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EMMANUEL INIOLUWA BABAJIDE

A METHODOLOGY FOR FLOOD RISK ASSESSMENT FOR TWO CITIES IN NIGERIA

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Aos 11 dias do mês de agosto do ano de 2023, às 09:00 horas, no(a) Sala De Reunião - DEC, realizou-se a defesa de DISSERTAÇÃO DE MESTRADO de EMMANUEL INIOLUWA BABAJIDE, intitulada **A METHODOLOGY FOR FLOOD RISK ASSESSMENT FOR TWO CITIES IN NIGERIA**. A Comissão Examinadora foi constituida pelos seguintes membros: Profa. Dra. ANNA SÍLVIA PALCHECO PEIXOTO (Orientador(a) - Participação Presencial) do(a) FEB / UNESPBauru SP, Prof. Dr. GUSTAVO GARCIA MANZATO (Participação Presencial) do(a) Programa de Posgraduacao em Engenharia Civil e Ambiental / FEB/UNESP/Bauru, Profa. Dra. ANA ELISA SILVA DE ABREU (Participação Virtual) do(a) IG / UNICAMP/Campinas (SP). Após a exposição pelo mestrando e arguição pelos membros da Comissão Examinadora que participaram do ato, de forma presencial e/ou virtual, o discente recebeu o conceito final:_Aprovado___ . Nada mais havendo, foi lavrada a presente ata, que após lida e aprovada, foi assinada pelo(a) Presidente(a) da Comissão Examinadora.

Profa. Dra. ANNA SÍLVIA PALCHECO PEIXOTO

DEDICATION

I dedicate this magnificent height to God and my cherished mother, who is of blessed remembrance.

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So, with joy in my heart, I would want to express my gratitude for the kind assistance I received from those who I believe to be part of God's provisions for the accomplishment of this magnificent adventure. First and foremost, I want to thank the administration of the Federal University of Agriculture, Abeokuta, where I currently attend, for considering me deserving of nomination for the Agricultural Research and Innovation Fellowship for Africa (ARIFA) scholarship. I also want to thank the Tertiary Education Trust Fund (TETFund) and the Forum for Agricultural Research in Africa (FARA) for the partnership initiative. My deepest gratitude is extended to my father, Dr. Samuel Oluwole Babajide, and my sisters, Boluwatife Babajide and Tolulope Onasanya, for their unwavering support and practical expression of love, even though they live far away. In addition, I have nothing but the deepest gratitude for my supervisor, Professor Anna Silvia Palcheco Peixoto. Her guidance, inspiration, and commitment to helping me develop into a giant were equally bracing and helpful in positioning me for this process, from which I have emerged as a sharp thinker. Her focus, openness, and insightful suggestions not only raised the caliber of my work but also inspired in me a growing sense of logic and science. My Nigerian colleagues Abayomi Bankole and Abraham James are deserving of special recognition. The brotherly affection, moral encouragement, and practical assistance I received along the way strengthened my will to keep going. Additionally, the maternal care provided by Mrs. Racheal Bankole, and the welcoming smile of newborn Rejoice Camila Bankole helped to reduce stress and open up the mind. And finally, I would like to thank my friends both home and abroad for their ceaseless prayers, encouragements and moral support throughout the journey.

Summary

As inundações/enchentes são consideradas uma das ameaças mais comuns à vida humana e às propriedades. A avaliação da vulnerabilidade e da suscetibilidade é a primeira etapa do gerenciamento do risco de inundação uma vez que é vital que pode ajudar os formuladores de políticas a identificar e implementar políticas que minimizem o risco de ocorrências. Esta pesquisa tem como objetivo desenvolver uma metodologia usada para mapear duas cidades selecionadas no sudoeste da Nigéria usando análise multicritério em um ambiente GIS para criar um mapa de suscetibilidade e risco de inundação para a detecção e previsão de locais propensos a inundações. Fatores ambientais e antropogênicos, como características hidrológicas, geomorfológicas, geológicos, tipo de solo e uso e ocupação da terra, bem como pontos de ocorrência de inundações, foram coletados de diferentes bancos de dados para essa análise. A partir dos resultados, as quatro principais categorias de nível de risco de inundação são baixo, médio, alto e muito alto, representando 13,04, 31,29, 36,42, 19,25% da área total de Abeokuta South e 11,48, 22,73, 35,06, 30,73% da área total de Lekki, respectivamente. O uso e a cobertura do solo, bem como a distância da rede de drenagem, são os principais determinantes do fenômeno de inundação em ambas as áreas. Embora a elevação não desempenhe um papel importante na distribuição dos níveis de risco em Lekki, ela desempenha no caso da cidade de Abeokuta South, uma vez que algumas áreas próximas à rede de drenagem tinham baixa suscetibilidade por estarem localizadas em altitudes elevadas. Como as inundações na Nigéria são um problema grave que requer a atenção de todas as partes interessadas com o objetivo de prevenir e resolver seus efeitos adversos que representam uma ameaça à sobrevivência humana, os resultados deste estudo servem como uma ferramenta fundamental de avaliação para o desenvolvimento sustentável pelas autoridades públicas com jurisdição territorial.

Palavras-Chave: Inundação, GIS, Mapeamento, Análise Multicritério, Abeokuta, Lekki.

Abstract

Floods are considered one of the most common threats to human life and properties. And assessment of vulnerability and susceptibility is the first step in the management of flood hazard. It is a vital step that can help policymakers identify and implement policies that will minimize the risk of flooding. This research aims to develop a methodology used to map two selected cities in South-western Nigeria that are vulnerable to flooding, using multi-criteria analysis under a GIS environment to create a flood susceptibility and risk map for the detection and forecasting of flood-prone locations. Environmental and anthropogenic factors such as hydrological, geomorphological, land use, and socio-economic characteristics, soil type and geological data as well as points of flood occurrences were collected from different databases for this analysis. From the results, the four main categories of flood risk level are low, medium, high, and very high representing 13.04, 31.29, 36.42, 19.25 % of the total area for Abeokuta South and 11.48, 22.73, 35.06, 30.73% of the total area of Lekki respectively. Land-use and Land cover as well as the distance from drainage network are the main determinants of the flooding phenomenon in both areas. While elevation does not play an important role in the distribution of risk levels in Lekki, it does for the city of Abeokuta South, as some areas close to the drainage network had low susceptibility because they were located at high altitudes. Because flooding in Nigeria is a severe problem needing the attention of all stake holders with a view to preventing and resolving its adverse effects that pose a threat to human survival, the results of this study serve as a fundamental tool for evaluation for sustainable development by public authorities with territorial jurisdiction.

Key Words: Flood, GIS, Multicriteria Analysis, Abeokuta, Lekki.

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1 INTRODUCTION

Annually, hundreds of millions of people globally are affected by different kind of disasters which include floods, landslides, cyclones, earthquakes and many others. Environmental susceptibility combined with hazard is causing the world to experience an increase in both the frequency and impact of these disasters (Amangabara et al., 2012). Amongst all these disasters, flooding seems to be the most occurring and devastating (Wizor and Week, 2014; Nwankwoala and Jibril, 2019). One of the reasons for this is because waterbodies are a major factor that dictates and influences the pattern of human settlement. Also, climate change, rapid urbanization, decrease in permeable surfaces and change in land use patterns has also caused increase in the occurrence and intensity of floods (Aronoff, 1995).

Flood can be defined as large masses of water that temporarily covers dry land and are usually triggered by excess rainfall. It is a phenomenon that also occurs naturally in rivers and natural drainage systems. It can cause significant damage to the environment and human lives (Thilagavathi, et al., 2011).

Every human settlement stands the risk of experiencing a flood disaster and the effects of flooding differ across settlement and places on earth. The difference in these effects is defined by how susceptible or vulnerable the environment is to this hazard. A location's susceptibility to flooding depends on the area's exposure to the hazard (a natural occurrence) while its vulnerability is a function of the exposure and manmade activities carried out inside the catchment area that obstruct the free flow of water.

Due to the fact that human population is predisposed to natural disasters all over the world, and in recent years the effects of floods have become more significant as more people are exposed to their negative effects, quite a number of investigations have been carried out in assessing areas at risk of flooding. Flood susceptibility and vulnerability assessment is a vital part of any disaster risk analysis. It can help identify areas of susceptibility or vulnerability that are most likely to cause flooding (Colburn and Seara 2011; Prasad and Narayanan 2016; Yan and Li 2016).

Recently, geoinformation technologies like remote sensing and GIS have been used to evaluate flood susceptibility and create flood risk maps, which are crucial tools for identifying areas at risk of flooding. (Jeb and Aggarwal, 2008). According to Demessie (2007) and Manandhar (2010), GIS has been used in developing flood risk maps that show susceptibility and vulnerability of different places around the world to flooding (Balica, 2007). All these methods help in assessing the flood risk an environment faces and gives decision makers ideas of how to prepare and mitigate the effects of the incoming disaster. The idea of flood risk management is aimed at mitigating and managing the effects of floods on human lives and property.

Over the past few decades in Nigeria, many lives and property worth millions of dollars has been lost to flooding events (Eguaroje et al., 2015). Over the last 40 years, there have been floods (flash floods, urban floods, channel floods, back-swamp floods, coastal inundation, and so on), but the flood of 2012 caught everyone off guard. According to the National Emergency Management Agency (NEMA), the storm hit about 30 of Nigeria's 36 states, affecting 7 million people, destroying 597,476 homes, displacing 2.3 million people, and killing 363 people. The flood damaged homes and cut off transit lines in the impacted areas. Farmland and other means of livelihood were also severely impacted, as were animals and other biodiversity.

