

4.1.3. The spatial relation between land cover change and potential flood areas

The land cover change areas (from other land covers to built-up) were overlayed with the flood likelihood change areas (from a relatively lower to a very high likelihood of areas being flooded) to establish a spatial relationship between the two. The overlay analysis results, as shown in Figure 4-11, indicates there were flood likelihood change areas, thus 24.2% falling within the land cover change areas. The remaining 75.8% flood likelihood change areas were also outside the land cover change areas. Additionally, the transformed flood likelihood areas were mostly located in relatively downstream areas of the land cover change areas and locations.

Therefore, relating the land cover changes statistics and the flood likelihood change areas from 2015 to 2020, it was revealed that the net increase of 7.03km² of built-up (hard surface areas) led to about 0.95km² of areas in the municipality been transformed into a very high flood likelihood area. This finding is buttressed with the number of flood events recorded in 2015 and 2020 (see Appendix 5), irrespective of the higher rainfall amounts recorded in 2015 than in 2020. Hence, there is a positive relation between hard surfaces (built-up) and the coverage of the very high flood likelihood areas taking into consideration landcover and the average daily rainfall amounts for the two years.

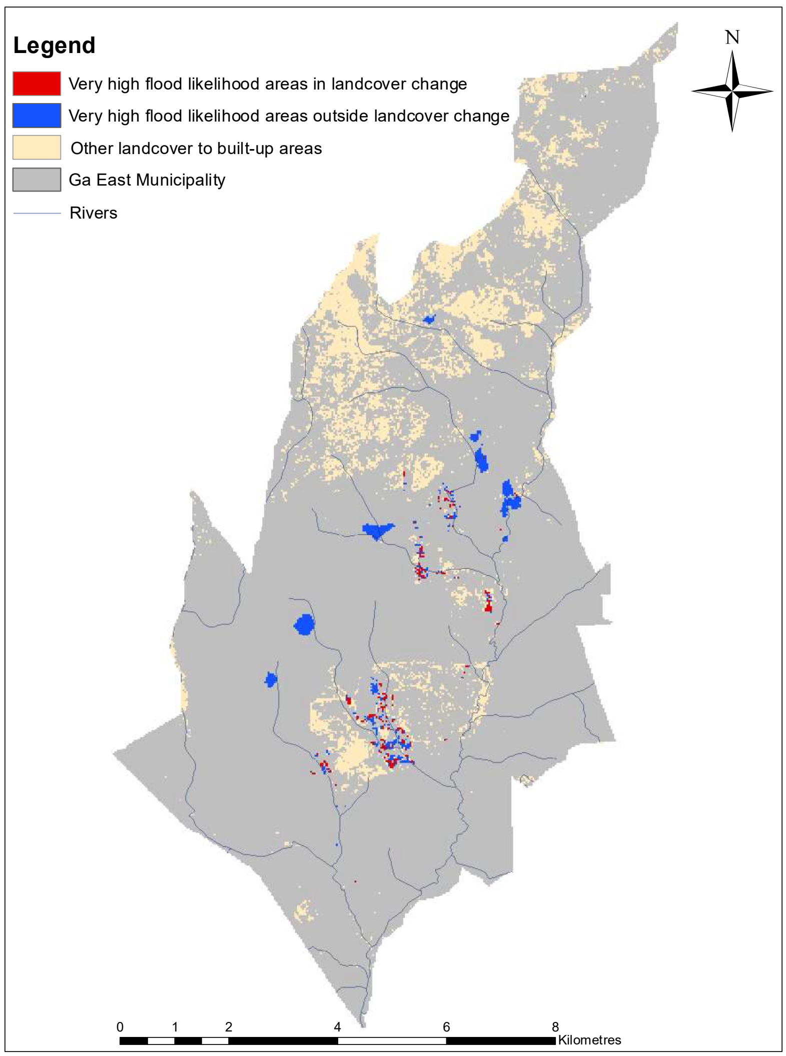


Figure 4-11:Change in flood likelihood areas and land cover change areas

In summary, the 2020 land cover shows the municipality is almost covered with hard surfaces and has affected the increasing occurrence of urban floods in the municipality based on the flood likelihood areas statistics. Moreover, despite the numerous flood prevention measures outlined in the municipality and the entire city of Accra, records from NADMO also reveals an increasing number of flood events within the five-year period even though less rainfall amounts were recorded in 2020 as compared to 2015. This calls for the adaptation of nature inclined measures like NBS to be applied to improve urban surfaces and reduce the increasing flood occurrences and further improve the greenery in the municipality.

4.2. Objective 2: To identify target areas in Ga East Municipality for implementing NBS measures.

4.2.1. Target areas for NBS implementation

Based on section 2.4, five major urban floods-related NBS measures (green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements) that are mostly used in well-planned and developed countries were considered in this study. These NBS measures could be applied in the municipality as a possible way of improving urban surfaces to reduce runoff depths and preventing urban floods.

Based on the SMCA, target areas where the urban flood-related NBS measures can be implemented were identified. The identified target areas were informed by the five criteria thus, spatial elements and physical characteristics of the study area that are subjected to surface runoffs and inundation. Based on the results obtained, the target area index value per each spatial unit of the study area was further classified into 5 categories. The classified target areas were named Type 1, Type 2, Type 3, Type 4 and Type 5 as shown in Figure 4-12.

Also, in validating the results of the SMCA, frequently flooded communities[2] and areas that were indicated by flood management professionals were assumed to be worse off areas in terms of surface runoff and inundation. Out of the 12 communities[2] indicated, 8 of them were also located in the type 5 target areas (see Appendix 10).

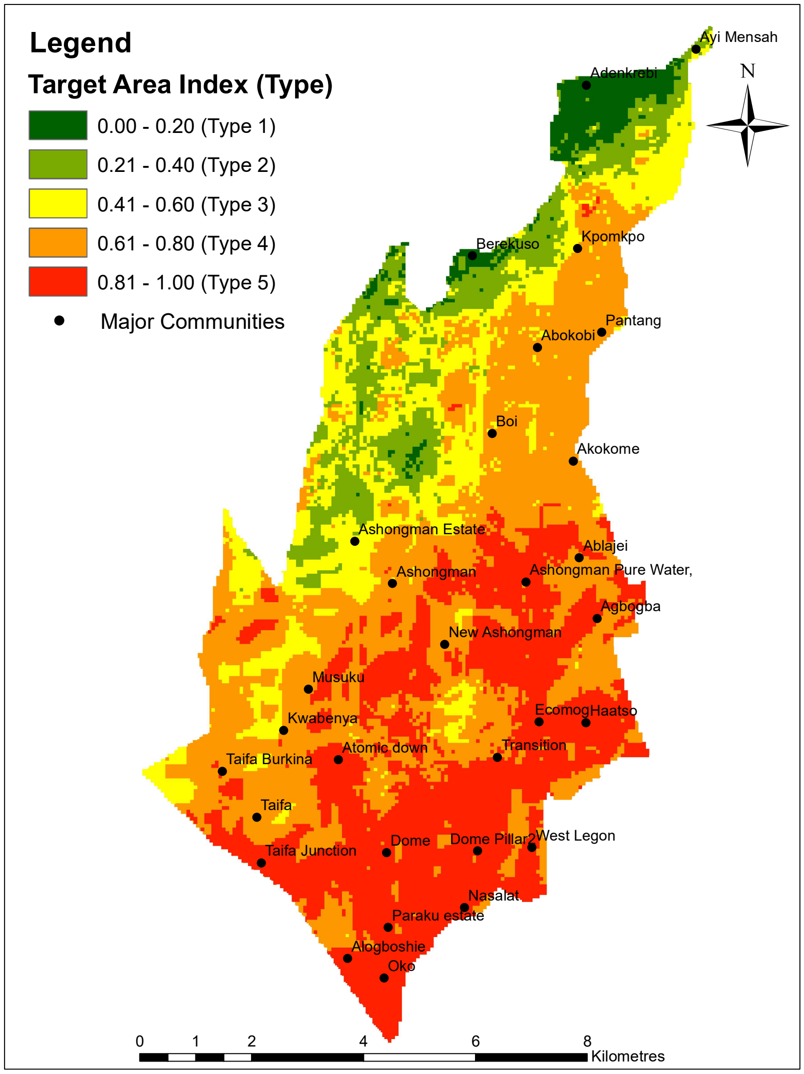


Figure 4-12: NBS Target areas

As presented in Figure 4-13 and depicted in Figure 4-12, type 5 areas, which have the highest index score ranging from 0.8 to 1.0 signifies the areas constitute relatively "worse off" criteria values in terms of surface runoff and inundation. These areas may need some special flood intervention or specific NBS measures that will help improve on the surfaces of these areas in dealing with flood situations. On the other hand, type 1 areas were with index scores ranging from 0 to 0.2, which signifies, the areas are made up of "better off" criteria values in terms of surface runoff and inundation. This also depicts an indication that these areas may require some level of flood intervention or specific NBS measures in improving the infiltration of surfaces, detention and controlling overflows to deal with the flood situation in the municipality.

Figure 4-13 presents the statistics per the coverage of the target area types. Type 5 and 4 occupy a greater percentage of the study area's total land area with 39% and 28%, respectively. Type 3 covers about 17% of the study area's total land, which is about 13.92km2. Additionally, type 1 and 2 areas occupy smaller portions of the study area's total land, which is 4% and 12%, respectively.

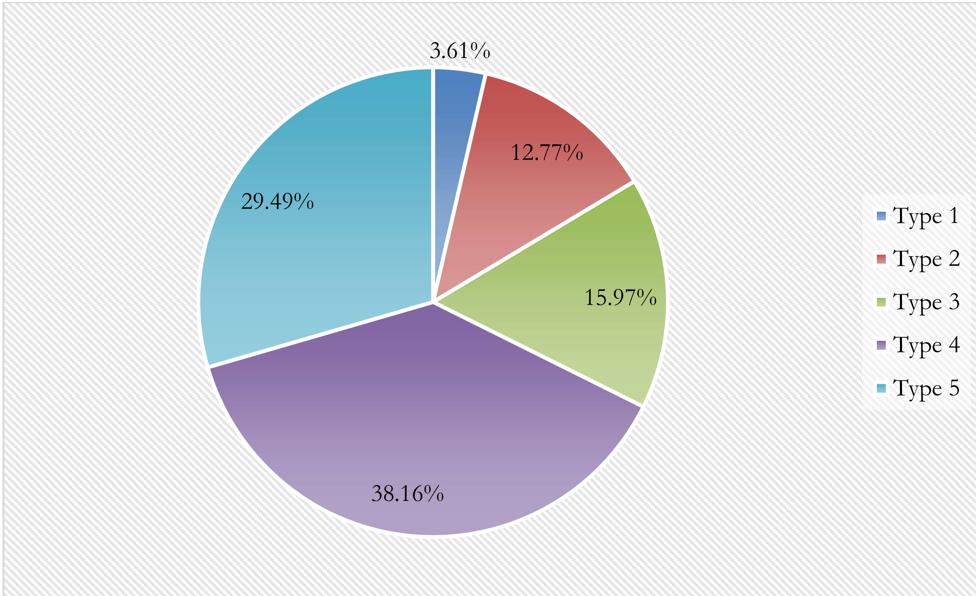


Figure 4-13: The coverage per each target area

4.2.2. Characteristics of the target area types

Further overlay analysis of the target areas with the criteria maps reveals a detailed physical geographical and land cover characteristic of each target area. Table 4-2 explains these characteristics and the associated communities[2]. Figure 4-14, therefore, presents an overview of the target area characteristics.

Table 4-2: Characteristics of the different target areas

Target area	**Characteristics**						
	Impervious ness	**Distance to rivers**	**Soil**	**Elevation**	**Slope**	**Total area (km²)**	**Communities**
Type 1	Made up of 70% forest and grassland, 30% built-up	93% of the area are outside a buffer of 800m t the nearest river	Made up of 89.2% sandy-loamy soil	Made up of 70% moderate to high elevation areas	80% of the area fall within high slopes	3.02	Adenkrebi, Berekuso,
Type 2	Made up of 72% built-up	60% of the area are outside a buffer of 400m to the nearest river	98% sandy and sandy-loamy soils	Made up of 75.7% moderate to high elevation areas	Made up of 80% high slope areas	10.67	Ayi Mensah
Type 3	82.9% of this area is built-up	60% of these areas are outside a buffer of 400meters	Made up of 86.4% sandy and	About 60.4% low elevation areas	Made up of 64.5% low	13.34	Ashongman Estates

		to the nearest river	sandy-loamy soil		slope areas		
Type 4	The area is 92%built-up	73% of the area are within a buffer of 400meters close to rivers	More than 70% of the area is made up of sandy and loamy soils	96% of the area are also relatively low land	98% of these areas are generally low slope	31.89	Boi, Abokobi, Pantang, Akokome. Kpomkpo, Ashongman, Musuku, Kwabenya, Taifa, Taifa Burkina, and Ablajei.
Type 5	The area is made up of about 98% built-up	92% of areas also within a buffer of 400 meters to the nearest river	58% percent of the area are clayey soil	The entire area is characteris ed with low land	Entire area is characte rised with flat slopes	24.64	Taifa junction area, Dome, Dome Pillar 2, Alogboshie, Oko, Paraku Estate, Nasalat, West Legon, Haatso, Haatso Ecomog and Ashongman Pure Water

In summary, Type 1 target areas are generally steep slope and mainly highland areas. They are characterised with sandy-loamy soil. They are further away from rivers and water ways and predominantly forest and grassland areas. Type 2 target areas are also generally steep slope areas, intermediate of highland and lowland areas, and also characterised with sandy and sandy-loamy soils. The areas are also further away from rivers and water ways and predominantly built-up areas. Type 3 areas are generally gentle sloped areas, also intermediate of highland and lowland areas and comprised of sandy and sandy-loamy soil areas. The areas are moderately close to rivers and waterways and mainly built-up. Type 4 target areas are flat/horizontally sloped areas. They are mainly lowland areas characterised by both clayey and sandy soils. They are also moderately close to rivers and waterways and primarily built-up areas. On type 5 Target areas, they are also flat/horizontally sloped, mainly lowland areas, characterised by clayey soils. The areas are very close to rivers and highly built-up.

Harnessing the specific land uses for the identified target areas, all suburbs in the municipality are broadly classified as residential (LUSPA, 2017). However, there are other land uses such as educational, commercial, industrial, civic and culture, among others that make up the residential suburbs. Table 4-2 summarises the key physical geography and landcover characteristics of the different target areas.