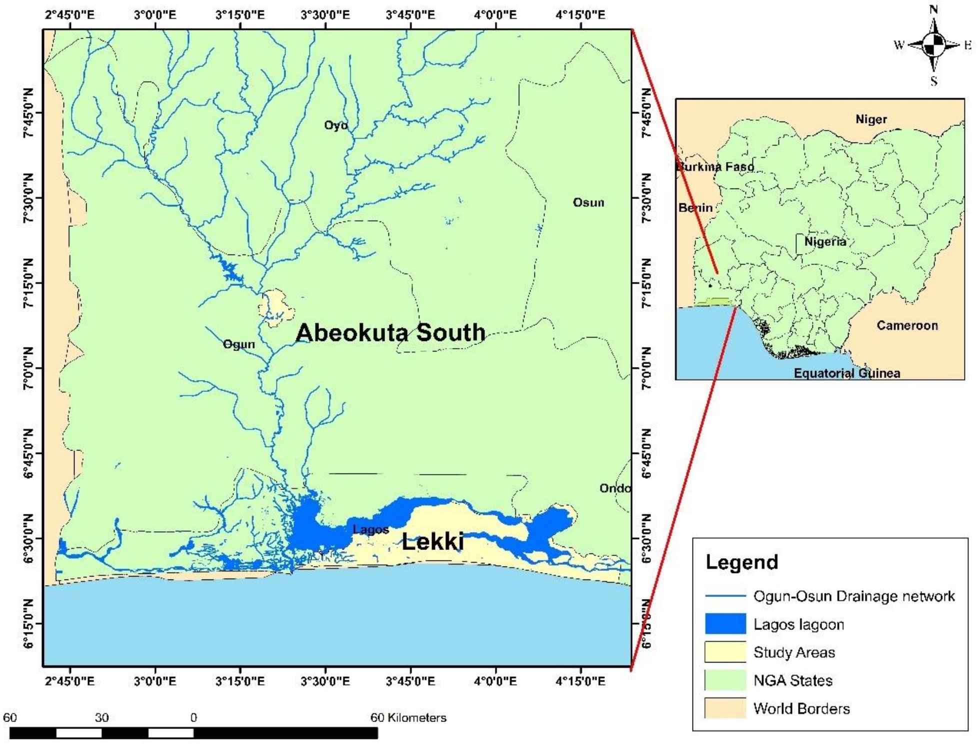
The flood took its toll on the economic indices of the country by causing damages totaling $5.09 billion, or 2.83% of the country's 2013 Gross Domestic Product (GDP) (Okoruwa, 2014). It reportedly damaged more than 1.9 million hectares of land and decreased food production in flood plains, according to Anugwara and Emakpe (2013). This caused the prices of food stuff to go up as the transportation of harvested products to the market were more difficult and expensive. As a result of these devastating floods, the Department of Petroleum Resources reported that Nigeria's crude oil production had been substantially decreased by 500,000 barrels per day. Despite all these figures, the scale and nature of Nigeria's flooding made it impossible to accurately determine the number of displaced people, property damage, and fatalities (Cirella and Iyalomhe 2018). With Nigeria having the largest economy in Africa, these catastrophic events prevent the country from reaching the SDG goals achievements made over many years of growth are being undone.

The thorough knowledge about the projected frequency, nature, and severity of hazardous events, as well as the sensitivity of people, buildings, infrastructures, and economic activity in a potentially risky location, can be used to successfully reduce the impact of flooding. Unfortunately, most metropolitan centers in underdeveloped countries like cities in the southwestern part of Nigeria which are rapidly increasing, consistently lack this in-depth information (Ifatimehin et al. 2009). Making sure all vulnerable places are identified and appropriate precautions are taken to provide adequate preparedness, effective response, rapid recovery, and effective prevention are some ways to lessen the effects of floods.

Abeokuta South and Lekki are amongst these cities in the southwestern part of Nigeria that are affected by floods annually. During rainy season rivers are likely to overshoot their banks and flood neighboring communities. The city of Abeokuta lies within the Ogun-Osun drainage basin. This basin runs through the states of Oyo, Osun, Ogun and Lagos. Lekki on the other hand lies at the mouth of the Ogun-Osun river basin as shown in Figure 1.

This dissertation aims to suggest a methodology for assessing and mapping the flood risk in the cities of Abeokuta South and Lekki in Nigeria (Figure 1) through the use of a multicriteria analysis which will analysis some physical characteristics such as geology and geomorphology of the study areas. This is due to the fact that both regions are particularly susceptible to floods caused by meteorological circumstances due to the low height of the terrain above sea level. Some other correlated data are also included in the analysis, with the help of geo-information technologies.

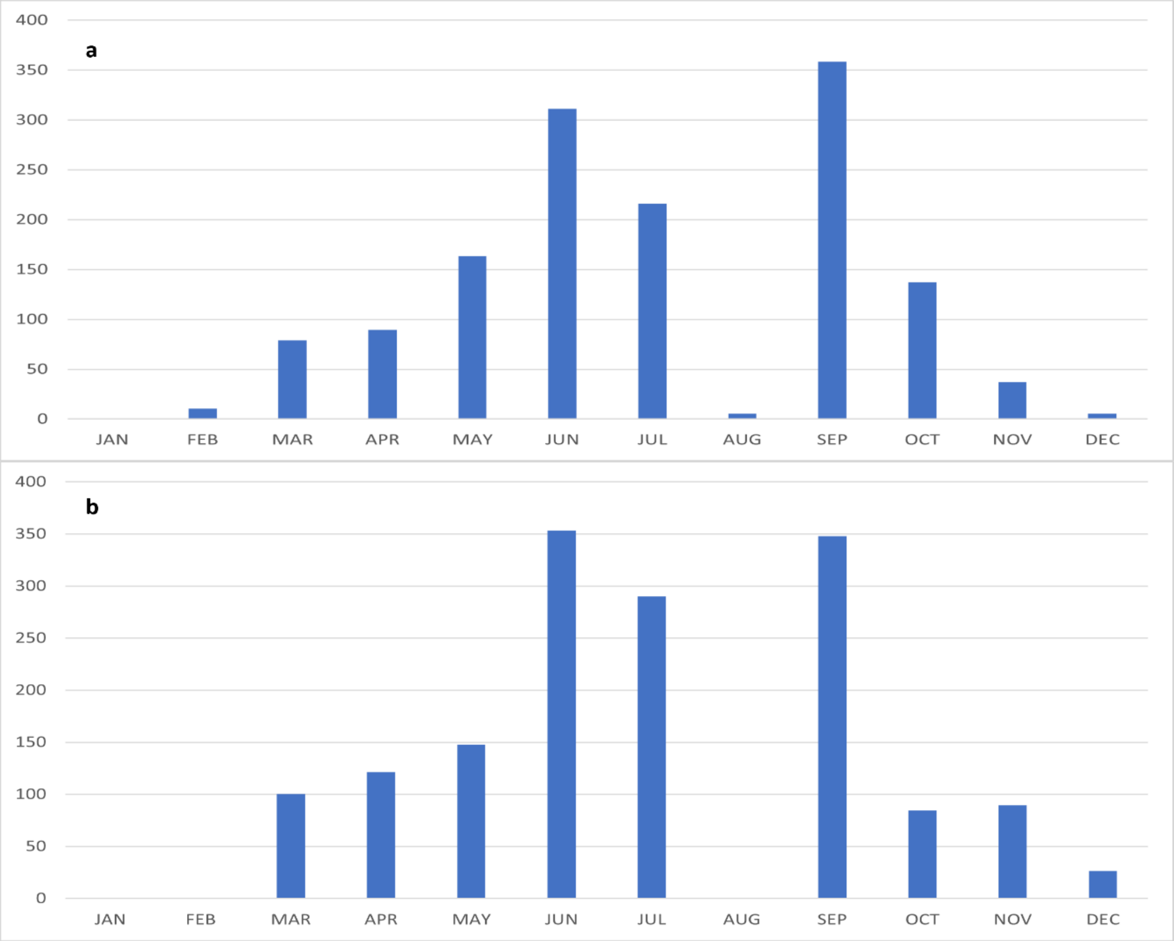
Figure 1. Map of Abeokuta South and Lekki



1.1 Justification

Flooding is majorly caused by rainfall which is very common within the southern parts of Nigeria. In these parts, the rainy season begins in March and lasts until the end of July, with a peak in June. The rainy season is followed by a brief dry period in August, known as the August break, which lasts two to three weeks. The short rainy season follows, beginning in early September and lasting until mid-October, with a peak phase towards the end of September (tcktcktck.org). Amongst all the cities located within the southern part of Nigeria, the city of Abeokuta South and Lekki were selected for this study as they have been recorded to have been constantly experiencing floods annually. During both peak periods as shown by the chart in Figure 2, flooding in the city of Lagos and Abeokuta has the potential to be disastrous, affecting hundreds of thousands of people and causing significant economic damage as shown in Figure 4 and Figure 5.

Figure 2. Graph showing the Monthly Rainfall distribution in (a) Abeokuta South and (b) Lekki in the year 2022.



The major city and Ogun State's capital is Abeokuta. The advantageous location of this city has led to its dynamic economic activity, which has been fueled by a variety of natural resources, rapid population increase, and improved political status. According to the National Population commission of Nigeria (NPCN), the population of this city as of 2006 was 250,295 and projected to be about 425,700 in 2022 with a 3.4% annual population rise and a population density of 4,730/km² (https://nationalpopulation.gov.ng/). The economy in the area is made up of a few large-scale industrial facilities, along with trade, personal services, finance, and insurance services. Additionally, Abeokuta serves as a hub for agricultural trade and for the export of a variety of cash and food crops. Abeokuta's population is expanding quickly, primarily as a result of natural factors, immigration, and rural-to-urban movement.