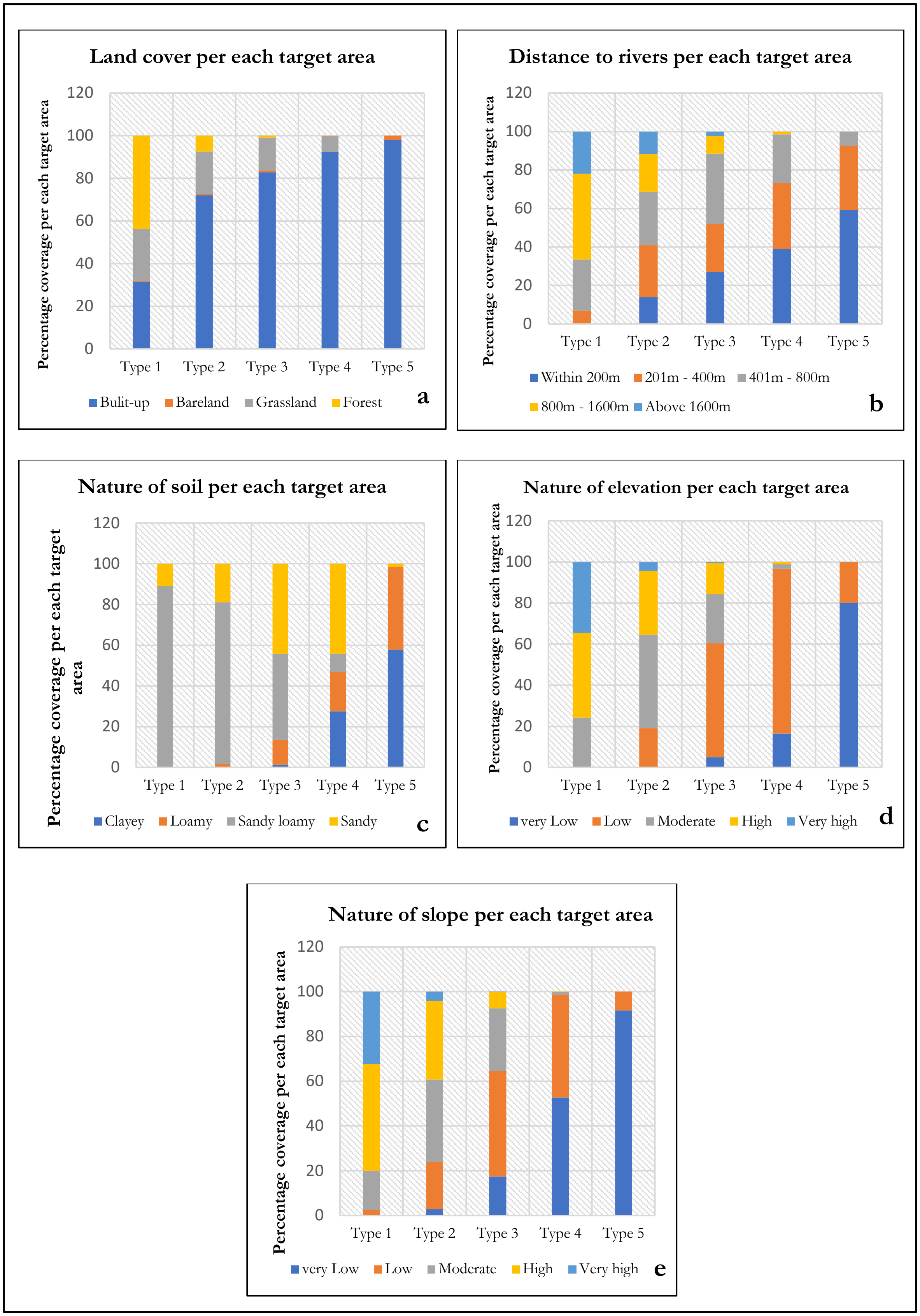


Figure 4-14: Slope(a), elevation(b), soil(c), distance to rivers(d) and landcover(e) per target areas

4.2.3. Relation between NBS target areas and flood likelihood areas

Relating the target areas with the flood likelihood areas, about 70% of the 2020 flood likelihood areas were within the Type 5 target areas (see Appendix 11). This complements the results of the SMCA, and indeed the Type 5 target areas are worse off in terms of surface runoff and inundation and require specific NBS measures.

In summary, the characteristics of the different target areas clearly reveal that they are of different nature in terms of surface runoff and inundation. Due to this, improving upon the surfaces of these areas to reduce a higher possibility of higher runoff depths and inundation will also require the implementation of different urban flood-related NBS measures and strategies per each target area. The next section will therefore highlight which of the NBS measure(s) adapted for this study will be appropriate for each of the target areas based on their characteristics.

4.2.4. Sensitivity analysis

A sensitivity analysis was performed to assess the robustness of the identified target areas and also ascertain how the change in the criteria weights could affect the location of the different NBS target areas in the municipality. Hence the sensitivity analysis was done by applying equal weights to the criteria used and generating another target area map for the municipality using the same equal interval in delineating the different target areas (see Figure 4-15).

The result of the target areas map based on the equal weights of the selected criteria was slightly different from the target area map prepared based on the relative weights given by key informants. For instance, as seen in Figure 4-15, there was more coverage of type 5 target areas (41.26%) using equal weights as compared to the coverage of type 5 areas (38.16%) in Figure 4-12 which was based on relative weights. Also, there was significant coverage of type 5 areas in relatively upstream areas which does not portray a clear description of a "worse off" area in terms of runoff and inundation. On the other hand, the location and coverage of other target areas like the type 1 and 2 based on the equal weights were almost like the target area map prepared using the relative weights. Therefore, harnessing on the difference in the type 5 target areas, change in weight assigned to criteria could lead to different outcome which could also affect decision making on appropriate NBS that will be very effective in the area.

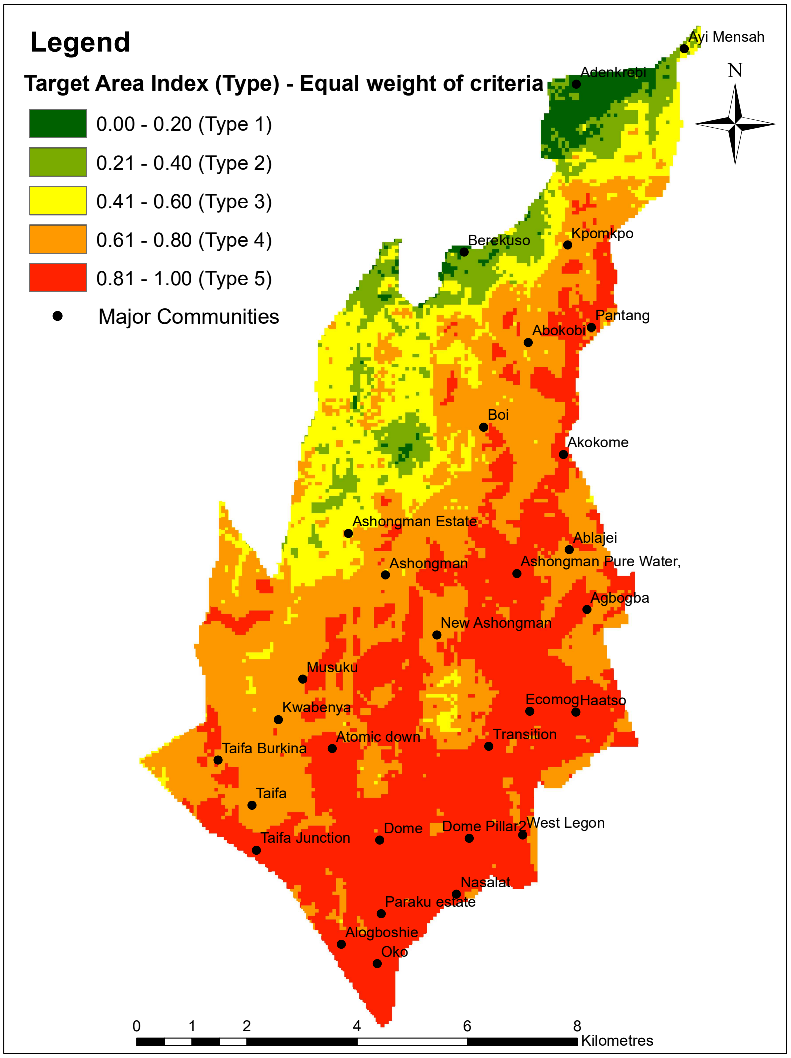


Figure 4-15: NBS target areas using equal weights

4.3. Objective 3: To identify an appropriate NBS measure with the potential to reduce urban flood occurrences in the identified target areas in the Ga East Municipality.

4.3.1. Design conditions for NBS measures

The design conditions for the adapted NBS measures for this study were identified based on literature and previous studies done per each NBS measure. These NBS measures, as highlighted in the literature review section of this report, include green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements. Each of the mentioned NBS measures requires different physical geographic and land use characteristics to be effective in urban flood mitigation (Ruangpan et al., 2020). Hence, the design conditions of the specified NBS measures, as highlighted in section 2.4, were related to the physical geographical characteristics of the different target areas. Appropriate.

4.3.2. Appropriate NBS measures for the identified target areas

Table 4-3 presents the comparison of the characteristics of the target area types to that of the design conditions of the specified NBS measures. The comparison assumes that an NBS measure is compatible with a target area if there is more than 50% coverage of a particular target area characteristic in line with the stated design condition of a specified NBS measure. The 50% or more threshold was used based on the assumption that more than 50% coverage of criteria characteristics dominates the nature of the criteria, and it is enough for decision making. Another assumption is that the NBS measures can be applied in all built-up areas since the entire municipality is almost covered with hard surfaces. Table 4-3 presents the matrix of the target area types and design conditions of the NBS measures. Figure 4-16 also shows the map of the target area types with the appropriate NBS measures to be applied.

Table 4-3: Matrix of target area types and NBS design conditions

NBS measures key design condition	**Target areas**				
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 5**
Green roofs					
Suitable for both horizontal, gentle, and steep sloped areas	✓	✓	✓	✓	✓
Can be used in high and low land areas	✓	✓	✓	✓	✓
Suitable for any type of building being it residential, commercial, industrial, etc.	✓	✓	✓	✓	✓
Vegetated swales					
Suitable for horizontal and gentle sloped areas	✕	✓	✓	✓	✓
Practically best applied in low land areas	✕	✕	✓	✓	✓
Good for sandy-loamy areas	✓	✓	✓	✕	✕
Suitable for all land use areas including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Rain gardens					
Suitable for horizontal and gentle sloped areas	✕	✓	✓	✓	✓
Suitable for loamy and sandy-loamy soil areas	✓	✓	✓	✕	✕
They are best applied in highland areas	✓	✓	✕	✕	✕
Not ideal for areas with shallow water table and close to water bodies	✓	✓	✕	✕	✕
Suitable for all land use areas including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Rainwater harvesting					
Suitable for gently sloped areas	✕	✓	✓	✓	✕
Effective in highland areas	✓	✓	✕	✕	✕
Suitable for medium textured soils (Sandy-loamy and loamy) – not suitable for heavy clay soils	✓	✓	✓	✕	✓
Not ideal for areas with shallow water table and close to water bodies	✓	✓	✕	✕	✕
Suitable for all land use areas including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Detention basins (ponds)					
Practically best for lowland areas	✕	✕	✓	✓	✓
Not suitable for sandy soil areas	✓	✓	✓	✓	✓
Ideal for areas close to water bodies especially areas near the outlet of a watershed	✕	✕	✓	✓	✓
Suitable for all land use areas including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Porous pavement					
Suitable for both gentle, and steep sloped areas	✓	✓	✓	✓	✕
Suitable for both highland and lowland areas	✓	✓	✓	✓	✓

Suitable for moderately infiltrated soils (sandy-loamy and loamy soil areas)	✓	✓	✓	✕	✕
Suitable for areas with relatively deep water table (HGIC, 2013)	✓	✓	✓	✕	✕
Suitable for all land use areas including residential, commercial, industrial, etc	✓	✓	✓	✓	✓

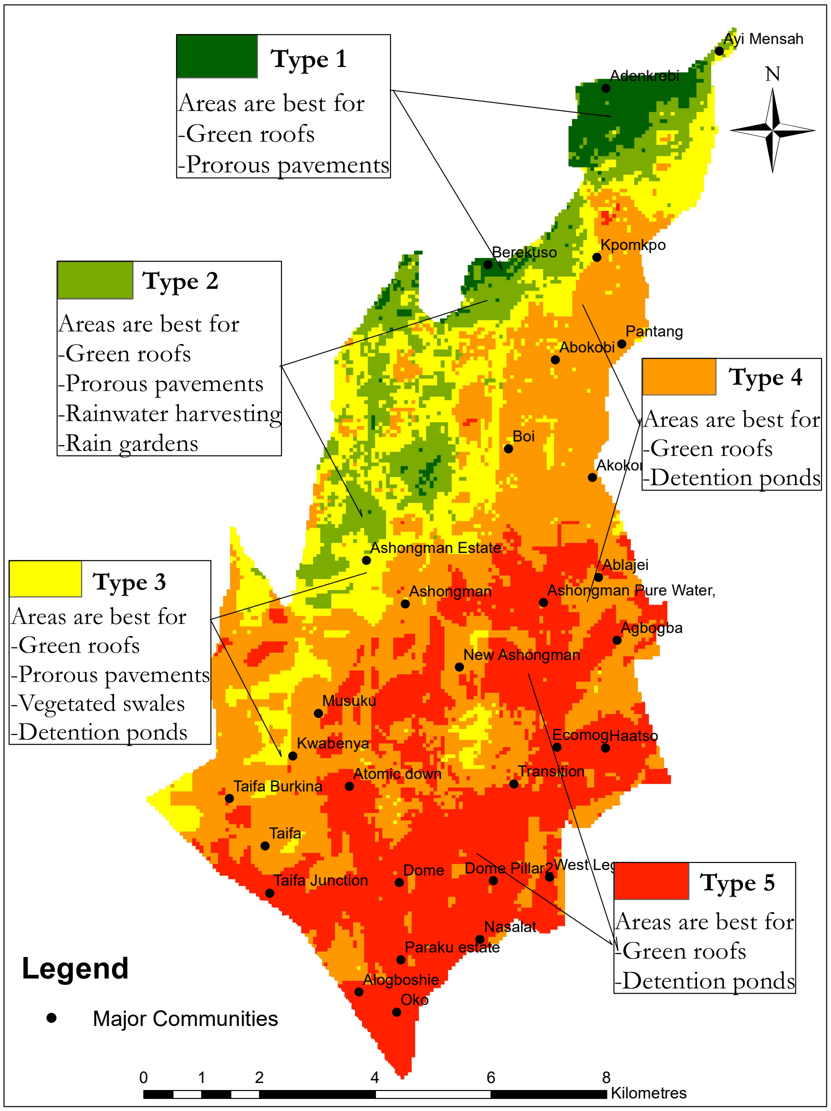


Figure 4-16: Target area types with the appropriate NBS measures to be applied

From the comparison table above, it is shown, green roofs can be applied in all the target area types. This is because in general, green roofs are implemented on buildings and does not require a specific landform characteristic for its effectiveness (Cascone, 2019).