The national Ogun-Osun River Basin Development Authority has its headquarters in Abeokuta, and it runs initiatives to help Lagos, Ogun, Osun, and Oyo states make the most of their water and land resources for rural development. There are projects for irrigation, food processing, and electrification. Both a sizable contemporary cement factory at Ewekoro and the Aro granite quarry, which supply construction supplies for a large portion southern Nigeria, are close to the town (https://www.britannica.com/place/Abeokuta).

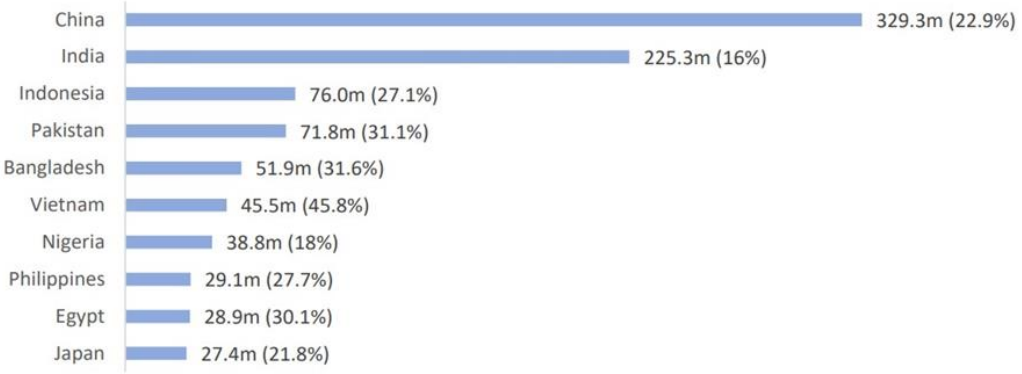
Lekki is a city in Lagos and Lagos continues to be the financial and commercial center of Nigeria as well as the wider West African area. This city was recorded by the NPCN to have a population of 401,584 and projected to be about 604,500 in 2022 with a 2.5% annual population rise and a population density of 557.17/km² (https://nationalpopulation.gov.ng/). The settlement in this city is very clustered towards the western part as most part of this city is swampy and unhabitable. In addition to producing almost 50% of the non-oil industry, it contributes a considerable 26.7% of the country's GDP. The majority of these funds originate from taxes, levies, dues, and rates collected on everyday business transactions in Lagos Island's Central Business District. The largest seaport in Nigeria as well as one of the largest in West Africa is located in Lekki (https://www.britannica.com/place/Lekki).

The Lekki Free Trade Zone, where this seaport is situated, is a region that is being transformed into a brand-new, contemporary metropolis with the integration of industries, trade, and business, as well as real estate development, warehousing and logistics, tourism, and entertainment (https://www.premiumtimesng.com/). Once operations begin, this seaport will serve as a crucial engine for the development of the Nigerian economy. Lekki is also home to a number of tourist attractions, including the LUFASI Nature Park, the Lekki Conservation Center, and numerous more beach resorts.

These cities have experienced their fair share of floods, many of which have claimed lives and destroyed property. The negative effects are felt in economics, infrastructure, health, and agriculture of these cities. Some studies which include, Echendu (2021); Komolafe at al. (2015) and Aderogba, (2012), have been conducted to determine the causes of flooding, and various reasons have been identified, including dumping of waste over time has resulted in the filling of lakes and clogging of other natural drainage channels or ditches; high impact rainfall combined with a slight slope for water accumulation; dam failure accompanied with almost pavement surface; quick increase of unforeseen settlement resulting in poor drainage network, and so on.

In addition, Rentschler and Salhab (2020) sited that Nigeria is amongst the top ten countries with the highest number of people exposed to significant flood risk, Figure 3.

Figure 3. Top 10 countries: Number of people exposed to significant flood risk.



Source: World Bank Group.

The increase in frequency of this occurrence and its severity over the past few years which is as a result of climate change, emphasizes the importance and justifies the conducting of this research in order to come up with a suitable solution, preventive, and mitigation strategy for this threat, especially when it concerns people's safety and the prevention of environmental disasters. This will act as a starting point for an early warning system to prevent insufficient risk analysis in relation to city planning.

Figure 4. Impact of Flooding in 2017 and 2022 in Lekki, Nigeria.

Source: punchng.com and nairaland.com

Figure 5. Impact of Flooding in 2018 and 2021 in Abeokuta South, Nigeria.

Source: independent.ng

Despite the exposure and constant occurrence of floods, there has been very little study in examining the areas at risk of flooding in these areas at risk of flooding in these areas failed to take into consideration important factors such as the physical characteristics of the environment (Adelekan, 2007; Obiefune, 2021) or distance from water course (Oyedepo et al., 2021). In this sense, this research intend to bridge some of these gaps and develop a mechanism for zoning areas at risk of flooding. Which will encourage the two cities capability in resisting, absorbing, and quickly recovering from the effects of flooding and, in an organized way, and in this way aid in the preservation of assets and lives.

2 OBJECTIVE

The Main/General objective of the study is to develop a methodology in assessing the flood risk in these two cities, to contribute to the study of the physical environment conditions that cause floods, with the goal of reducing technical, social, and economic threats.

Specific Objectives: To attain the general objective, two study areas were selected. Each city located in different states in Nigeria so that the following specific objective could be achieved.

- Development of susceptibility maps that depict the urban environment based on environmental criteria.
- Assessment of the environmental characteristics and anthropogenic activities around the flood points.
- Risk assessment based on the linkage of environmental and anthropogenic criterion maps with the flood density map in question.
- Provide suggestions for mitigation measures to better preparedness for flooding events.

3 LITERATURE REVIEW

At this stage of the literature review, regional and global publications in the field were examined in order to gather relevant information for the study. The literature review also looks at geomorphological mapping and subdivision methodologies for Flood risk assessment, as well as referencing agents/conditions, characteristics, and behaviors responsible for flooding processes.

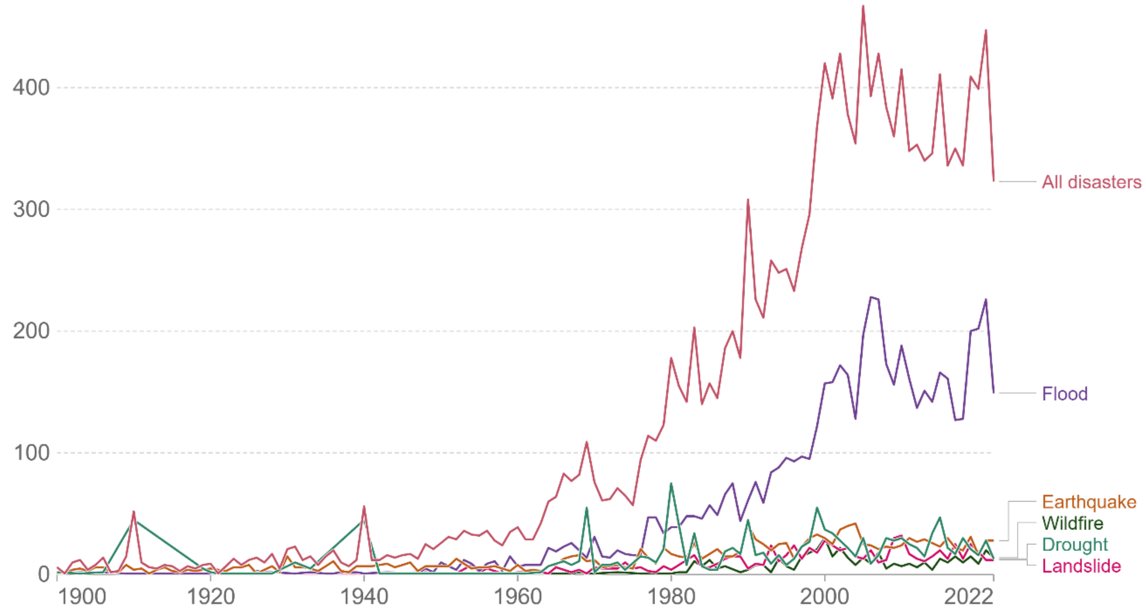
3.1 Climate Change and Floods

Climate change according to the United Nations (UN) is the long-term shifts in the weather patterns and temperature. These shifts could be as a result of the changes in the sun's activity or volcanic eruptions. It is important to establish that natural disasters are direct results of nature and are inevitable. However, since the 1800s, the primary cause of climate change has been human activity which sped up the rate of climate change and has consequently led to the increase in various natural disasters such as severe fires, water scarcity, acute droughts, increasing sea levels, flooding, melting polar ice, catastrophic storms, and a loss of biodiversity.

Disaster as defined by the United Nations Office for Disaster Risk Reduction (UNDRR), is a major disturbance in the operation of a community or society at any size caused by hazardous occurrences interacting with conditions of vulnerability, susceptibility, and capacity, resulting in one or more of the following losses and impacts: human, material, economic, and environmental. The level of risk is dependent on some environmental factors such as elevation, slope, etc. as well as anthropogenic factors such as land use, population density, etc.

Amongst these disasters, meteorological related disasters, specifically floods, are the most predominant as shown in Figure 6. This is because the increase in the earth's temperature has caused a rise in evaporation, which results in denser clouds that can contain more water. Over time, this causes higher precipitation that may eventually result in flooding. Secondly, flooding may result from increasingly frequent and powerful storms like hurricanes. Finally, coastal flooding may result from rising sea levels brought on by melted glaciers.

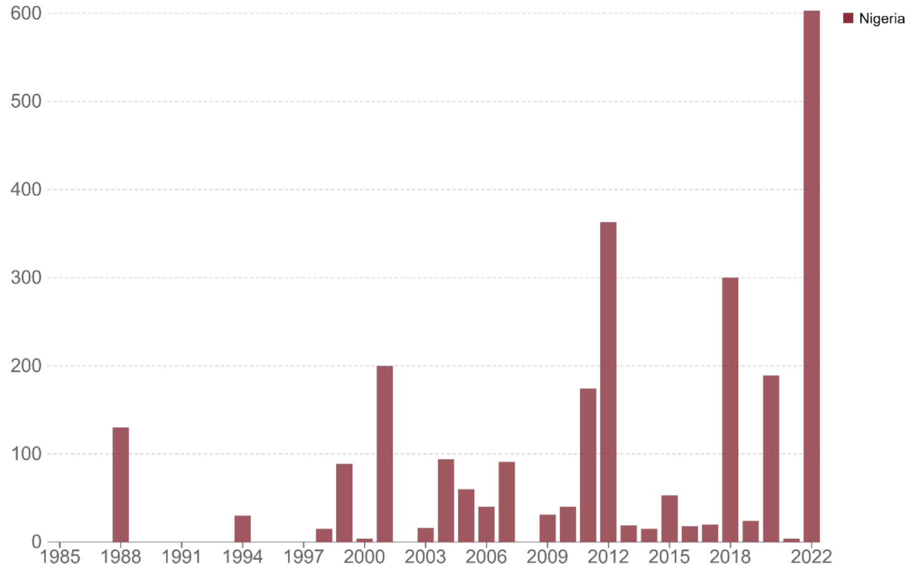
Figure 6. Meteorological Disasters over the years.



Source: EM-DAT, CRED / Université catholique de Louvain, Brussels (Belgium).

There has been an unusual rate of flood occurrences and the negative effects they cause in many developing countries. Nigeria is no stranger to this fact as several reports have recorded devastating flooding events across the country which has claimed the lives of many over the past decade as seen in Figure 7. Some of which includes the coastal cities of Lagos, Ogun, Port Harcourt, Calabar, Uyo, Warri among others (Olaniran, 1983) that claimed many lives and properties worth millions of dollars as seen in Figure 8. For instance, in 2012, extensive territories were drowned by rivers that burst their banks in 30 of the country's 36 states, killing over 300 people and uprooting 1.3 million more. According to Nigeria's National Emergency Management Agency (NEMA), that disaster caused damage worth an estimated $17 billion. Floods affected 277,555 people overall in 2019; 158 people died as a result. At the presentation of the Nigeria Hydrological Services Agency's (NHSA) 2021 annual flood prediction, Muhammadu Muhammed, the former head of NEMA, stated that 2,353,647 people were affected by floods in 2020, resulting in 69 fatalities.

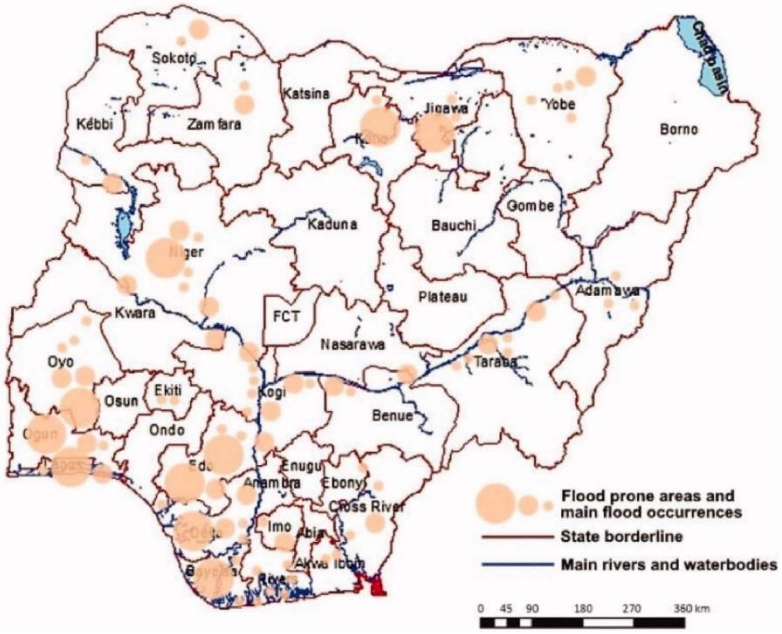
Figure 7. Deaths from Flooding in Nigeria



Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (D. Guha-Sapir).

Despite the NHSA identifying factors such as soil moisture, extreme weather conditions and topography as to being the major cause of flooding in Nigeria, several authors suggests anthropogenic factors to have contributed to the incidence of floods. Rapid urbanization, inadequate drainage and waste management, poor spatial/physical planning, and heavy rainfall that has been exacerbated by climate change were all named by Echendu A.J. (2021) as the main causes of flooding in Nigeria and Ghana.

Figure 8. Nigerian map highlighting regions at risk of floods.



Source: Cirella and Iyalomhe, 2018.

In spite of Adegboyega et al (2018) identifying land-use change due to urbanization has a trigger for flood, Komolafe at al. (2015), Aderogba, (2012) and Agbonkhese et al. (2014) went further to identify the absence of proper drainages in these urban areas as being the most common attribute which contributes to flooding. This is why several authors have established that despite the fact flooding in Nigeria is induced by heavy rainfall, numerous anthropogenic elements linked to bad governance compounds the problem. However, data suggests that by developing and implementing a proper integrated flood risk-management strategy, the floods in Nigeria may be successfully avoided or controlled (Adelekan 2016).

3.2 Terminologies and Universal Concepts Associated with Flood Risk Management.

Since it has been established that absolute protection from floods is unachievable, the paradigm of risk management has gained tremendous attention when it comes to flood research. Over the years and across borders the development and determination of flood risk assessment procedures, conceptual frameworks and conformity assessment have become essential. These notions have been the topic of several debates involving a wide range of terms. Flood risk management covers a broad range of topics and tasks, from the forecasting of flood risk through to their effects on society and the tools and methods for risk reduction (Schanze 2006). The management and assessment of flood risks requires systematization and integration due to the range of factors involved. To fully understand the various concepts relating to the assessment of flood risks we need to define some of the words associated with it.

3.2.1 Flood

Flood has been defined in variety of ways over the years as shown in Table 1. Some of these definitions include;

Table 1. Compilation of definitions of Flood.

Source	**Year**	**Definition**
Dingman	2008	Hydrologically, a flood occurs when the drainage basin experiences an unusually intense or prolonged water-input event and resulting streamflow rate exceeds the channel capacity
Ishaya et al	2009	When there is a lot of water within a wrong location
Chima et al	2010	A water flow that exceeds the channel's carrying capacity
Nkeki et al	2013	This includes incredibly high stream flow which overtops a stream's natural or man-made banks
Wizor and Week	2014	Floods are common natural disaster occurring in most parts of the world resulting in damages and loss of human life and livelihood sources, deterioration of environment and retardation to development
Berezi	2019	Floods can be defined as a large quantity of water covering dry land. It occurs when water temporarily covers an area that it usually does not due to excess rainfalls than the soil and vegetation can absorb

Source: prepared by the author.

From the definitions provided, it shows that flooding is a natural and artificial ecological hazard that has an adverse environmental and socio-economic effect.

3.2.2 *Susceptibility*

In simple terms, susceptibility is a tendency to be affected by something. For instance, susceptibility associated with slope instabilities denotes a region's tendency for the occurrence of landslides. In Table 2 are different definitions of susceptibility according to authors.

Table 2. Compilation of the definitions of Susceptibility.

Source	**Year**	**Definition**
Brabb	1984	susceptibility is the probability of an event happening in a specific zone, depending on the correlation of the instability-determining factors with the distribution of the past movements.
Zuquette	1993	Possibility that a landslide will occur in an area, based on local terrain conditions. Susceptibility does not explicitly consider the probability of occurrence that also depends on the recurrence of triggering factors, such as precipitation or earthquakes.
Zêzere	2005	As the spatial probability of occurrence of a given phenomenon in a given area, taking into account the conditioning factors existing on the ground, regardless of its recurrence period, that is, the susceptibility reflects a spatial probability, but not a temporal one
J. Hervas and P. Bobrowsky	2009	Susceptibility refers to the spatial likelihood or probability (given in either qualitative or quantitative terms) for a landslide to occur in the future.
Samuels et al.	2010	the propensity of a particular receptor to response. This describes the nature of the response caused in objective terms
Domínguez-Cuesta, M.J.	2013	In natural hazards terms, susceptibility is related to spatial aspects of the hazard. It refers to the tendency of an area to undergo the effects of a certain hazardous process (e.g., floods, earthquakes, tsunamis, subsidence, etc.) without considering either the moment of occurrence or potential victims and economic losses.
Sayer et al.	2013	describes the propensity of a particular receptor to experience harm during a given flood event which includes material destruction
Nsagou et al	2021	susceptibility to flooding can be further defined as the sensibility or ease with which each area of the basin is flooded

Source: prepared by the author.

3.2.3 Vulnerability

the term "vulnerability" according to Sarewitz et al. (2003) refers to these components' innate qualities that determine their potential for harm. It can be conceptualized as a synthesis of susceptibility and value of society and manifested through both direct and indirect consequences (FLOODsite-Consortium, 2005). Some of the definitions used to define vulnerability is shown in Table 3. To fully understand what vulnerability is, we need to define some of the words associated with it. The various terms used for vulnerability were described as a function of exposure and resilience and susceptibility expressed in Table 3 and also in eq. 1 (Dilip Kumar et al., 2020).

$$Vulnerability = Exposure + Susceptibility - Resilience \tag{1}$$

Where exposure refers to the condition of people and facilities in areas that are prone to flooding or hazardous conditions. The susceptibility of a system to certain hazards is determined by the components within it. While resilience can be seen as the ability of a system to manage and recover from a flood.

Table 3. Compilation of the definitions of Vulnerability.