Design conditions of vegetated swales, match with that of the physical geographical characteristics type 2 and type 3 target areas. Hence vegetated swales will be very effective when implemented in these areas. However, there could be a possibility to also implement vegetated swales in type 4 and 5 target area but may not be entirely effective due to the nature of soil characteristics in these areas, which is predominantly clayey.

The comparison also highlighted that rain gardens can be best implemented in type 2 target areas. The areas are generally moderately sloped, made up of sandy and sandy-loamy soils, relatively highland areas and farther away from waterways which conforms to the design conditions of raingardens. Therefore, raingardens will be very effective when implemented in type 2 and 3 target areas. There may also be a possibility to implement rain gardens in type 1 target areas, but the nature of the slope, which is steep, will affect its effectiveness. Additionally, type 1 areas are predominantly made up of forest and grassland areas and implementing rain gardens may not be significant.

The comparison table also reveals that rainwater harvesting will be best implemented in type 2 target areas. Their physical geographical characteristics conform to all the key design conditions of rainwater harvesting. Hence, rainwater harvesting will also be very effective in the type 2 target areas. The nature of the areas' steep slope of type 1 areas, not ideal for rainwater harvesting.

Detention basins will be very effective in type 3, 4, and 5 target areas due to their physical geographical characteristics generally lowland, close to water bodies and soil characteristics are rarely sandy (see Table 4-3). the table reveals the physical geographical characteristics of type 3, 4, and 5 target areas conforms to the key design conditions of the NBS measure. These areas are generally lowland, close to water bodies and soil characteristics are rarely sandy. Hence, detention basins will be very effective in these areas.

Porous pavements, are best implemented in type 1, 2, and 3 areas characterised by soil types with good infiltration capacities. Thelen & Howe (2011) highlighted porous pavements can be implemented at any location where traditional pavements can be laid in the urban area. However, the clayey soil of type 4 and 5 target areas is practically not ideal for porous pavement (Thelen & Howe, 2011).

In general, type 2 and 3 areas tend to be areas having physical geographical characteristics that fits most of the specified NBS measures design condition including green roofs, vegetated swales, rain gardens, rainwater harvesting, and porous pavements. These two target areas are relatively upstream, and their land use characteristics indicates 78% built-up. Implementing the different kinds of NBS measures will help improve the infiltration capacity of these areas and reduce runoff volumes that could accumulate at downstream areas which will eventually help minimize flood occurrence in the municipality.

Also, considering the relation between very high flood likelihood areas and Type 5 target areas, communities[2] that are mostly flooded in the Ga East Municipality, the implementation of green roofs and detention basins will be an effective approach to minimize the extent of floods in these communities[2].

4.4. Objective 4: To indicate possible ways of integrating NBS measures in spatial and flood mitigation plans.

4.4.1. Reflection of NBS in spatial plans

The spatial planning and development of Accra and Ghana as a whole are guided by a National Spatial Development Framework and the national zoning guidelines and planning standards as explained in section 2.9 of this report. Consequently, in analysing the spatial plan document for the study area, two documents were used. These include the Greater Accra Spatial Development Framework (GARSDF) volume 2 and the National Zoning Guidelines and Planning Standards.

The GARSDF was prepared by the Greater Accra LUSPA Office based on the elements of the NSDF for the GAMA of which Ga East municipal is part of. The framework is based on the concept of ensuring sustainability in the entire metropolitan area. The framework covers the spatial development of the natural, built, social, economic, and institutional environment. Thus, the framework seeks to ensure that the natural, built, social, economic, and institutional component of the metropolitan area are sustainably and orderly executed in space (LUSPA, 2017).

In the GARSDF, the Ga East Municipality is broadly zoned as a residential development area (see Figure 4-17). Also support zones as shown in Figure 4-17 are industrial and economic corridors in the metropolitan area. Even though the municipality is broadly residential, there will be other land uses such as open spaces, industrial, commercial, educational, civic, and culture, including other infrastructure and transportation facilities. The GARSDF indicated that all physical developments should be in line with the specifications highlighted in the national zoning guidelines and planning standards.

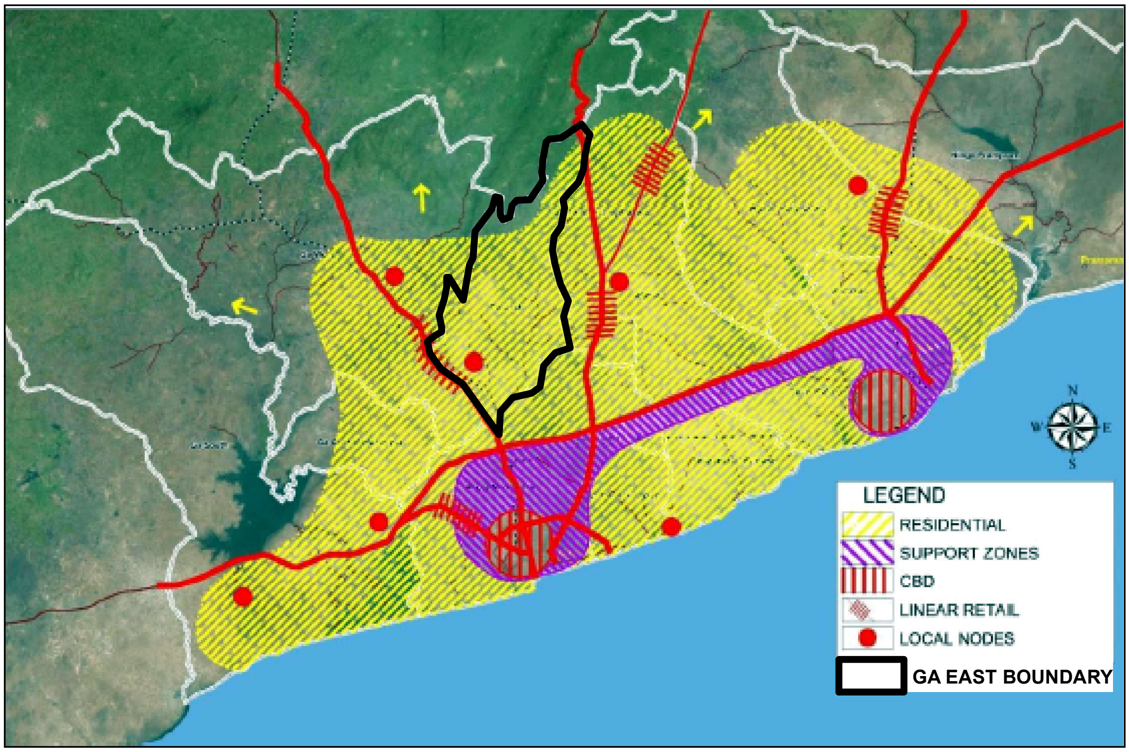


Figure 4-17: Urban functionality of GAMA
Source: (LUSPA, 2017)

The zoning guidelines and planning standards provide detailed instructions and specifications on Ghana's approved components of any physical development. Table 4-4 below gives an overview of the analysis of the principles and specifications highlighted in the document related to Group A, B, and C NBS themes explained in section 3.4.4.1. Where Group A highlights specifications related to the protection of natural areas, Group B also highlights specifications related to the promotion of green areas development and Group C also describes specifications with no relation with either green areas protection or promotion.

Table 4-4: Overview of the Ghana zoning guidelines and planning standards concerning Group A, B, and C NBS themes:

Domain	**Principle /section**	**Description**	**NBS Theme**	**Remarks/specification**
Site development	Site planning	Involves the setting up and preparation of plots for a building or a structure to be put up.	Both group A and B NBS	The document highlighted that developers should include landscaping and tree planting not less 2 metres wide on the plot in preparing a site to put up a building or any structure..

Land uses	Development of open spaces Development of buffers	Includes parks, gardens, sports centers, and other recreational areas.	Both group A and B NBS	The document highlighted no development, or a structure for sports, etc., should be erected very close to rivers and environmentally sensitive areas. Thus, development can only be done from 30 to 60 metres and 10 to 20 metres away from rivers and forest areas, respectively.
	Residential development	Involves the putting up of buildings to be used as homes	Only group B NBS	The document highlighted that developers should make space for open area(s) in the design of a residential area or when putting up a house. As specified by the document, these areas can be used as a playing ground for kids and children and public gatherings.
	Development of civic and cultural areas	Is comprised of health facilities, churches, offices, among others.	Only group B NBS	The document specifies hospital designs and facilities should have landscaping around to enhance natural thermal comfort and aesthetics
	Development of commercial areas	Is comprised of markets, shopping malls, and other shop complexes.	Group C	No greenery specification, rather a specification focused on space and occupancy requirements
	Development of industrial areas	Consists of manufacturing, oil and gas, warehouse, among others	Group C	No greenery specification, rather a specification focused on space and occupancy requirements
	Development of educational areas	Is comprised of constructing schools and other training facilities	Group C	No greenery specification, rather a specification focused on space and occupancy requirements
Infrastructure/ transport	Development of transportation facilities	Transportation facilities in this context consist of roads, pavements, and parking lots.	Only group B NBS	The document specifies that highways and urban roads must have medians of about 5 to 10 meters and have buffers on the roadsides for future road expansion.
	Water and electricity	The building of pipe borne and borehole facilities as well as putting up high	Group C	No greenery specification, rather a specification focused on the infrastructure coverage

		tension lines and transformer stations		

4.4.2. Reflection of NBS in the flood management plan

The National Disaster Management Act 1996, Act 517, as described in section 2.8, establishes NADMO and gives them the mandate to prepare a National Disaster Management Plan. Therefore, in analysing the flood management document, the National Disaster Management Plan (NDMP) 2010 was used. The plan is to guide NADMO in achieving its mandate of ensuring that all disasters, including urban floods, are properly managed. The main objective of the plan is based on the principle of effective coordination among flood management institutions. According to the plan, the management of all disasters, including urban floods is done in three phases. The phases include the pre-disaster phase, which constitutes mitigation and preparedness, the emergency phase, which comprises response and relief, and the post-disaster phase, which also constitutes rehabilitation, resettlement, and reconstruction. Hence, Table 4-5 below presents an overview of the analysis done on the Ghana National Disaster Management plan.

Table 4-5: Overview of the Ghana National Disaster Management Plan 2010

Domain	**Principle /section**	**Description**	**NBS Theme**	**Remarks/ specification**
Administrative	Institutional coordination	Creating a well-coordinated programme for agencies and departments involved in disaster (flood) management for government, non-governmental and the private sector.	Group C	The coordination as specified by the document focuses on marrying the activities and functions of different institutions
Land use	Hazard mapping	To identify ecological and geographical locations of hazards (flood) that would guide other policy and legislation nationwide	Only group A NBS	The document specifies as part of flood management, all areas prone to different hazards be mapped to ensure an effective land use planning and identify and develop safe havens to be used during disaster (flood) emergencies
	Rehabilitation, resettlement, and reconstruction	Remaking of disaster (flood) affected communities[2]	Both group A NBS	The document specifies the relocation of communities[2] or people living in flood prone areas for redevelopment
Innovation	Awareness creation/ training	Providing education for all flood management	Group C	The document specifies the education, and the awareness creation is geared

		stakeholders and creating awareness		towards emergency response functions
	Plan review	The periodic review of disaster (flood) management plan	Group C	The plan review as specified by the plan is geared towards mainstreaming and promoting a comprehensive disaster (floods) risk reduction culture
	Research	Conducting studies on disasters (flood)	Group C	The plan specifies research to be conducted to assess the socio economic effect of the various disasters (floods) to aid training purposes

In summary, as presented in Table 4-4, the GARSDF, in line with the National Zoning Guidelines and Planning Standards, which guides the spatial development of GAMA, including the Ga East municipality, have group A NBS elements that seek to prohibit physical development to be carried out in areas close to rivers and waterways, wetlands, forest reserves and other environmentally sensitive areas. Additionally, the planning guidelines provide specifications that are also in line with group B NBS elements which promote and encourage the creation of green in any physical development that is carried out in the municipality and GAMA. The relatively more (five out of the nine) highlighted principles in the spatial plan specifications of group A, and B NBS elements show a strong reflection of NBS integration.

On the flood management plan, Table 4-5 also gives an overview of what is presented in the plan. Based on the thematic areas shown in Table 4-5 only the land use related principles had specifications associated with group A NBS. The other domains in the flood management plan were silent on the protection of natural and environmentally sensitive areas as well as creating green developments. Hence, the relatively fewer (two out of the six highlighted principles) specification of group A and B NBS elements in the flood management plans shows a weak reflection of NBS integration. However, drawing inferences from section 2.8, flood management activities like the prevention of encroachment and developments close to rivers and on wetlands as well as Demolishing of buildings, properties and other structures built in waterways and other environmentally sensitive areas activities by the TCPD, and EPA have imprints of group A and B NBS. Thus, they ensure the protection and conservation of natural areas and making space for green development

The reflection of NBS elements in both planning and flood management documents reveals there is a possibility to integrate the specified NBS measures in the spatial development and flood management perspective per the documents analysed. Nevertheless, integrating the specified NBS measures into the spatial development and flood mitigation system in the municipality is also another dynamic to be considered.

4.4.3. Integration of the specified NBS measures

In order to explore the possibility of integrating the specified NBS measure in the spatial planning and flood mitigation measures in the Ga East Municipality, the views and opinions of 10 flood management professionals (key informants) were used (see table 3-2). The views of the key informants helped in getting insights into the issues that will make the specified NBS measures integration and implementation a reality in the context of the Ga East Municipality. In this light, the views of the key informants were analysed, covering the NBS integration techniques, as well as situations and actions that could be a barrier or facilitate the implementation of the specified NBS measures.

4.4.3.1. Integration techniques for the specified NBS measures

Analysis revealed five main NBS integration techniques in the context of the municipality. These techniques are core actions that must be taken to make green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements part of the spatial development and flood prevention actions in the Ga East Municipality. The techniques include piloting the specified NBS measures, education, sensitization, legal obligation, and re-strategizing enforcement of plans.

Piloting of the NBS measures

In making the specified NBS measures part of the spatial development and flood mitigation in the municipality, key informants raised views of first piloting the measures before their implementation. According to them, specified NBS measures must be implemented in few selected locations in the municipality to first determine how effective they will be in reducing the rate of flood occurrences. The piloting is to ascertain the functionality of the specified measures. The outcome of the piloting will then be the basis for implementing the measures throughout the municipality. In relation to the piloting one key informant stated: *"I think including the NBS in the physical developments of areas is the best option. It requires trials and study thus first piloting to see how it will work before doing full scale implementation. So, I think it is the best option gradually making the NBS part of the municipality and it is very possible and advisable. So, when the trials are implemented, and they are successful then the full scale implementation rolls out." – key informant 8*. Moreover, as revealed in section 4.3, selected areas for piloting can be in line with the areas identified best locations for the respective NBS measures to ensure their effectiveness. In relation to the research principle in the disaster management plan, the piloting of the NBS measures can be part of the research specification highlighted in the plan. Hence, the research outcome will be a basis for the specified NBS measures to be implemented on a full scale, as mentioned by key informant 8. Hence, the piloting acts as one of the initial action to integrate the specified NBS measures in the spatial development and flood schemes in the municipality.

Public education and Sensitization

Making the specified NBS measures well known and educating the public and developers on how they work is very important, the key informants also highlighted. Green roofs, vegetated swales, rain gardens, detention basins/ponds as well as porous pavements are not well-known in the Ghanaian context. Rainwater harvesting, on the other hand, seems to be a popular action that is known by several homes and it is termed in the Ghanaian context as rain gutters. However, the usage of the rain gutters to effectively prevent floods is also not well-known. Hence, flood management institutions, developers, builders and the public must then be educated on the need to have some of the specified NBS measures in their communities[2] and how they are properly designed and constructed. On this, one key informant said: *"I think it will be very helpful if people start using some of these measures. But the issue is, not so many people in the municipality and even country wide know much about NBS, how much more telling them to do it in their homes. May be the government can roll out some form of education to create awareness on the use of NBS and people will start developing interest in it." – key informant 2*. The public education then gives flood management institutions and public a reason to use the specified NBS measures. Also, in the flood management plan, it was revealed, there was a principle on training and awareness creation towards emergency response action. This awareness creation can include in it providing education for flood management institutions and the public on using some of the specified NBS measures. Hence educating and sensitizing should also be another technique of integrating the specified NBS measures.

Legal obligation

The application of the specified NBS measures must be part of the legal codes for any physical development. In Ghana, the Local Government Act, 1993 (Act 462), section 94 (1) states, "*No physical development shall be* *carried out in a district without prior approval in the form of written permit granted by the District Planning Authority"* (Government of Ghana, 1993). Prior to the development permit granting, developers need to submit their development design to the LUSPA office within their municipality or district for processing, checks by the District Planning Authority, which is now the Statutory Planning Committee of a district or municipal assembly. The statutory planning committee consists of officials from the municipal or district Chief Executive officer who is the chair of the committee, municipal physical planning officer, engineer, development control officer, an official from EPA, fire service, NADMO, Department of Urban Roads and the Hydrological Service Department. In the processing and checks for the development design approval, the committee checks whether the development design is in conformity with prepared local plans and other details like the consideration of building lines, sub-division of the plot, orientation of the development, among others. Relating to the key aspects that are checked in the development design, some of the key informants highlighted the inclusion of some of the specified NBS measures must be one of the key aspects to check before the design is approved. With this, one key informant said: *"it will also be advisable to also include in some of the things we check when we are issuing development permit for people to build. For instance, we can check if the developer has allocated a space on the plot of his or her development to be used to develop a rain garden." – key informant 7.*

The planning document (see Table 4-4) states that developers should leave at least 2 metres wide on their plot to be used for landscaping and tree planting. Therefore, as part of the legal obligation, further instructions can be given to transform the 2 metres wide space left into rain gardens. Also, the legal obligation should not be limited to only developers but also flood management institutions to use some of the specified NBS measures in their urban flood mitigation related projects. Another key informant also explained: *"Vegetated swales for instance can easily be implemented if road contractors are mandated to do so in the construction of roads." – key informant 6*

Based on the findings presented in section 4.3.2 on the NBS measures best for the respective target areas, the municipality can roll out plans to ensure that, depending on the location of development, some specific NBS measure must be included in the developers permit application designs. For instance, per the results presented in section 4.3.2, developers building in Type 1 or 2 areas, thus Adenkrebi, Berekuso, and Ayi Mensah communities[2], will be obliged to include in their designs, green roofs, rain garden, rainwater harvesting or porous pavements. Road contractors, on the other hand, can also be given the mandate to use vegetated swales when constructing roads in type 3 areas, thus in Ashongman Estates and Akokome communities[2].

Combination with existing practices and flood projects

Another integration technique highlighted by the key informants in integrating the NBS measures is combining them with the traditional flood mitigation and other related practices. This combination will be a slow approach to introducing the specified NBS measures in the Ghanaian spatial planning and flood mitigation scheme. For instance, as presented in section 2.8, one of the main traditional urban flood mitigation measures is the construction, dredging, and desilting of drains. On this, most of the key informants indicated that the use of the vegetated swales can easily be combined with other drain construction during road projects. Vegetated swales can be a very good complement in the management of runoffs to control floods. Since the swales are forms of drain that have vegetation cover, it presents an advantage of natural infiltration that normal drains do not have. In the Ghanaian context, there are several studies that relate flood occurrence to poor solid waste management (Amoako & Boamah, 2014). According to the Ga East medium-term development plan 2018 – 2021, communities[2] like Dome, Taifa, Taifa Burkina, Haatso, and Kwabenya are mostly faced with poor solid waste management issues, which sometimes choke storm drains. Also, reflecting on the results presented in section 4.3.2, vegetated swale will be best implemented in target area type 2, of which Kwabenya and Abokobi are included. Since vegetated swales are characterised with grass and other plant covers, there is a probability of water draining into the soil even when there are solid waste issues. Just like the traditional drains, they are normally sealed with concrete and if there are solid waste issues, water cannot penetrate nor flow. Hence, vegetated swales will be a perfect measure to be done alongside drain construction to effectively manage water flows and reduce the rate of urban floods in the municipality. In this regard, one key informant explained: *"well, it is very possible. Like I have said earlier, during road construction, we can use something like the vegetated swales in some areas to support the drains that will be constructed." – key informant 5.*

Additionally, there already exist practices in the municipality which include traditional way of rainwater harvesting and the backyard gardens that individuals use in their homes. These existing practices could be upgraded and used as a modern rainwater harvesting and rain gardens. The purpose of rainwater related activities in homes, however, are not necessarily linked to reducing runoff volume. Rather, they use it to obtain water for domestic uses. Mostly in poor water supply areas, various homes use barrels to collect water from roofs anytime there is rain. With this, more water volumes still end up on the ground. Only a few houses in the municipality have a well-constructed system that connects roofs to underground storage. The rainwater harvesting, as used in Ghana, is termed *"rain gutters"* (see Figure 4-18). In this sense, the way individuals harvest rain can be improved upon to meet the international design standards to reduce runoff depth effectively. One key informant explained; "*Even aside seeing some houses around using this harvesting approach, anytime it rains you will sometimes see people collecting the rainwater from their roofs using pan, buckets, barrels, and other containers. I think you can testify to this; you live in this country, and I know you have been seeing it yourself. I think this will be a positive line of action introducing this rainwater harvesting to reduce flood though the purpose with which people use them is mostly for domestic" – key informant 8.* This indicates the traditional rainwater harvesting can be upgraded to help reduce the rate of urban floods in the municipality.

Figure 4-18: first example of "rain gutters" (a) and second example of "rain gutters" (b)
Source: (From field 2021)

On the backyard gardens, developers and house owners, especially in the municipality, mostly convert portions of the home compounds into a mini garden where they sometimes grow fruits, vegetables and other herbs for domestic consumption (UN-HABITAT, 2011). The backyard gardens can be upgraded to meet the rain garden specifications to help reduce runoff depths and prevent floods. As highlighted in section 4.2.1, the type 2 target areas, which include Berekusu and Ayi-Mensah reveal to have homes engaged in backyard garden activities (see Figure 4-19). These backyard gardens, according to key informants, can be upgraded into rain gardens to help reduce floods in the municipality. One key informant stated: *"Another* *thing is the backyard gardens that people have in their homes can also be transformed into some of these rain gardens. So, it will be very possible to combine with the other traditional flood prevention measures." – Key informant 3.* This also gives an indication that rain gardens can be combined with some traditional measures to help reduce urban floods in the municipality.

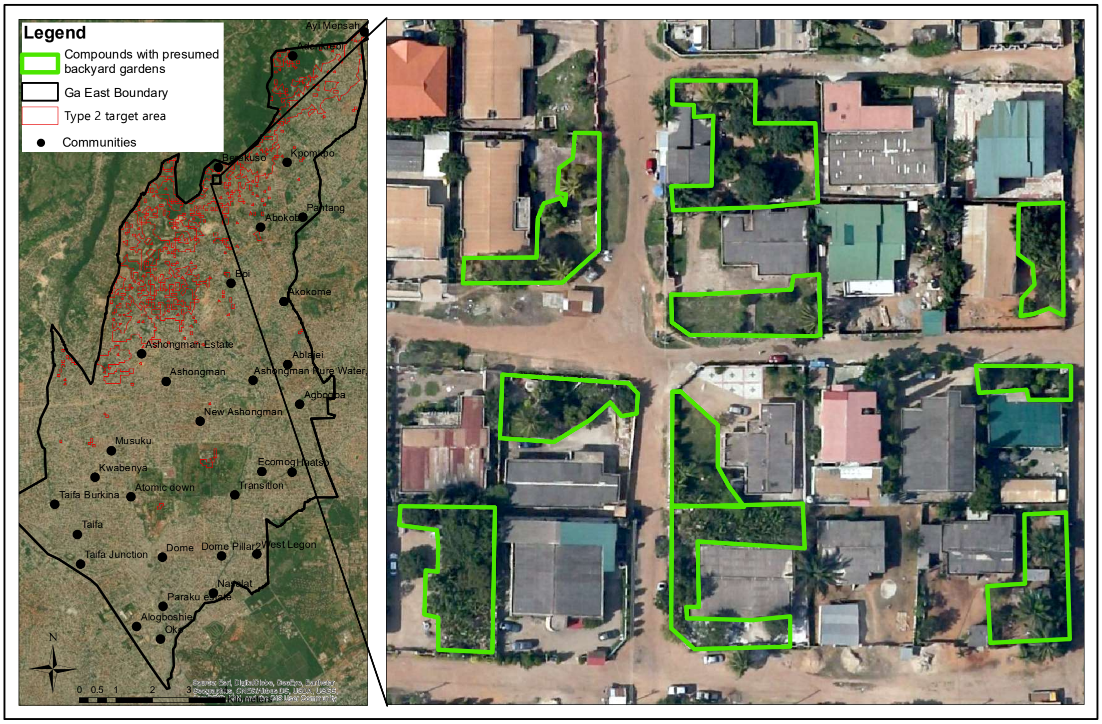


Figure 4-19: Presumed backyard gardens and greenery in a section of type 2 target areas

Re-strategizing enforcement of plans

Integrating the specified NBS measures must also consider the re-strategizing of the existing enforcement mechanism as another key technique in the Ghanaian context. Enforcement of laws guiding the spatial development of the Ga East municipality and Ghana as a whole has been and is currently one of the major problems retarding the orderly physical developments of major communities[2] in Ghana. As highlighted in section 4.4.1, the existence of the GARSDF, National Zoning Regulations and Planning Standards, the National Building Regulation 1996 (LI 1630) and the local layout plans prepared by districts LUSPA signifies there are systems in place to ensure physical development in the municipality is orderly done. Also, the mentioned plans encourage developers and home builders to include in their development landscaping and greenery and protect rivers and other environmentally sensitive areas. However, in the Ga East municipality, there exist irregularities in the physical development of most communities[2]. The irregularities include building in waterways, river buffers, and wetlands (see Figure 4-20 and Figure 4-21), encroachment on road spaces, farmlands and other forest areas, as well as the adherence of including landscaping in physical developmental projects (Amoateng, Cobbinah, & Owusu-Adade, 2013). One key informant explained: *"I would say the main problem is when the municipalities do not adhere to the town and country planning laws. For instance, wetland areas have building, trees are pulled down but not replanted." – key informant 6.*

Sometimes, developers are also able to get a permit from the Ga East Municipal Assembly and LUSPA to build in unauthorized areas due to political influences. One key of the informants explained: *"very interesting thing about the building in unauthorized areas is some of these people have building permits meaning the assemblies gave them the permission to build and put up these structures and these assemblies have information regarding areas which are not meant* *for building. But interesting, they give permission for people to build". – key informant 8.* These irregularities happen due to non-enforcement of spatial plans and associated laws (Amoateng et al., 2013).