Source	Year	Definition
Kates	1971	defined vulnerability as a decision model to decide how people understand hazards.
United Nations	1982	Vulnerability is a level of damage to particular objects at flood risk with a specified amount and presents on a scale from 0 to 1 (no damage to full loss).
Zaman	1999	Vulnerability indicates the social and economic aspects of a person, a household, or a group in terms of their capacity to cope with and to recover from the impacts of disaster
Buckle and Smale	2000	defined vulnerability as the measure of susceptibility and resilience of the inhabitants and their corresponding environment to hazards
UNDP	2004	defined vulnerability as a state which is influenced by physical, social, economic, and environmental circumstances that raise the susceptibility of a community to the hazard.
Balica	2010	Vulnerability is defined with the relationship between exposure, susceptibility, and resilience of society in case of disaster

Source: Applied from Corteletti (2017)

3.2.4 ***Hazard***

According to the Oxford English dictionary, the literal definition of hazard means ‘chance’ or ‘probability’ but when taken as a noun it means ‘something that is dangerous and likely to cause damage’. In geotechnical fields there are different types of hazards and several authors have adopted different definitions of this word as seen in Table 4. So, flood hazard can be defined has the probability or likelihood that potentially harmful flood event will occur (ITC 2004).

Table 4. Compilation of the definitions of Hazard.

Source	Year	Definition
Varnes et al.	1984	The probability of a potentially harmful process occurring in a given area and in a given period of time.
Zuquette	1993	Hazardous event: represents a (latent) hazard that is associated with a phenomenon of natural or man-made origin, which manifests itself in a specific place, at certain times, producing adverse effects on people, property, and/or the environment.
Fell	1994	Refers to the potential for landslides to occur that cause damage to an area; such damage could include loss of life or injury, damage to property, social and economic disruption, or degradation of the environment.
Einstein	1997	It works with the uncertainty of a hazard, with its limited predictability. It is the probability that a particular hazard will occur in a given period of time.
Rodriguez Carvalho	1998	Natural hazard: the probability of occurrence, in a given period of time and in a given area, of a potentially harmful phenomenon (taken from the United Nations Disaster Relief Office - UNDRO, 1992).
(ESG) Environmental, social and corporate governance	2007	A condition with the potential to cause an undesirable consequence. In describing a landslide, the hazard should include the location, volume (or area), classification and speed of landslides, and the probability of their occurrence over a given period of time.

Source: Applied from Corteletti (2017).

3.2.5 ***Risk***

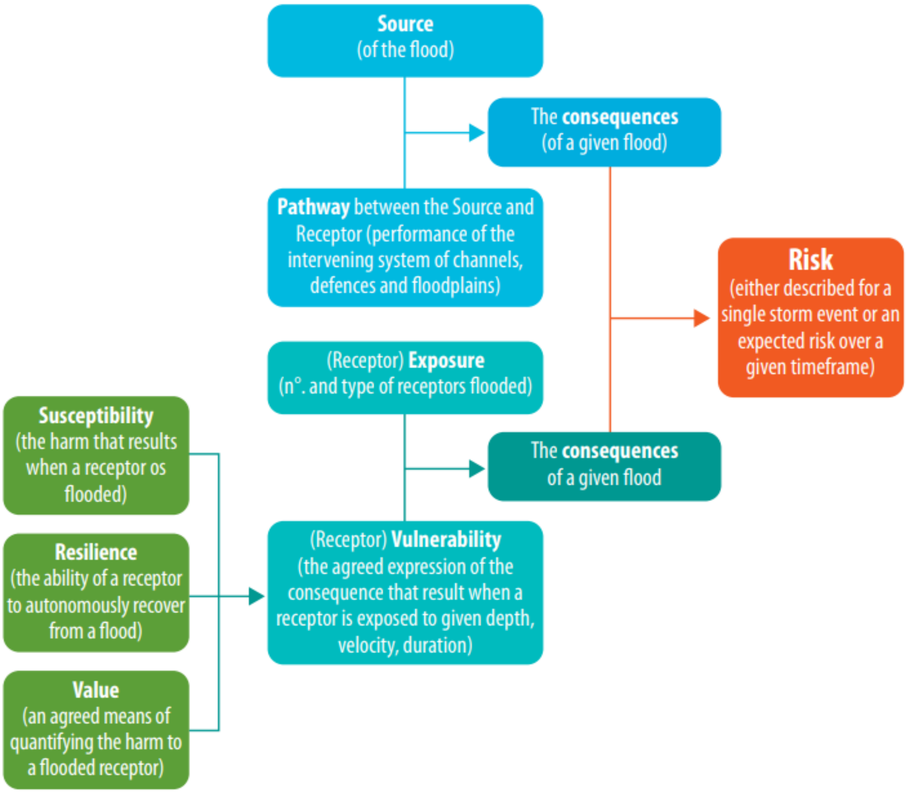
Generally speaking, the phrase "risk" refers to a mix of probability/hazard and vulnerability as shown in eq 2 with several definitions used by different authors are displayed in Table 5. These basic components of risk are elaborated and shown in Figure 9.

Table 5. Compilation of the definitions of Risk.

Source	**Year**	**Definitions**
Varnes	1984	The expected number of lives lost, people injured, property damage and disruption of economic activity, due to a particular phenomenon for a given area and reference period.
Zuquette	1993	It is the probability that losses (economic, social and environmental) will occur, in addition to a value being considered normal or acceptable for a specific place, during a determined period of time. It is considered the result of the relationship between a hazard and vulnerability of the exposed elements (human beings, residences, among others).
(ABGE) Brazilian Association of Geology and Engineering	1995	Process, situation or event in the geological environment of natural origin, induced or mixed, that can generate economic or social damage to communities, whose prediction, prevention or correction will employ geological criteria.
(AGS) Australian Geomechanics Society	2007	A measure of the likelihood and severity of an adverse health and environmental effect. Risk is often estimated by the product of probability and consequences. However, a more general way of interpreting risk implies a comparison of probability and consequences in a non-product way.
(UNDRR) United Nations Office for Disaster Risk Reduction	2017	The potential loss of life, affected or destroyed or damaged property that can occur in a system, society or community in a specific period, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.
Kumar and Kumar	2020	probability of occurrence of hazard

Source: Applied from Corteletti (2017).

Figure 9. The Components of Risk.



Source: Flood Risk Management: A Strategic Approach. Paris, UNESCO (2013).

Finally, the different terms related to susceptibility, vulnerability and risk according to Michael-Leiba (2002), Vojtek and Vojtekova, (2019), UNCHS-HABITAT (1981) and hazard and disaster according to UNDRR (United Nations Office for Disaster Risk Reduction) are:

- Susceptibility 'is seen as the predispositions of an area which is determined by its physical characteristics (excluding rainfall) that defines its propensity/tendency to flooding.'
- Vulnerability which is 'the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.'
- Risk is 'a potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period, determined probabilistically as a function of hazard, exposure, vulnerability and capacity'.
- Hazard is 'a potentially damaging physical event, phenomenon that may cause loss of life or injury, property damage, social and economic disruption or environmental degradation.'

- Disaster is ‘a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources’.

Therefore, flood risk is simple a function of the vulnerability/susceptibility of the environment and the hazard which could be given as;

$$Risk = Hazard + Vulnerability \tag{2}$$

3.3 Flood Risk Assessment

Understanding risk helps comparing different options and prioritizing actions. The effort put into analyzing the measures taken can be designed to be proportionate in scope with the risk that must be faced via the assessment of risk and uncertainty. As a result, the risk assessment gives the decision-maker a proper knowledge of the link between the suggested actions and the resulting risk reductions, rewards, and possibilities sacrificed (UNESCO 2013).

Flood Risk Assessment is a methodical procedure that seeks to determine the causes and gravity of a site's flood threats (Tarlengco, 2023). Risk Mapping, Planning and Assessment improves a community’s ability to make educated decisions about lowering risk by providing more accurate flood mapping products, risk assessment tools, planning and outreach support, and more. Before making any big decisions, a systematic method of flood risk assessment is required.

3.3.1 *Flood Risk Assessment Methods*

There are many different methods for assessing flood risk and vulnerability, including indicator-based methods, curve methods, disaster loss data approaches, and modelling approaches.

- Most Flood risk analysis are conducted based on an indicator selection (Kumar et al, 2020). This technique performs quantitative risk assessment by choosing, quantifying, and weighing the right indicators into a composite index (Zhen et al, 2022). The indicator technique entails actions like choosing indicators, weighing them, and aggregating them into a final index. The most delicate stage of index construction is indicator weighting since indicator weights can significantly affect the outcomes of the index and, consequently, how decisions are made (Becker et al., 2017; Papathoma-Köhle et al., 2019b).

- The curve method is used in the susceptibility/vulnerability curve approach to assess how closely a disaster's intensity and a person's level of impact are related. This strategy is largely based on data from thoroughly documented case studies, which are often limited to residences in a certain area. A sample of things from each chosen class are chosen by this series of methods, and a list of potential subjects is organized (Nasiri et al 2016). The accuracy of the evaluation results must be increased, even though this method may be able to reflect the actual sensitivity of catastrophe bodies and the impact of social protective measures.
- The disaster loss data approach is a straightforward strategy but a little inaccurate due to unevenly recorded data, therefore results should be taken with caution. This method is built on data collecting from actual flood hazards and their usage as a pointer to future disasters.
- Utilizing the frequency, size, and form of the hydrograph, computer models may assess the depth, altitude, and pace of a flood. One-dimensional (1D) or two-dimensional (2D) models that are based on solutions of the exact or approximative forms of surface water equations are frequently used to calculate flood inundation. For accuracy, these techniques rely on comprehensive information about topography, hydrographic, and economic data in the studied region.

In the era of advanced technology, the combination of data from these approaches and other datasets with information gleaned from geographic information systems (GIS) and remote sensing (RS) offers enormous potential for the detection, monitoring, and evaluation of flood disasters. GIS, a very flexible tool, particularly for spatial analysis, simulation, visualization, processing of data, and management and satellite remote sensing techniques which provide ongoing and current measurements with worldwide coverage based on their orbital features, has provided an enormous potential for flood disaster identification, monitoring, and assessment (Wang and Xie, 2018). Over the years GIS and remote sensing techniques have gained so much attention both globally and in Nigeria, becoming useful tools for assessing and estimating flood risk. These studies also conducted flood risk in various regions concerning social, physical, economic, environmental, and coastal contexts. These assessments were focused on identifying areas of vulnerability and developing strategies to minimize the loss of life due to floods.

External data combined with High resolution images, Shuttle Radar Topography Mission (SRTM) and digital elevation models (DEM) are analyzed on a GIS software (ArcGIS/QGIS) to develop flood prone areas (Karamat et al., 2016, Berezi et al., 2019, Amangabara et al., 2015, Eguaroje et al., 2015, Ogarekpe et al., 2020). Where the DEM can be reclassified into high risk, moderate risk and low risk zones using equal interval of separation based on elevation (Lillesand, et al., 2004; Forkuo, 2008; Forkuo, 2010).

3.3.2 *Geospatial Techniques and GIS*

For decades, assessments have been done using various ways to determine areas with flood threat, with GIS tools making important contributions to flood modeling and the calculation of flood effect areas. This is due to how successfully GIS integrates geographically referenced data into various environments for problem-solving (Tehrany et al., 2014). Several authors globally and in Nigeria have applied the use of Geo-processing techniques in assessing areas susceptible, vulnerable and at risk of flooding (Isiaka et al., 2023; Nkeki et al., 2022; Msabi and Makonyo. 2021; Das, 2020; Tiryaki and Karaca, 2018). To pinpoint flood-prone locations, the term "flood susceptibility" is frequently employed. The likelihood that a region would flood is known as its flood susceptibility and is often defined by its geo-litho-morphological and climatic factors (Del Vecchio et al., 2020).

Flood Susceptibility Mapping (FSM) and natural hazard assessment utilizing remote sensing (RS) and Geographical Information System (GIS) methods has been used in making substantial contributions to hazard assessment. This is because the prevention and mitigation of floods can be made possible by flood susceptibility mapping. An example of the value of FSM comes from a case study in the Dodoma region of Tanzania, where Msabi and Makonyo (2021) used 7 influencing factors to map out areas susceptible to floods as well as validate the results achieved.

There is little consensus on the precise factors that should be used in flood susceptibility assessments. However, a number of scholars frequently employ similar factors, indicating their significance in flood mapping (Tehrany et al. 2014). For example, when trying to determine possible flood susceptible areas, Tiryaki and Karaca (2018), Omid et al (2016) and Fernandez and Lutz (2010) employed the multicriteria decision analysis. Despite the fact that different number of factors were used, similar factors such as slope, elevation and proximity to river were present across these three studies. The factors were then weighed and used to develop a reliable flood susceptibility map.

Zeleňáková, et al. (2018) and Berezi et al. (2019), study was a simpler approach to the multi-criteria method. Where every layer of data extracted from the topographical map, soil map, satellite image and meteorological data were classified/ranked and integrated into a GIS environment and subjected to a multi-criteria analysis using the weighted linear combination approach which allowed vulnerable areas of flooding to be mapped. Nazeer and

Bork (2019) approached the flood vulnerability assessment of North-West Khyber Pakhtunkhwa, Pakistan by constructing the flood vulnerability indices through not just one but different methodological approaches of data rescaling, weighting, and aggregation schemes, along with a fairly simple approach for robustness. Not that using a single method to develop a flood vulnerability indices was not a good approach, but the authors kept in mind the interdisciplinary nature of flood risk and decision makers prioritize the areas that have the greatest potential for flooding and actions to reduce it. The methodology used in this study was proven to be useful in other parts of the world to assess flood or social vulnerability using composite indicators.

The evaluation of flood vulnerability by (Romanescu et al. 2018) in a mountain plateau transition zone Marginea village in Romania also adopted the use of the multi-criteria methodology based on a series of indicators. And with this the authors were able to assess the population of people vulnerable in this area, the economic vulnerability, and the social impact it could have. Sanyal and Lu (2005) also applied GIS and remote sensing techniques in assessing how vulnerable the settlement of Gangetic West Bengal, India to flood. Though the study was cost effective and efficient, it was not all that conclusive due to some limitations which ranges from unavailability of high-resolution terrain maps to partial cloud over the area and predominance of tree canopies. These limitations affected the accuracy of classified results. Even with those constraints, it is very unlikely that any potential flood-vulnerable settlement was be left unidentified.

El Morjani (2011) used multicriteria analysis for nations in Central Europe and Africa. A composite flood hazard index is used in the methodology, which is based on six causal elements (land use, elevation, soil, lithology, flow accumulation, and precipitation). Furthermore, flood data from 1985 to 2009 were categorized alongside each cause factors. The standardized and weighted scores of each causal factor along with the categorized historical flood map were then utilized to present the map of flood hazard intensity and spatial distribution.

Highlighting this to be the first of its kind, S. Das (2020) utilizes a wide variety of environmental flood conditioning parameters from many sources to produce the flood risk map of the whole Western Ghat coastal belt of India. Factors such as; land use, soil texture, topographic roughness index, geology, elevation, slope, proximity to drainage, density of drainage, flow accumulation, topographic wetness index, and precipitation were used to produce a flood susceptibility map. Socio-economic parameters (road density, population density, literacy rate, and population density of the literate) were used to create a vulnerability map. both maps were then used to produce a flood risk map. The employment of this technique was necessary due to the fact that an area being highly susceptible to flooding does not necessarily entail a high risk of flooding. Instead, the risk level is influenced by the likelihood of flooding and vulnerability.

In order to identify locations that were at risk of flooding during the 2012 flood, Nkeki et al. 2013 used the geospatial technique to analyze flood risk in the Niger-Benue basin. Wahab and Ojolowo 2018 discovered that more than 60% of the 1,025 structures evaluated in Lagos city breached the building rules in flood-prone areas using GPSs and a method of stratified sampling. When Komolafe et al. 2020 used GIS techniques to describe flood-prone areas close to the Ogun River basin in Nigeria, they concluded that combining multi-criteria analysis mapping with the Height Above Nearest Drainage (HAND) terrain model produced better results than the two models used separately. Due to its proximity to the Ogun River, the vulnerability map shows that a portion of Lagos state is particularly vulnerable to floods.

Despite the fact that geo-spatial techniques are commonly used in flood modeling, Komolafe et al. (2020) and Echendu (2021) point out its drawbacks. For instance, optical remote sensing cannot be used when there is a flood because of the cloud cover. The use of GIS may be more challenging than in the dry season due to seasonal fluctuations that include cloud cover throughout the rainy season and possible inadequacy of images in time and location.

For this study the methodology document for the WHO e-atlas of disaster risk, authored by Dr Zine El Abidine El Morjani (2011) is used in defining the terminology used for this research. The methodology used in this document integrates the geographic distribution of the key factors with the extent of previous flood occurrences. These key factors used in this document are similar to the ones that would be adopted for this research. This document provides users with a procedure that would enable them to produce the final risk distributions maps in order to enable any other region or nation to apply the models independently.

4 MATERIALS AND METHOD

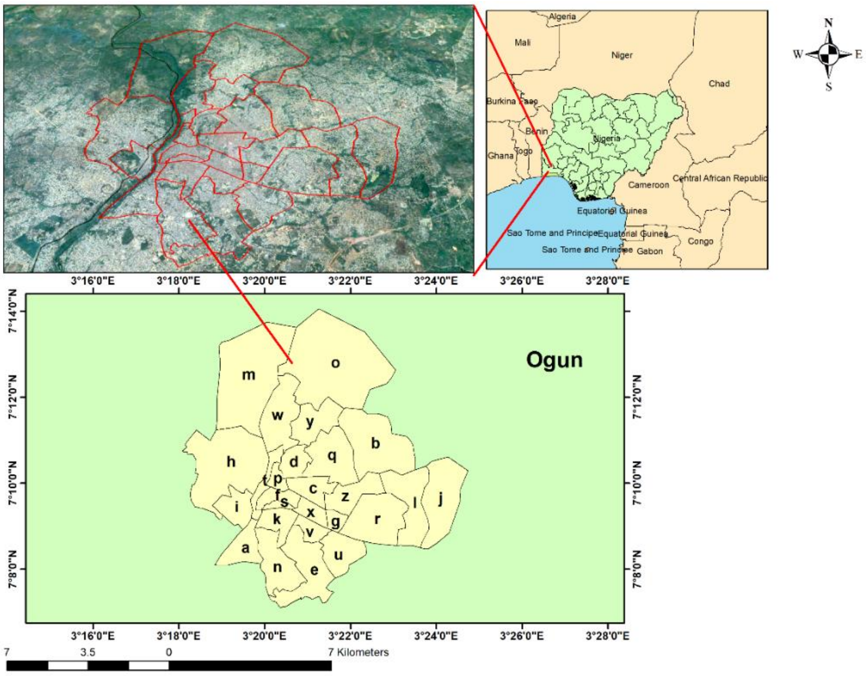
In order to further develop the risk mapping of flooding events in the two investigated cities, this chapter gives a description of the study area as well as discusses the methods utilized in database preparation, Anthropogenic and Environmental criteria that are being taken into consideration in this work and data collection.