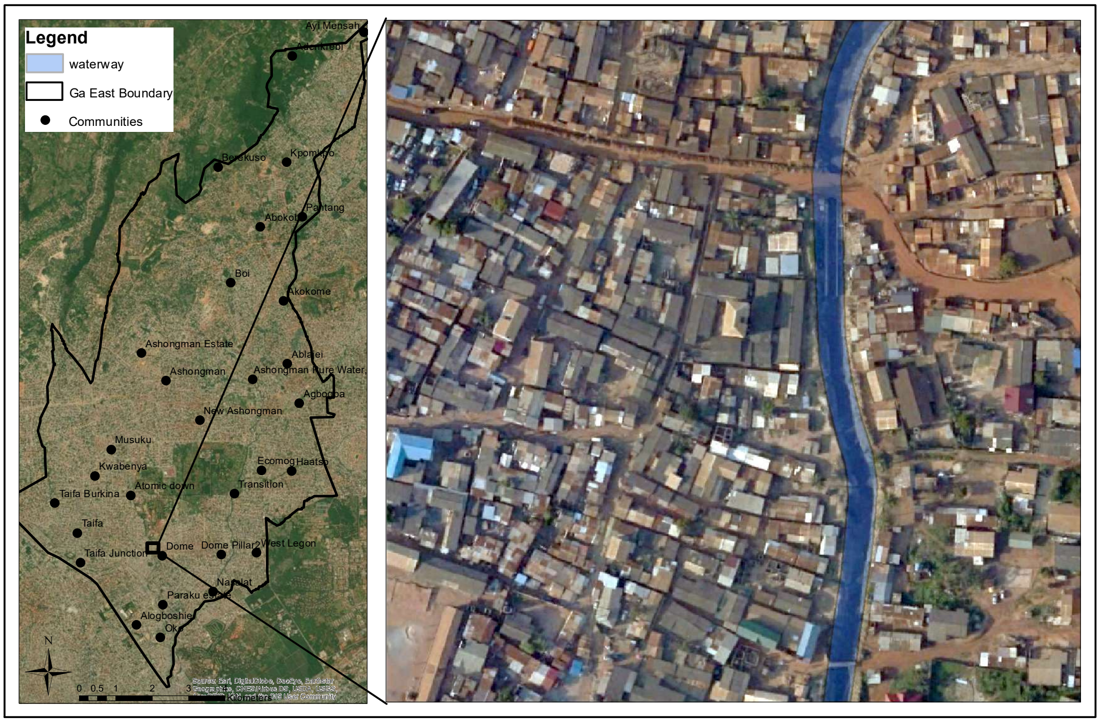


Figure 4-20: Buildings in rivers buffers at Dome community[1]

Figure 4-21: Buildings very close to waterways
Source: (From field 2021)

Re-strategizing the existing enforcement mechanism to be, for instance, free from political pressures will ensure an actual realization of the usage of the specified NBS measures and effective spatial planning system in the municipality. Hence having the specified measures embedded in the system will also be enforced accordingly. One of the key informants explained: "*well, I think we should take a second look at how plans are enforced in this country. Lack of spatial plans enforcement and implementation I should say is the key cause of the irregular developments we see in the country. Yes, we can make some of these NBS measures a mandate, but the issue is we already have a lot of planning guidelines that people do not follow. On my part we need to deal with the present non-enforcement of spatial plans then the use of the NBS measures will also come in". – key informant 7.*

To sum up, the techniques thus, piloting, education and sensitizing, legal obligation, combining NBS with existing practices, and re-strategizing enforcement mechanism would be key in integrating and implementing the specified NBS measures in the Ga East Municipality. However, there are situations that can either hinder or facilitate the smooth implementation of the specified NBS measures in the process of the integration in the municipality.

4.4.3.2. The implementation barriers and facilitation of the specified NBS measures

The implementation of the specified NBS measures will be instrumental in improving urban surfaces and complementing the traditional flood mitigation measures to reduce the rate of urban floods in the Ga East municipality. However, key informants cautioned that, there are important factors that must be considered as they can hinder or facilitate the smooth implementation of the measures in the municipality. These factors include economic or finance, land, the collaboration of flood management institutions, and knowledge base and local people interest.

On the barriers, analysis revealed seven barriers to the specified NBS implementation. These include existing flood mitigation project finance issues and cost requirement of the specified NBS measure, which is economic related. Another is land unavailability and political interference in land acquisition which is land related. On institutional collaboration the barriers included poor communication and coordination of activities and different interest from the various institutions. little expertise knowledge and interest from local people.

Further analysis also revealed four main actions that could facilitate the specified NBS implementation. These include providing government subsidies to support the cost of the NBS measures, which are economically related. Another is providing attractive compensation packages for land acquisition, which is also land-related. The effective institutional collaboration will also aid the NBS implementation and, finally, involving the locals to increase their interest in the usage of the NBS measures. Table 4-6 and Table 4-7 gives an overview of the barriers and facilitation measures in the implementation of the specified NBS measures in the Ga East Municipality.

Table 4-6: Overview of the specified NBS implementation barriers

NBS implementation Barrier code	Description	Quote from key informant	Related specified NBS measures
Existing flood mitigation project finance issues	Currently, one of the challenges flood management institutions face in managing floods in the municipality is the inadequate and delay in the release of funds to carry out their mandate. This existing finance problem could also be a major barrier in the	*"I think the main challenge we face is financial. Sometimes, we have wait for the government to approve and release funds before we can ahead to carry out specific task. At times, there might be a need to maintain and fix sections of roads in the municipality but due to the*	Links to all the specified NBS measures

	implementation of some specified NBS measures in the municipality	*delay and unavailability of funds we are not able to carry out the maintenance works. These maintenance works also come with fixing the drains that will help prevent floods." – key informant 5*	
Cost requirement of the specified NBS measure	Some of the specified measures are very expensive to establish. Also, GEMA (2018) asserted most of the inhabitants, thus about 60%, are middle-income earners. Therefore, it is not likely for them to spend additional costs in the construction of some of the specified NBS measures.	"G*reen roofs, implementation might be very difficult because most housing developments are done on individual basis and some people mostly in the city are just looking for places, they want to put their head. So, they might not be interested in doing a project like this that will put some additional cost on their expenses." – key informant 10.*	Links to green roofs, rainwater harvesting, rain gardens, and detention basins
Land unavailability	Looking at the rate of increase in the built-up, which is about 1.2 km2 annually, the entire municipality will be built up totally in the next probably 5 to 10 years. Implementing the specified NBS measures will also require land. Therefore, the unavailability of land could also be a barrier, implementing some of the specified NBS measures	"*Currently, the entire municipality is almost built-up, and the way buildings have been put very close to roads leaves no space for us to implement the swales." – key informant 10.*	Links to Vegetated swales, rain gardens and detention basins
Political interference in land acquisition.	Unexpected influences from some political leaders sometimes interrupt institutions from acquiring land for urban flood mitigation-related projects. Even though there exist regulations like The State lands Act, 1962 (Act 125), that gives mandate to the government of Ghana (respective institutions) to compulsorily acquire lands in the nation's interest to carry out developmental projects. This political influence could also hinder some of the NBS implementation.	*"Sometimes we have to change to designs of roads we intend to construct because we could not reach an agreement with property owners. This disagreement normally happens when the property owners have political aids. As an institution, we have the power by law to acquire lands that are of national interest, but because of the political influences things do not happen as planned". – key informant 9*	Links to detention basins and vegetated swales.
Poor communication and coordination of activities	According to the key informants, there exist poor communication and coordination of activities in the management of floods. This sometimes affect the smooth implementation of flood-related projects. Hence, this existing issue could also be a barrier in the	"*Some of the challenges we face with other institutions are when some of the institutions carry out projects including drainage management and developing without consulting us. Sometimes this results in an uncoordinated development of stormwater management systems which invariably sometimes do not contribute to*	Links to all specified NBS measures

	implementation of the specified NBS measures.	*benefiting from stormwater systems as its intended". – key informant 10*	
Different interest from the various institutions	There exists different interest in terms of organisational schedule, structure and activities among institutions involved in flood management in Accra. This has also affected the smooth implementation of flood-related project and could also be a hinderance in the implementation of the specified NBS measures	*"You will agree with me that in the collaboration process, everyone has their vested interest. So, everybody tries to tune the engagement to suit their interest. When this happens, it becomes difficult to bring other organizations on board and expect them to work towards a common goal when they have different directives. So, trying to lure them into pursuing your goal is sometimes challenging." – key informant 9.*	Links to all specified NBS measures
Little expertise knowledge and less interest from local people	The lack of experts and little knowledge about the specified NBS measures is likely to diminish the development of interest that the local people will have in the usage of the NBS measures. This, according to the key informants will also be another barrier in the implementation of the specified NBS measures.	*"I think for now it might be very difficult to apply green roofs in our system because we do not have experts in the country who have high knowledge in applying green roofs." – Key informant 8.*	Links to all specified NBS measures

Table 4-7: Overview of the specified NBS implementation facilitation measures

NBS implementation Facilitation code	**Description**	**Quote from key informant**	**Related specified NBS measures**
Provision of government subsidies to support the cost of the NBS measures	Key informants indicated the government should provide subsidies to support the construction and implementation of the NBS measures. Hence, if the Government can roll out subsidy policies, it will encourage developers to make the NBS measures part of their development design and construction.	*"If the government provides subsidies to developers who wish to make green roofs for their homes, it may encourage other developers and increase their interest in using the green roof. I think this is very possible for the government to do". - key informant 2*	Links to green roofs, porous pavements rain gardens and rainwater harvesting.
Providing attractive compensation packages for land acquisition	Providing compensation packages will ensure quick and easy land acquisition for the NBS measures. In this regard, key informants highlighted, families and individual land and property owners should be willing to offer their lands, if	*"Since most lands are privately owned, landowners should also be willing to avail their lands for a possible purchase, and the government should also present good offers even in the realm of compensation to carry out these*	Links to Vegetated swales, rain gardens and detention basins

	need be, to carry out some of these NBS measures.	*NBS projects." – key informant 10.*	
Effective institutional collaboration	Effective collaboration on the part of the flood management institutions would facilitate the implementation of the NBS measures. Over the years, some flood management institutions were able to deal with collaboration challenges through a series of meetings. Flood management institutions can therefore hold similar engagements to discuss how to apply some of the specified NBS measures in a coordinated way.	*"I think all stakeholders coming together and accepting these measures will also be a step in ensuring an easy implementation of these NBS measures" – key informant 8.*	Links to all specified NBS measures
Local people involvement	Since urban floods are rampant in the municipality, local people are ready to embrace any government outlines to prevent flood events. Hence, there should be sensitization exercises to educate the local people on using the NBS measures and how important they are in preventing urban floods to involve them in the NBS integration process. This will build on people interest in using the NBS measures	*"The people in the municipality are yearning for solutions to the flood happenings in the municipality. Therefore, I do not think they will reject projects like this. However, the local people should be well-informed and involved through a form of public education about the measures" – key informant 5.*	Links to all specified NBS measures

As presented in Table 4-6, the possible barriers that may hinder the smooth implementation of the specified NBS measures are mainly issues and problems with the existing flood management system in the municipality. Some of the existing problems, however, contradicts with the specifications made in spatial planning and flood management plan documents. For instance, on the issue of land unavailability, analysis from the spatial planning document revealed that the physical development of the municipality should done in such a way that some spaces could be reserved and possibly be available to implement some of the specified NBS measures. Also, the existing poor coordination of activities amongst flood management institutions also contradicts with some of the specifications highlighted in the Ghana Disaster Management Plan document. Hence, dealing with the barriers will act as facilitators to ensure a smooth implementation of the specified NBS measures. In this light, provision of the government subsidies with help solve economic related problems that could hinder the NBS implementation. Additionally, making available attractive compensation packages could also deal with the land related barriers. Effective institutional collaboration could also eliminate the uncertainties among the various flood management institution which will be advantageous in implementing the specified NBS measures. Furthermore, involving the local through sensitisation and other training ventures will build the interest in people on the usage of the NBS measures which will solve the problem of low interest in the usage of the NBS measures.

Furthermore, based on the economic, land and lack of expertise knowledge related issues that could hinder the smooth implementation of the specified NBS measures, the key informants generally highlighted it will be difficult to implement detention basins and green roofs (see Appendix 12). On the other hand, based on some existing practices that look like some of the specified NBS measures, key informants generally highlighted that it will be easy and very possible to implement porous pavements, rainwater harvesting, rain gardens, and vegetated swales (see Appendix 12).

In summary, the spatial and flood-related mitigation plans that govern the Ga East Municipality reflect the possibility of integrating the specified NBS measures due to the specifications on protecting natural areas and promoting green spaces, which is a positive sign for NBS usage. However, in practice, the implementation of some of the plans tends to be the contractionary. In that regard, integrating the specified NBS measures based on the views of key informants revealed some core techniques. The techniques include piloting the specified NBS measures, education, sensitization, legal obligation, and re-strategizing enforcement of plans. Also, further analysis from the views of the key informants revealed possible NBS implementation barriers, which include existing flood mitigation project finance issues, cost requirement of the specified NBS measure, land unavailability, political interference in land acquisition, poor communication and coordination of activities, different interest from the various institutions, little expertise knowledge, and interest from local people in the integration process. Additionally, it was also revealed that the NBS implementation could be facilitated through providing government subsidies to support the cost of the NBS measures, providing attractive compensation packages for land acquisition, effective institutional collaboration and, involving the locals to increase their interest in the usage of the NBS measures.

5. DISCUSSION

This chapter of the report presents interpretation and discussion of the study results presented in the previous chapter. In this context, the relationship between land cover changes and urban flood likelihood areas was compared with the outcome of other land use and flood occurrence studies. Also, the results of the NBS target areas were related to the location preferences of flood-related NBS measures done in the western world. Furthermore, the way and manner the NBS measures can be integrated into the spatial planning and flood mitigation scheme in the Ga East Municipality as highlighted by flood management professionals were also compared with other integration strategies highlighted at the western and international level.

5.1. The relationship between land cover changes and urban flood likelihood areas

One of the main research objectives was to determine the relationship between land covers and the occurrence of urban floods in the Ga East Municipality. Based on analysis, it was found that the increase in hard surfaces had influenced the transformation of some areas in the municipality into very high flood likelihood areas. Specifically, the transformation of the 7.03km² into hard surfaces from 2015 to 2020 led to about 0.95km² of areas in the municipality being transformed into very high flood likelihood areas within a five-year period even though there were little rainfall amounts recorded in 2020 than in 2015.

This finding is attributed to first, the nature with which hard surfaces (built-up) are developing in the municipality. Harnessing on the land cover change analysis, the transformation of natural areas into hard surfaces mostly happened in the northern part of the municipality, which is also relatively upstream areas. The increase in the hard surfaces is associated with the high in-migration and population growth rate within GAMA, which is 3.5% annually (World Bank, 2014). Aside from the migration, another factor to the increasing built-up is the change in the preferences of housing types people want to live in (Grant, 2009). Thus, people in urban areas would prefer to live in single-tenant houses over compound (multiple) tenant houses (Grant, 2009). As Grant (2009) mentioned, the development of the single stories is very evident in the Ga East Municipality. Multiple estates have also been set up in the municipal, which also take the form of single stories residential development. These residential developments tend to seal natural surfaces which makes it very difficult for water to penetrate soils, thereby reducing the infiltration capacity of areas in the municipality. As the built-up or hard surfaces in the study area are increasing, another thought is given to the exact locations where the increasing is happening. Are they in an authorised and appropriate place? The land cover analysis for this study also revealed that out of the 7.03km² built-up transformation, grassland constitutes about 85%. Some of the grassland land cover types are reserved farmlands owned by the Ghana Atomic Energy Commission, and they are now being encroached upon for residential development. This nature of physical development in the study area was in line with the findings by Acheampong & Ibrahim (2016), where they also highlighted lots of physical developments in Ghana that happen in unauthorized areas, including river buffers and other reserved areas. This encroachment in the Ga East Municipality affirms the claim highlighted by Acheampong & Ibrahim (2016).