4.1 Study Areas

For this research, two cities in Nigeria were studied. One of which is within Ogun state's capital, Abeokuta south which is located in southwest Nigeria. This city falls on the geographical coordinate of latitude 7˚9’39” N and longitude 3˚20’54” E as shown in Figure 10. It is on the Ogun river's east bank, among a collection of rock formations in a forested savanna. The elevation of Abeokuta South is 71.72 meters above sea level. A tropical wet and dry or savanna climate is also present in this city (Classification: Aw). The average annual temperature is 29.53°C and around 142.49 millimeters of precipitation and 225.62 wet days (61.81% of the time) are typical yearly totals for Abeokuta.

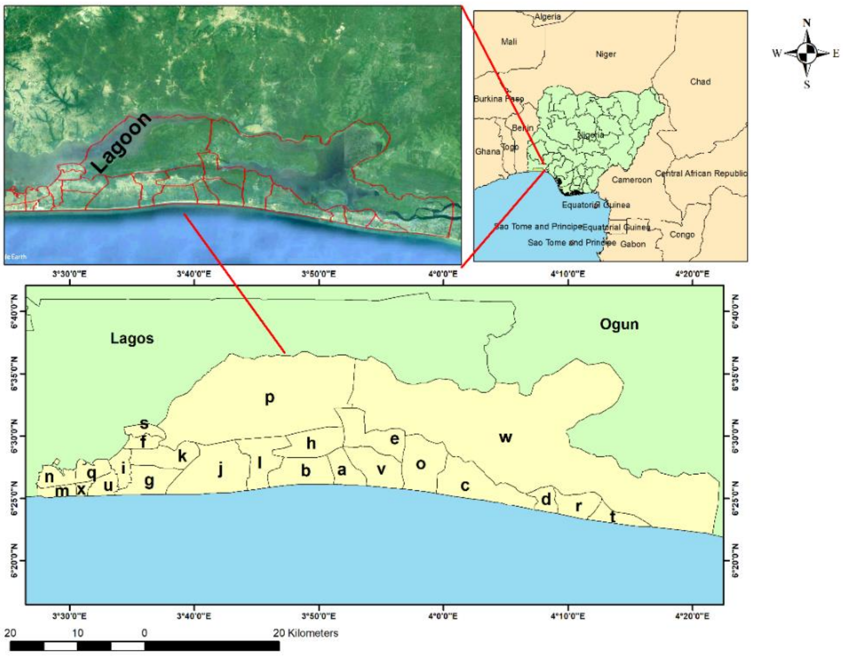
The other city being studied in this research is Lekki city which is located in south-east of Lagos state. A state which is located at the southwestern region of Nigeria. This city falls on the geographical coordinate of latitude 6˚29’36” N and longitude 3˚43’14” E. Lekki is a naturally created peninsula that borders the Lagos districts of Victoria Island and Ikoyi to the west, the Atlantic Ocean to the south, Lagos Lagoon towards the north, and Lekki Lagoon to the east, as shown in Figure 11. The city of Lekki is situated at a height of 0 meters above sea level, according to tcktcktck.org. Its climate is tropically wet and dry or savanna (Classification: Aw). The average annual temperature is the same as Abeokuta south. Lekki experiences 198.96 wet days (54.51% of the time) and receives an average of 135.64 millimeters of precipitation yearly.

Figure 10. Abeokuta City with wards.



Where **a**: Totoro 4; **b**: Ake 2; **c**: Ake 1; **d**: Iberekodo 1; **e**: Ibara 1; **f**: Totoro 1; **g**: Kuto/Imo/Isabo; **h**: Sabo 2; **i**; Sabo 1; **j**: Ijaiye; **k**: Iporo/Sodeke/Sale-Ijeun I; **l**: Kemta; **m**: Itoko; **n**: Ibara 2; **o**: Emere; **p**: Iberekodo 2; **q**: Ijemo; **r**: Ijeun Titun/Ago-Egun/Ijesa; **s**: Totoro 3; **t**: Totoro 2; **u**: Oke Ijeun; **v**: Igbore/Ago Oba; **w**: Iberekodo 5; **x**: Iberekodo 3; **y**: Iberekodo 4; **z**; Ake 3

Figure 11. Lekki City with wards.

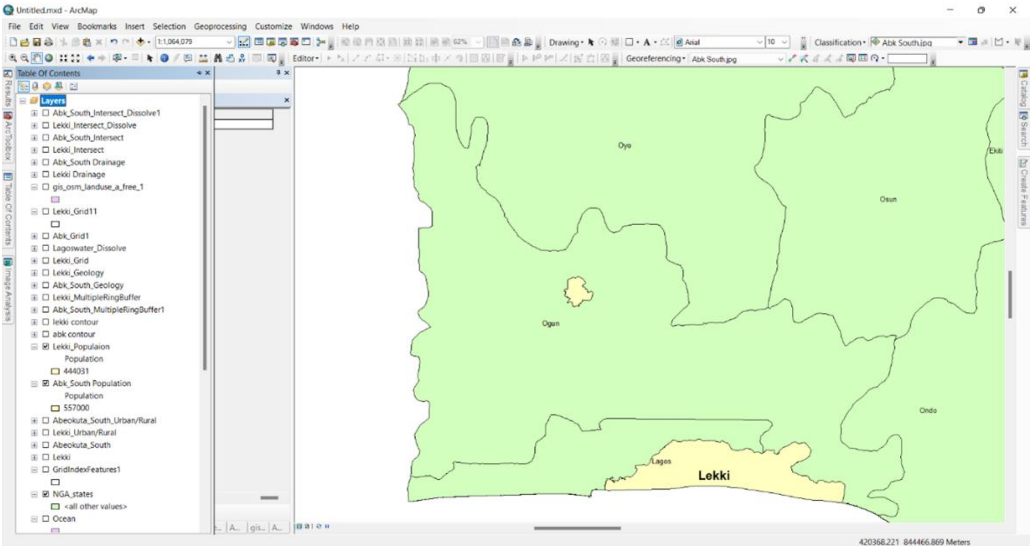


Where **a**: Orimedu 2; **b**: Orimedu 3; **c**: Lekki 1; **d**: Siriwon/Igbekodo 1; **e**: Ibeju 1; **f**: Addo/Okeira; **g**: Okun Ajah/Okunmopo; **h**: Ibeju 2; **i**; Ajah; **j**: Iwerekun 1; **k**: Sangotedo; **l**: Iwerekun 2; **m**: Ilasan/Orile; **n**: Ikate/Lekki; **o**: Lekki 2; **p**: Mayunre-Oriba/Orepete-Ito Omu; **q**: Ajiran/Osapa; **r**: Siriwon/ Igbekodo 2; **s**: Badore/Langbasa; **t**: Ise/Igbogun; **u**: Igbo-Efon/Maiyegun; **v**: Orimedu 1; **w**: Olugbokere/Abomiti; **x**: Maroko/Okun Alfa

4.2 Database Preparation

Some of the data analysis for this study includes the examination of flooding occurrence covering the period from 2001 to 2020. The coordinates of these occurrences were collated in a spreadsheet. The frequency of these flooding occurrences could not be included in this examination as there were no reliable sources for this information. The ArcGIS program as seen in Figure 12 was used to cross-analysis data that was presented as tables and maps. Data in worksheet format was imported in csv format, and the visualization in the application was carried out in a layer with the coordinates represented by points together with the map of the cities. Imported map data came in line, polygon, or raster formats.

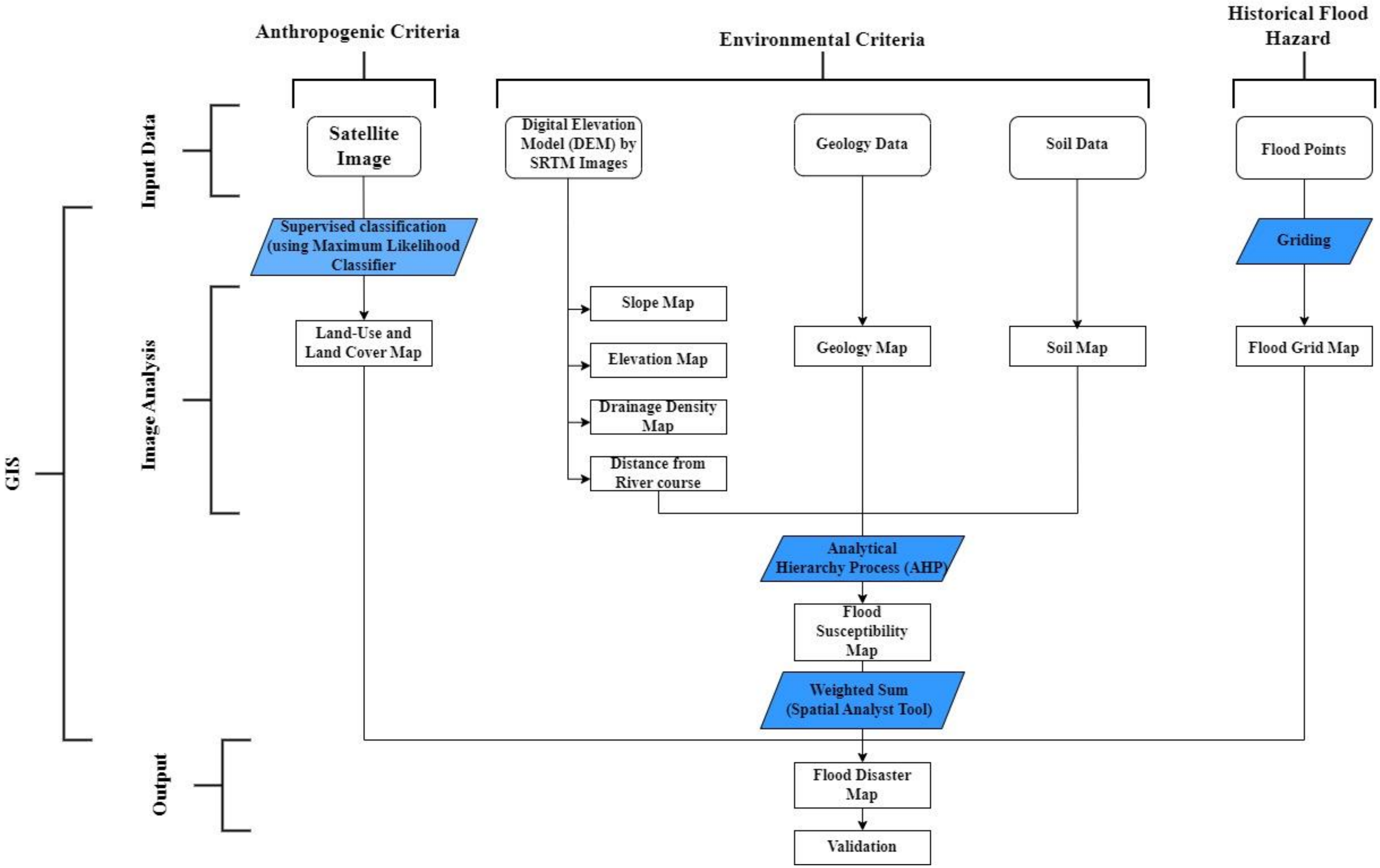
Figure 12. ArcGIS 10.4 Program.