Secondly, on rainfall, the study finding for the first objective revealed it had less influence on the transformation of areas into very high flood likelihood area. This was because in 2015, the average daily rainfall amounts for peak periods used were higher than that of the 2020. In this light, it was expected for the coverage of the very high flood likelihood area in 2015 to larger than that of the 2020 but the study results revealed the otherwise. Hence, flood occurrence in the Ga East Municipality is mainly attributed to the increasing hard surfaces. Therefore, this finding from the study fortifies the stated hypothesis that the development of hard surfaces has increased the frequency and extent of urban floods in the Ga East

Municipality. This study finding therefore, comes in line with the claim made by Shiqiang Du et al. (2019), where different scenarios of green design strategies led to a decrease in inundation areas in Shanghai's central city. Shiqiang Du et al. (2019) also applied an SCS method together with the drainage capacity of Shanghai central city to arrive at its findings. Again the study findings on land cover change relation with urban flood in the municipality were also in line with other flood studies in Ghana, including Amoako (2012); Amoako & Boamah (2014). These studies also revealed that the increasing built-up in Accra, that is haphazardly done has partly contributed to urban flood happenings.

Concerning the pattern of rainfall and flood happenings in Accra and Ghana, Amoako (2012); Amoako & Boamah (2014) also mentioned rainfall intensity as another urban flood influencing factor in Accra aside increasing built-up. However, this study's finding revealed a different claim, as was highlighted by Amoako (2012); Amoako & Boamah (2014). Notwithstanding, Amoako, (2012); Amoako & Boamah (2014) also mentioned engineered drain capacity and solid waste management issues as other flood influencing factors in Accra, which this research did not consider due to data limitations. Also, drainage calculation was limited to the study area due to the unknown externalities outside the study area's jurisdiction, like terrain that could influence water flows. The engineered drained capacity considers the inflows and outflows of water in relation to areas outside the municipality. Conceivably, including the solid waste and existing engineered drain capacity in the study could have reinforced and clarified the relationship of the increasing hard surfaces in the municipality and the urban flood likelihood areas. Also, the absence of the solid waste and existing engineered drain capacity could be a reason for the less influence of rainfall on the flood likelihood areas in the municipality.

Nevertheless, the positive relationship between increasing hard surfaces and the urban flood likelihood areas from 2015 to 2020 in the Ga East Municipality justifies the need for urban flood-related NBS measures (Green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements) to be introduced and integrated into the municipality. Applying these NBS will help improve urban surfaces to prevent and minimize urban flood occurrences.

5.2. Target areas for implementing the specified NBS measures

Due to the hard surface development and flood likelihood relation in the Ga East Municipality, another objective for this research was to identify target areas where specified NBS measures can be implemented. The study revealed different areas in the municipality where the specified NBS measures can be implemented to aid in preventing and mitigating urban floods. The study identified five areas to be targeted in the municipality to implement the specified NBS measures, with areas labelled as Type 1 being better off areas in terms of runoff and inundation and Type 5 being worse off in terms of the runoff and inundation. The type 1 areas being better off in terms of runoff and inundation means the areas' surfaces are highly sensitive to water and they are generally upstream areas. Thus, anytime it rains, the surfaces in type 1 areas can absorb relatively more water thereby, reducing runoff depths. Also, the type 1 target area being better off to runoff and inundation means the area might not necessarily need any implementation of the specified NBS measure. On the other hand, type 5 target areas being worse off in terms of runoff and inundation means the areas have very low water sensitivity and they are generally downstream areas. Thus, it is difficult for water to penetrate through the surfaces of these areas. Therefore, since these areas have low water sensitivity, it will be ideal not to only apply NBS but also complement the NBS with specialised drains to effectively reduce flood happenings. This study finding is in line with what Lee et al. (2018) also found. Lee et al. (2018) also identified areas of high water sensitivity and upstream areas in Gwanghwamun-hyoja District in Seoul to be low physical flood vulnerability areas and low water sensitivity and downstream areas to be high physical flood vulnerability area.

Additionally, the worse and better off areas that translated into the five target areas were influenced by the views and opinions of key informants; thus, flood management professional working in the confines of Accra on the importance of the selected criteria (ratio of impervious surfaces-land cover, distance of areas to rivers, soil, elevation, and slope) used in this study.

Hence in the ranking of the criteria weights using pairwise comparison of AHP, slope criteria were ranked as the highest and soil ranked as the lowest. The ranking outcome of the criteria was partly similar to Dahan & Al-Komaim (2017), a study done to identify areas to implement NBS measures. Dahan & Al-Komaim (2017) used experts' and professionals' ideology in the criteria weighting approach, of which higher importance was also given to slope, which is in line with this study. On the other hand, the land cover was given the lowest importance in Dahan & Al-Komaim (2017) studies, which differs from this study, giving the lowest importance to soil texture. This is attributed to the highly built-up nature of the Ga East Municipality compared to Sana city, which had broader coverage of undeveloped areas. Harnessing on the sensitivity analysis presented in section 4.2.4 revealed the use of different weight will lead to different results. Hence, applying appropriate weights in the identification of "specified" areas is very important. Comparing the Ga East Municipality and Sana city on the importance of different geographical aspects on locating areas for NBS measures supports the assertion of Stagakis et al. (2019), which describes the implementation of NBS to be area specific. Therefore, identifying target areas to implement NBS measures in the Ghanaian context might not be the same as other areas.

5.3. Appropriate NBS measures for different locations

Another research objective was to identify appropriate NBS measures that have the potential to reduce urban floods effectively for specific locations in the municipality. As discussed in section 5.2, the target areas were identified based on the physical geographical characteristics of the study area in relation to the local knowledge of key informants. Relating the different target areas with the design conditions of the specified NBS measures adopted for this study, it was found that not all NBS measures will be very effective at all locations in the municipality. Specifically, specific NBS measures can only be functional at particular locations or communities[2] in the Ga East Municipality. This finding means in the quest of applying NBS measure to fight floods in cities different strategies must be employed for different locations. For instance, there are measures that will be very effective in upstream areas in the fight of urban floods but will be ineffective when applied in downstream areas. This finding also confirms the second hypothesis of this study which states that different areas in the municipality require different NBS measures to mitigate urban floods.

Applying different NBS measures for different locations in the Ga East Municipality was also in line with a study by Lee et al. (2018) which also point out that different flood management measures are required for different locations in a city. In their study, they also identified green design strategies to reduce surface water flooding in Gwanghwamun-hyoja District in Seoul, South Korea. Their study used empirical data to ascertain the application of specific green strategies that could reduce surface water floods in the district. Based on their measurements and findings, it proposes using measures like green roofs and porous pavements, among other measures for areas that have natural soils with the ability to infiltrate stormwater. This claim by Lee et al. (2018) confirms what this research also revealed, where green roofs and porous pavements were proposed for Type 1, 2, and 3 target areas. Soils in these areas, as described by the study, are generally sandy-loamy to loamy soils which have good infiltration abilities. Lee et al. (2018) also proposed using detention ponds, rain barrels, greens roofs for highly built-up areas, and poor drainage natural soil ability. Hence the usage of the rain barrels will be stationed beneath the parking lots of residential areas. This claim from Lee et al. (2018) partly aligns with this research finding on the usage of green roofs and detention basins in the area characteristics described above. Thus, this research also found green roofs and detention basins to be the NBS measures that will be very effective when implemented in Type 3, 4 and 5. This study describes these areas as relatively highly built-up areas, made up of clayey soils and flood accumulated areas. However, as specified by Lee et al. (2018), the usage of rain barrels contradicts this research's findings. This may be attributed to the design of the rain barrels, which may be different from the aspects of the rainwater harvesting approach adopted in this research.

5.4. Possible ways of integrating the specified NBS measures in spatial plans and flood mitigation schemes in the municipality

The final objective of the study was to unravel possible ways the specified NBS measures can be integrated in the spatial development and flood mitigation schemes in the Ga East Municipality. In this light, the spatial and flood management document that governs the municipality was analysed. The analysis found out that the spatial development framework of Accra, which is inspired by the Ghana national zoning regulation and planning standards, had multiple principles that made specifications that sought to promote and encourage the development of green areas and protect natural and other environmentally sensitive areas. This finding, therefore, presented strong reflection of NBS integration in the spatial plans. Concerning the flood management plan, findings also revealed a weak reflection of NBS integration since few principles sought to protect natural areas. However, other non-related greenery specifications like training, awareness creation, and institutional coordination in the city's spatial and flood management plan throws a green light in introducing the specified NBS measures in the Ga East municipality. This finding from the spatial and flood management plan means there are systems already in place to embrace the usage of the specified NBS measures in the municipality. This finding from the study falls in line with two principles thus, guiding principle (h) and (k) of the Sendai Framework for Disaster Risk Reduction 2015 – 2030 which is a framework outline by the United Nations Disaster Risk Reduction (UNDRR) to ensure a sustainable disaster risk reduction worldwide. The Sendai framework guiding principle (h) and (k) explains disaster risk reduction plans, policies, and practices are essential in achieving sustainable development and laying down of firm structures in creating disaster risk awareness (UNDRR, 2015).

Aside from the spatial planning and flood management document giving green light to NBS integration in the municipality, further analysis from key informant interviews revealed five techniques of ensuring the integration of the specified NBS measures in the Ga East Municipality. The techniques include first, piloting the specified NBS measures in few locations to ascertain how effectively they will work. Another technique involves conducting education and sensitization activities to enlighten people in the municipality about the NBS measures. Making the NBS measures legal obligatory for home builders and other developers to adopt was also another way that was revealed. The re-strategizing enforcement mechanism in relation to planning execution and combining the specified NBS measures with some already existing practices were also revealed to be part of integration strategies. These integration techniques as revealed from the analysis tends to be actions that seeks to take advantage and deal with the deficiencies surrounding spatial development and flood management in Ghana. Hence taking actions that considers the highlighted techniques will help make the integration of the specified NBS measures a reality in the Ga East Municipality. Four out of the five integration approaches were in line with the UK Green Building Council, (2021) NBS integration principles. The UK Green Building Council (2021) highlighted first the assessment of the functionality and quality of NBS, which is similar to the piloting of the NBS measures revealed in this research. UK Green Building Council (2021) also mentioned education and innovation to upgrade the skills of key stakeholders, which is also in line with the conduction of education and sensitization activities revealed in this study. Another principle that UK Green Building Council (2021) mentioned is multifunctionality which is also explained by combining the NBS with existing traditional practices as revealed in this study. The legal obligation approach was highlighted in Snep et al. (2020) as another way of integrating NBS measures in cities.

The technique of re-strategizing enforcement of plans mechanism has not been clearly mentioned in other related studies. This is attributed to the differences in the spatial plans and flood schemes enforcement mechanisms in well-planned and developed countries as well as less developing countries. As revealed in the spatial and flood management plan document analysis, there are specifications in place to prohibit development in unauthorised areas and make instructions for developers to include greenery in their development designs. However, as explained by Acheampong & Ibrahim (2016), the enforcement of spatial plans in Ghana, in general, has been a great challenge and has retarded the quality of physical development in most areas. This affirms an explanation given by the United Nations (2008) on plan enforcement being one of the key differences in spatial planning in developed and developing countries. Hence, the technique of re-strategizing enforcement of plans mechanism will be essential in integrating the specified NBS in the Ga East Municipality.

In the quest of integrating the specified NBS measures in the municipality, the study revealed there may be barriers that will interrupt the NBS integration process. The barriers to implementing the specified NBS measures covers economic, land, institutional coordination, and the local people's interest and knowledge base. Hence the study found out that the high cost of applying some of the NBS measures and existing financial issues in the flood management systems will destabilize the NBS implementation. Additional finding also highlights land unavailability, poor institutional coordination, and little expertise as implementation barriers to the specified NBS measures. All the NBS implementation barriers revealed in this revealed are associated with the challenges facing the current flood management system Ghana. The study finding is in line with a study from Kopsieker et al. (2021) and Sarabi et al. (2019). Their research emphasized financial delays, lack of institutional collaboration, and poor knowledge base as hindrances to implementing NBS in the European region. This affirmation by Kopsieker et al. (2021) and Sarabi et al. (2019) aligns with some of the NBS measures implementation barriers revealed in this study including, the high-cost requirement needed to construct some of the NBS measures as well as existing flood mitigation project finance problems. Another barrier was the unavailability of land and political influences in land acquisition. Institutional coordination, lack of expert knowledge on the part of the flood management institutions and the local people were also in line with Sarabi et al. (2019).

To facilitate the effective implementation of the specified NBS measures, it was also revealed that, the government should provide subsidies in support of the cost of the NBS measures. Another facilitation approach is the provision attractive compensation packages to fasten land acquisition since the total land area in the municipality is almost built up. Effective institutional collaboration and involving local people to guarantee their acceptance on using the measures was also a key facilitating approach. these facilitation measures are geared towards the innovation policies the government should outline to help in the implementation of the specified NBS measures. Harnessing on the government providing subsidies for instance, there are already existing subsidy policies in the sanitation sector to encourage houses without toilet facilities to put up one. The toilet facilities subsidy approach can also be applied to support developers in the implementation of the specified NBS measures. Also having in place attractive compensation packages will lure landowners to offer freely portions of their land for the implementation of some of the specified NBS measures. These facilitation measures were also in line with Sarabi et al. (2019), where the study revealed stakeholder partnership, provision of economic incentives, and local people involvement.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The main aim of the research was to explain the need for NBS measures, identifying and analysing possible areas where they can be implemented and how they can be integrated into spatial plans and flood mitigation schemes. The Ga East Municipality, Accra, was taken as a case study because of the municipality's rapid urban expansion and the increasing urban flood occurrences. The key findings of the research were concluded in the context of the sub-research objectives.

6.1.1. The relationship between urban flood occurrences and land cover changes in 2015 and 2020 in the Ga East Municipality.

In analysing the relation between land cover changes and urban floods in the Ga East Municipality from 2015 to 2020, different approaches, including land cover change analysis and SCS model was used. On the land cover in 2015 and 2020, the analysis revealed significant landcover changes between the two years. Thus, the built-up area that signifies hard surface development increased about 7km^2, diminishing mainly grassland and forest areas. The increase in hard surfaces in Ga East was attributed to the strategic location and presence of connecting routes to the Central Business District of Accra, which influenced the setting up of more estate areas and other residential development in the municipality.

Based on land cover and rainfall records for the respective years, areas that were more likely to be flooded were determined using an SCS model and the drainage density of the study area. The study finding was that, there was an increase in the coverage of very high flood likelihood areas from 2015 to 2020. The very high flood likelihood areas in this study were presumed to be flooded areas in the respective years.

Therefore, in relating the land cover and rainfall to the flood likelihood areas, it was deduced that the increase in the hard surfaces in the municipality influenced the increase in the very high flood likelihood areas. This was because the coverage of the flood likelihood areas in 2020 was larger than that of 2015 though recorded rainfall amounts in 2020 were less than 2015. This relation of the land cover and flood likelihood areas affirmed the hypothesis that the development of hard surfaces has increased the frequency of urban floods in the Ga East Municipality. Furthermore, the relation gave a concrete justification for integrating urban flood-related NBS measures into spatial plans and flood mitigation schemes to mitigate urban floods in the Ga East Municipality.

6.1.2. Target areas in Ga East Municipality for implementing NBS measures.

Since there was a need to consider urban floods-related NBS measures to reduce the Ga East Municipality's flood situation, further analysis was done to identify target areas where the specified NBS measures adapted for this study can be implemented. In that regard, the SMCA revealed five different target areas, which were named Type 1, Type 2, Type 3, Type 4, and Type 5 target areas in the Ga East Municipality where the NBS measures can be implemented. Further analysis revealed Type 1 target areas were generally characterised by high elevation and steep slopes with sandy and loamy soils and predominantly forest and grassland areas. Adenkrebi was the main community[1] found in the Type 1 area. Based on the Type 1 area characteristics, it was considered the better off area in terms of runoff and inundation, which requires specific NBS measures to help mitigate urban floods.

On the other hand, Type 5 target areas were characterised with general lowland and flat sloped, mainly clayey soils, the areas were very close to rivers and waterways, and they were highly built-up. Communities[2] like Haatso, Dome, Taifa, and Ashongman were found to be located on the Type 5 target areas. Due to their characteristics, they were also considered the worst-off areas in terms of runoff and inundation, requiring a specific NBS measure to help mitigate urban floods. The other target area types were intermediate in terms of the runoff and inundation situation that also called for specific NBS measures.

6.1.3. Appropriate NBS measure with the potential to reduce urban flood occurrences in the identified target areas in the Ga East Municipality.

In relation to the physical geographical characteristics of the identified target areas and the design conditions of the specified NBS measures, appropriate NBS measures that can effectively reduce runoffs and inundation for the respective target areas were identified. The Analysis then revealed green roofs could be implemented in all locations since their implementation will be on buildings. Vegetated swales were also best implemented in Type 3 target areas, including communities[2] like Ashongman Estates and Akokome. Berekuso and Ayi Mensah, major communities[2], making up type 2 target areas, were also identified as the best areas to implement rain gardens and rainwater harvesting to effectively contribute to flood mitigation. Furthermore, Type 3, 4, and 5 target areas were also the best areas to apply detention basin since these areas were generally low land areas with little or no coverage of sandy soils. Also, due to mainly soil characteristics, only Type 1, 2, and 3 target areas were the best fit to implement porous pavement. In this light, it was deduced specific NBS measures must be targeted and implemented in specific locations to reduce runoff depths and ensure effective flood mitigation in the Ga East Municipality.

6.1.4. Possible ways of integrating NBS measures in spatial and flood mitigation schemes

Analysis of the spatial planning and flood management documents revealed some positive indications and specifications that can capture the specified NBS measures to be included in the respective plans. Specifically, there exist guidelines in the spatial documents that regulate the municipals spatial development that seeks to protect natural areas and promote the development of green areas. Therefore, the identified, green-related principles indicate a strong reflection of integrating the specified NBS measures in the Ga East Municipality. On the other hand, the analysis revealed limited specifications on the flood management plan that sought to promote green areas development, indicating a weak reflection of NBS integration. However, administratively, the flood management plan portrayed the positivity of NBS integration.

Furthermore, based on the views of key informants who are flood management professionals in Accra, the possible ways the specified NBS could be integrated and implemented in the municipality's spatial development and flood mitigation schemes were also discovered. Five major techniques of integrating the specified NBS measures based on the views of the key informants. The techniques included the piloting of the specified NBS measures, education and sensitization, legal obligation, combination of NBS and traditional measures, and re-strategizing enforcement of plans mechanism. Further analysis also revealed the integration of the specified NBS measures might face certain implementation barriers and possible facilitation measures. The barriers included existing flood mitigation project finance issues, the high-cost requirement of the specified NBS measure, land unavailability, political influences in land acquisition, poor communication and coordination of activities, different interest from the various institutions, little expertise knowledge, and interest from local people. On facilitating the NBS implementation, the study also revealed providing government subsidies to support the cost of the NBS measures, providing attractive compensation packages for land acquisition, effective institutional collaboration, and involving the locals to increase their interest in the usage of the NBS measures.

In general, the research outcomes presented above explains why the Ga East Municipality needs the implementation of NBS measures which was justified by the increased very high flood likelihood areas due to hard surface increase. The research also showed to mitigate urban floods effectively, specific NBS measures should be applied at specific locations in the Ga East Municipality. Finally, the research also revealed that integrating the specified NBS measures in spatial plans and flood mitigation schemes will require special techniques. However, in the process of applying the techniques, responsible institutions should take note of the possible barriers and what can be done to overcome the barriers. Therefore, scientifically, this research has added to the body of studies on using alternative approaches like NBS in mitigating urban floods and how NBS can be integrated into the planning system and flood mitigation schemes in less developed countries in terms of physical planning.

6.2. Limitation of study

The study had encountered some level of limitations. One limitation was restricting the drainage movement in the drainage density determination to the boundary of the Ga East Municipality due to the unknown external factors outside the confines of the municipality. However, several studies have highlighted the relevance of including external in and outflows in an area when conducting floods studies.

Another limitation of the study is the generalisation of the target area characteristics. In reality, there could be locations within a particular NBS target area having a different characteristic than what was generalised. Hence, the generalisation might affect the identification of appropriate NBS measures that will actually be effective for the respective target areas. Also, the coding of the key informants' interviews might have left out some vital information in the analysis. This is also about the generalisation of interview information that might not apply to all areas in the municipality.

Furthermore, the researcher was not able to visit the study area himself due to the Covid 19 restriction. Due to this limitation, some vital evidence and photographs that could have supported the presentation of results, specifically on the key informant interviews could not be obtained.

6.3. Recommendation and future research

This research has unravelled the need for NBS measures to be part of the spatial development and flood mitigation schemes of urban areas and the approaches to make the NBS integration effective, especially in the jurisdiction of the Ga East Municipality. Hence, since the existing flood prevention and mitigation measures in the Ga East Municipality and Ghana as a whole has proven futile, it is recommended for the NADMO, the lead organisation in flood management in Ghana, among other related institutions, to adapt the study outcome to integrate the specified NBS measures in dealing with the flood situation in Ghana effectively. Also, challenges facing the physical development of areas comprising encroachments and haphazard development in waterways and other unauthorised locations should be tackled by adapting spatial plan enforcement's re-strategization as it was revealed in the research findings.

Furthermore, future spatial plans and the national disaster management scheme review should capture some of the research findings on the integration techniques and be alerted on the possible barriers, and deal with them accordingly by employing facilitation measures revealed in the research. Nevertheless, in capturing NBS in the municipal's spatial planning and flood mitigation, the appropriate NBS that will effectively mitigate urban flood in specific locations, as highlighted in the study findings, should also be considered by the responsible institutions and organisations.

In relation to the findings revealed in this research, future studies may be needed to empirically analyse and quantitatively determine how the specified NBS measures will reduce runoff depth and inundation volumes. Since this research revealed how the specified NBS measures could be integrated from the perspective of flood management professionals, future research can also be done to look at NBS integration from the perspective of the local people and inhabitants. This will include a collection of how the local people understand urban floods and how the floods have been affecting their livelihoods and outline how they have been abiding by existing spatial planning and flood prevention rules to give their views on how the specified NBS can also be integrated.

Additionally, further studies can be conducted on the co-benefits of the specified NBS measures to see the possibilities of using rainwater as an alternative and complementary water supply in the Ga East Municipality since not all areas in the municipality are connected to the Ghana Water Company pipelines.

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APPENDICES

Appendix 1: Informed consent for key informant interviews

Consent Form for [Nature-Based Solutions (NBS) as an urban flood mitigation measure: the case of Ga East Municipality, Accra, Ghana]

You will be given a copy of this informed consent form

Study description and introduction

The current happenings of urban floods in the Greater Accra Metropolitan Area (GAMA) call for special attention on the part flood management stakeholders/ institutions to develop innovative ways of dealing with the menace. Hence, this research has been developed to throw more light on how the continuous hard surface development (on the other hand, loss of green and other natural areas) in the Ga East Municipality has affected urban flood occurrences. The research will also identify target areas where urban flood-related NBS measures (green roofs, vegetated swales, detention ponds, rainwater harvesting, rain gardens, and porous pavements) can be implemented and possible ways they can be integrated into flood mitigation schemes and spatial plans.

The conduction of this research on NBS measures and urban flood mitigation will add up to the existing knowledge on urban flood management in Ghana. This research will also provide knowledge to authorities on how NBS measures can be integrated into spatial and flood management plans to help shape cities and prevent urban floods.

In that regard, this form is to seek your consent of participation in an interview asking for your views relating to how the specified urban flood-related NBS measures can be captured in Ghana's/municipal's flood mitigation and spatial plans. The interview is therefore scheduled to last for about 20 to 25 minutes. Thank you.

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves [taking notes of interview responses]	☐	☐
I understand that taking part in the study also involves [recording (if possible - activating the recording of the online platform which will later be transcribed as text) of interview responses]	☐	☐
Use of the information in the study		
I understand that information I provide will be used for [Purely for academic purpose in the form of report presentation to the Faculty ITC, University of Twente]	☐	☐

I understand that personal information collected about me that can identify me, such as [name or position held in organization/ institution], will not be shared beyond the study team.	□	□
I agree that my information can be quoted in research outputs.	□	□
Future use and reuse of the information by others I give permission for the [*interview transcripts*] that I provide to be archived in [*Faculty ITC, University of Twente file repository*] so it can be used for future research and learning.	□	□
I give the researchers permission to keep my contact information and to contact me for future research projects.	□	□

Signatures

…………………………….. ………………………… ……………

Name of participant [printed] Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

…………………………….. ………………………… ……………

Researcher name Signature Date

Study contact details for further information: [*Prince Asare, p.asare@student.utwente.nl*]

Contact Information for Questions about Your Rights as a Research Participant
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-itc@utwente.nl

Appendix 2: Interview guide for key informant

Introduction to interview

Good morning/ afternoon/ evening Sir/ Madam. Please, my name is Prince Asare, a second-year master's student at the University of Twente, Faculty ITC, The Netherlands. I am currently doing my MSc. research on the topic "Nature-Based Solutions (NBS) as an urban flood mitigation measure: the case of Ga East Municipality, Accra, Ghana," as explained earlier. As part of conducting this research, I will be looking at the possible ways by which urban flood-related NBS measures (green roofs, vegetated swales, detention ponds, rainwater harvesting, rain gardens, and porous pavements) can be integrated into flood mitigation schemes and spatial plans to minimize the occurrence of urban floods in Accra, specifically, the Ga East Municipality. In that regard, I would like to ask some questions relating to how you think the specified urban flood-related NBS measures can be captured in Ghana's/municipal's flood mitigation and spatial plans. This interview will take at least 25 to 30 minutes.

Thank you - the interview starts.

Key informant institution and role

1. What is your professional background, position, and role in the institution/unit?
2. Can you describe your institution/unit's roles and responsibilities in relation to the management of floods in the city/ municipality?
3. Does the institution/unit collaborate with others in addressing flood issues in the city/ municipality? Can you please explain?
4. What are the existing methods or tools the institution/unit use in carrying out activities related to flood management? *(An example could be the presence of a flood risk map)*
5. What challenges do the institution/unit face in carrying out activities related to flood management?
6. What challenges do the institution/unit face in collaborating with other institutions in carrying out activities related to flood management?
7. How were the challenges handled in the past?
8. Are there any changes seen or foreseen for the future after the handling of the challenge?

General knowledge of urban floods and NBS

1. In your view, which area characteristics/factors do you think contribute most to the occurrence of urban floods? Please, give a rate from 1 (very low contribution) to 5 (very high contribution) for these indicators.

   -wetlands and areas proxime to rivers ……
   -high ratio of impervious areas……
   -poor soil drainage areas…….
   -low land areas/ flood accumulation areas…….
   -highly sloped areas………

2. Which communities in the city/ municipality experience floods the most? (A map showing the location of communities will be displayed as aid)
3. Have you ever experienced a flood event in your area where you live? If yes, how did that affect your professional work?

4. In relation to the specified flood-related NBS measures, to what extent is any of them happening in the city/ municipality /Ghana?
5. In your view, which areas do you think are important to consider when identifying places to implement the specified NBS measures? You may mention a range between 1 (not important) to 5 (very important) for these indicators.

   -wetlands and areas proxime to rivers……
   -high ratio of impervious areas……
   -poor soil drainage areas…….
   -low land areas/ flood accumulation areas…….
   -highly sloped areas………

Possible NBS integration strategies

1. How easy will it be to introduce the specified NBS measures? Please rate from 1 (not very easy) to 5 (very easy)

   Green roofs…….
   Vegetated swales……..
   Rain gardens……..
   Rainwater harvesting………
   Detention basins……..
   Porous pavement……..
   Can you please give a reason for each?
2. In your view, which areas (communities) in the municipality can the specified NBS measures be done? (A map showing the location of communities will be displayed as aid)
3. How do you see the possibility of combining some traditional flood mitigation measures with some of the specified NBS measures?
4. How do you see the possibility of replacing some existing projects or interventions with any of the specified NBS measures?
5. To what extent has any of the specified NBS measures considered in the city/municipality's spatial planning?
6. How can the specified NBS measures be enhanced or made part of the city/municipality's physical or spatial planning and development?

Possible challenges and solutions

1. What could facilitate the implementation of the specified NBS measures
2. What could hinder the implementation of the specified NBS measures?

General remarks

1. What will be your final remarks on integrating urban flood-related NBS measures in the city/municipality?

Appendix 3: Interview invitation letter

Prince Asare
Boulevard 1945 – 4
7511 AE Enschede
The Netherlands

02/02/2021

Institutional address

Dear Sir/Madam,

PERMISSION TO CONDUCT MSC RESEARCH INTERVIEW

My name is Prince Asare, a second-year master's student at the University of Twente, Faculty ITC, The Netherlands. I am currently doing my MSc. research on the topic "Nature-Based Solutions (NBS) as an urban flood mitigation measure: the case of Ga East Municipality, Accra, Ghana." As part of conducting this research, I will be looking at the possible ways by which urban flood-related NBS measures *(green roofs, vegetated swales, detention ponds, rainwater harvesting, rain gardens, and porous pavements)* can be integrated into flood mitigation schemes and spatial plans and flood mitigation schemes to minimize the occurrence of urban floods in Accra, specifically, the Ga East Municipality.

In that regard, I would like to have an interview with a planner, engineer, or a technical officer with your institution to seek their views relating to how the specified urban flood-related NBS measures can be made part of the flood mitigation and spatial plans in the Ga East Municipality and Ghana in general. Interview responses will be used solely for academic purpose.

I will therefore want to use this opportunity to seek permission to have an online *(zoom or any favourable platform)* or face to face (through a field assistant) interview with any of the above mentioned officials.

Thank you and I hope to hear from you soon.

Yours Sincerely,
Prince Asare
Email: p.asare@student.utwente.nl
Mobile: +31684443085

Appendix 4: 2020 Image classification accuracy report

Class Name	Reference totals	Classified totals	Number correct	Producers' accuracy	Users' accuracy
Unclassified	1	1	1	---	---
Built-up	93	109	92	98.92%	84.40%
Grassland	38	30	27	71.05%	90.00%
Forest	11	6	6	54.55%	100.00%
Bare land	8	5	5	62.50%	100.00%
Totals	151	151	131		

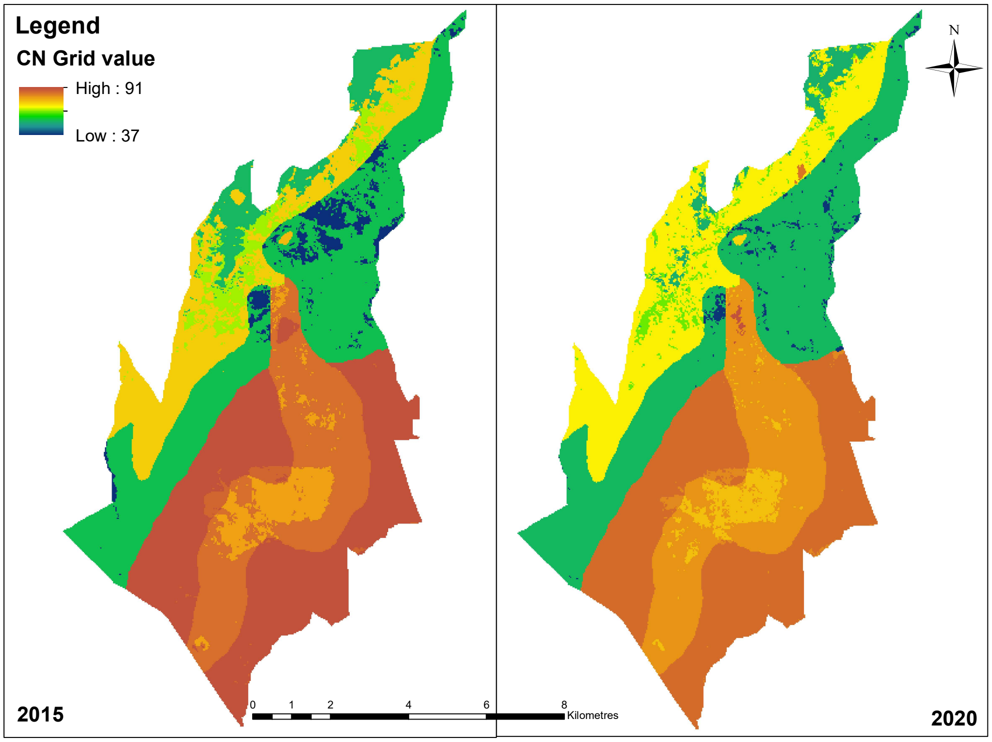
Overall Classification Accuracy = 86.75%
Overall Kappa Statistics = 0.7355

Appendix 5: flood events recorded from 2015 to 2020

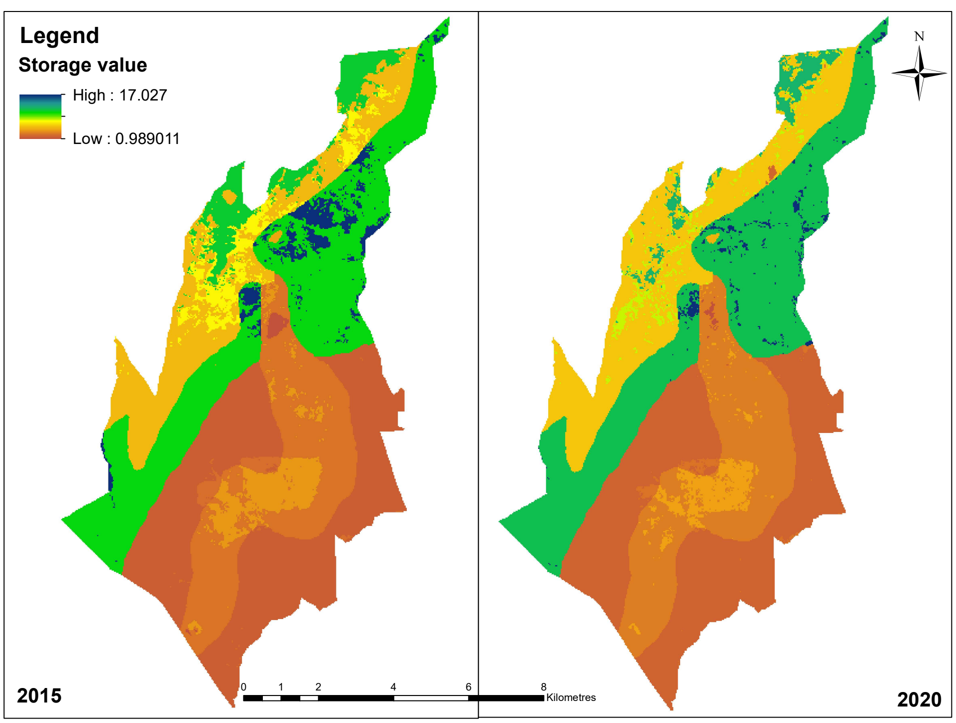
Year	Number of flood events recorded
2015	4
2016	8
2017	13
2018	29
2019	22
2020	19

Source: (NADMO 2020)

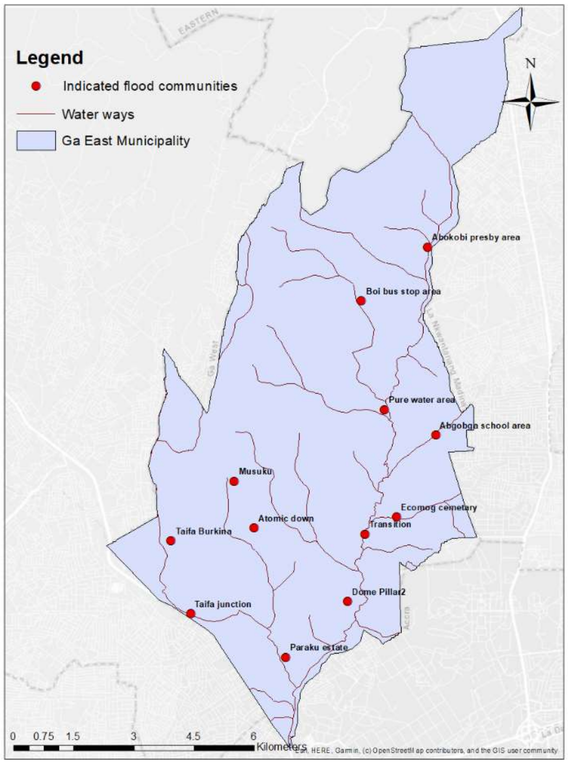
Appendix 6: Curve Number (CN) for the municipality



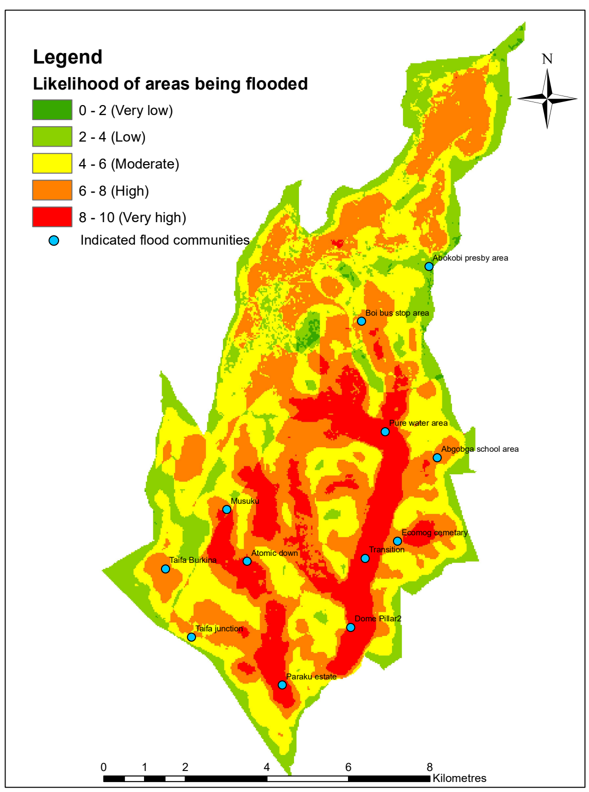
Appendix 7: Storage capacity of the municipality



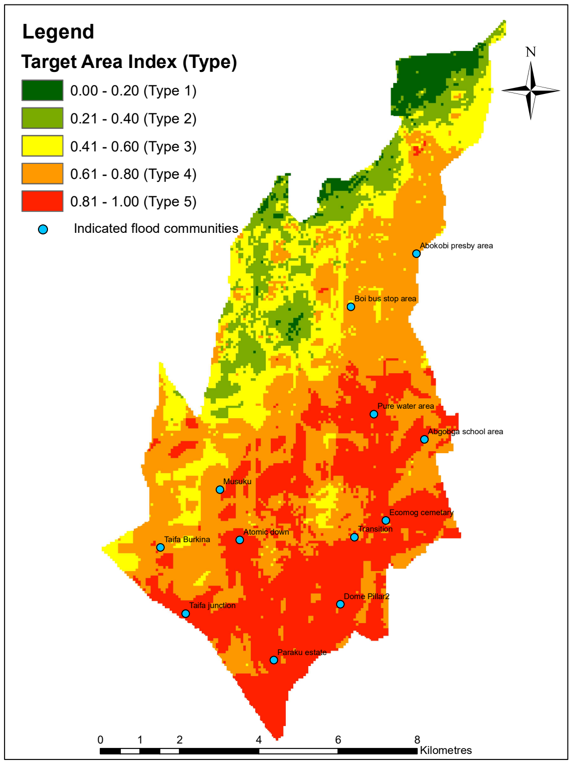
Appendix 8: Flood communities indicated by professional



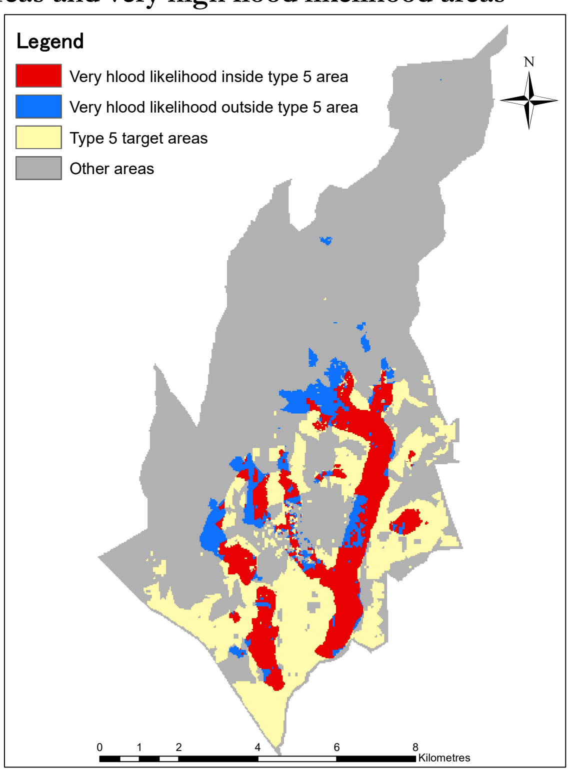
Appendix 9: Flood likelihood areas and indicated flood communities



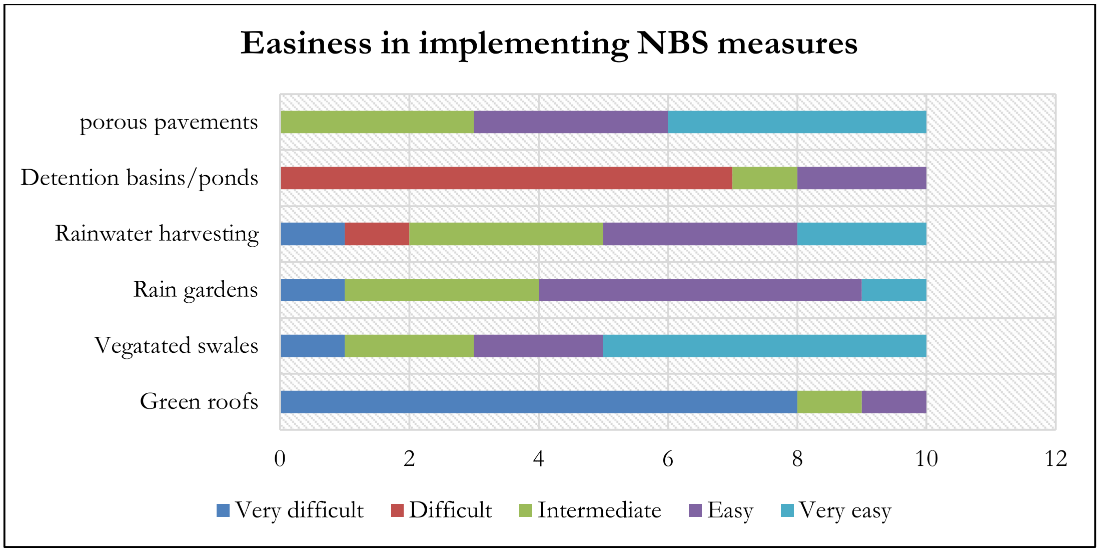
Appendix 10: Target areas and indicated flood communities



Appendix 11: Target areas and very high flood likelihood areas



Appendix 12: Easiness in implementing the specified NBS measures



Appendix 13: The network of themes and codes