4.3 Choice of Criteria

Various factors affect the probability and effect flood has on an environment. Eight factors were selected from the three major criteria as seen in Figure 13. The first criteria are the environmental criteria which will provide the level of susceptibility because the level of susceptibility of an area is determined by the physical characteristics present in that area. The physical characteristics selected for this study includes slope, elevation, distance from river, drainage density, soil type and geology. The second criterion is the anthropogenic criteria. The factor under this category selected for this study is the land-use and land cover. The third criterion is the historical flood hazard which is the location of flooding events that has occurred within both study areas.

Figure 13. Methodology



4.3.1 Environmental criteria

As earlier stated, the level of susceptibility of an area is determined by its physical characteristics. This means everywhere and anywhere on earth is susceptible to flooding or other natural hazards, but the physical and environmental characteristics makes the level of susceptibility of some areas different from other areas. Below are the environmental criteria selected to determine the level of susceptibility across both study areas.

- **Slope and Geomorphology**: Slope has a strong relationship with groundwater infiltration, surface runoff volume and velocity, and both. In sloped locations where runoff flows further down, low slopy areas flood more quickly. Lowland locations are particularly vulnerable to flooding because water flows from higher to lower elevations. The area's digital elevation model (DEM) was used to create the slope map.
- **Distance from the watercourse**: Greater risk of flooding during an overflow exists in areas close to rivers.
- **Drainage Density:** Since the river network has a larger flow velocity, drainage density has a considerable impact on the concentration time and, consequently, the peak flow magnitude. Therefore, rising drainage density means rising flood peaks.
- **Soil:** Water may penetrate the soil more effectively the more porous it is. The ability of the water to store water increases with the size of the pores. Flooding is decreased by the deep absorption and storage of water in healthy soils with good porosity.
- **Geology:** While impermeable rocks prevent water from passing through pores and fissures, permeable rocks do. Because there is more surface run-off when a valley is built of impermeable rocks, flooding is more likely.

4.3.2 Anthropogenic criteria

The Anthropogenic criteria are the physical, social or economic activities that affects the natural and physical environment of a community.

- **Land-Use and Land Cover**: Since humans have significantly altered the natural environment, runoff, infiltration, and groundwater recharge are affected by the nature of land cover, potentially having a significant impact on floods. Where the installation of hard, impermeable surfaces in urban areas has limited the ability of land to absorb rainfall. As a result, less water seeps into the ground, increasing the amount and pace of surface run-off. While forests have a crucial role in regulating floods, collecting rainwater (overland runoff), and stabilizing hydrological processes.

4.3.3 *Historical Flood Hazard.*

- **Flood Points:** This includes the areas which have previously experienced flooding events over the last 2 decades. Given that no measure has been taken to mitigate this disaster, areas with previous occurrence of flooding are at more risk than areas that have no previous experience.

4.4 Area Characterization and Data Collection

Images such as the Digital elevation model (DEM) and the Land Satellite data gotten from the United States Geological Survey (USGS) Earth Explorer website has a spatial resolution of 30 meters which can be converted to a scale of 1:60,000. Soil and geology map used was acquired at a scale of 1:100,000.

4.4.1 *Environmental criteria*

- **Slope and Geomorphology**: In Southwestern Nigeria, both Lekki and Abeokuta are part of the vast Dahomey Basin. But Lekki is described to be above the Ilaro Formation, it is underlain by sand, sandy clay, and lignite, with vegetation freshwater layers of primarily Recent-Quaternary alluvium (Malomo and Oloruniwo, 1983; Onwuka, 1990). While Jones and Hockey in 1964 classified the Abeokuta Formation as grits, loose sand, sandstone, kaolinitic clay, and shale. It was also regarded as having a base aggregate or a base ferruginous sandstone in most cases.
  The relief units on the terrain of these study areas will be represented by the Digital Elevation Model (DEM). These elements of the physical environment would be obtained from the United States Geological Survey (USGS) Earth Explorer website, the Shuttle Radar Topographic Mission (SRTM) will be used to generate the elevation/topographic data as well as the slope map.
- **Hydrology:** The drainage basin, slope and the Digital Elevation Model of both Lekki and Abeokuta was generated from the Shuttle Radar Topographic Mission (SRTM) data which would be sourced from the United States Geological Survey (USGS) Earth Explorer website. The drainage density for each grid will be calculated by

dividing the length of river present in each grid with the area covered by the grid. River buffers of 100,200 and 300 meters will be done to see houses that are much more vulnerable to flooding (Nsangou et al., 2021).

- **Soil and Geology:** The soil and geology data for the study Areas were acquired from a cartographic map (Sonneveld, 1997), scanned, imported in form of jpeg format into the ArcGIS environment and georeferenced to WGS 1984 UTM Zone 31 with reference to the shapefile of the study areas to ensure spatial referencing compatibility with these other datasets in a GIS context. The Geologic and Soil characteristics were then digitized and exported in form of vector data to be used for further analysis.

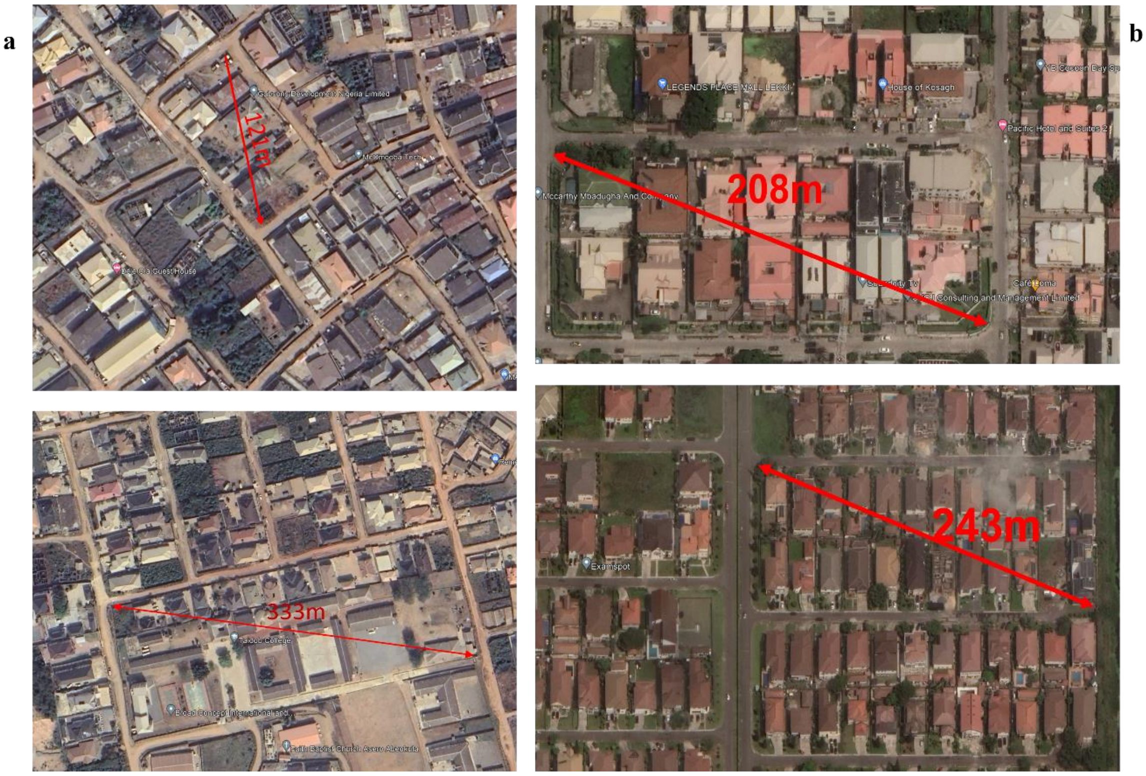
4.4.2 *Anthropogenic criteria*

- **Land-use and Land cover:** The Land use and Land cover data was obtained by downloading the operational land imager/thermal infrared sensor (OLI/TIRS) datasets for 2022 of the study areas from the United States Geological Survey (USGS) archives. Four primary land use land cover classes was generated through the supervised classification by utilizing the maximum likelihood technique in ArcGIS software: (1) built up area, (2) vegetation, (3) Barren land and (4) waterbodies.
- Data such as the Population Density and other socio-economic characteristics of each ward in the city were not included as part of the anthropogenic criteria as it was impossible to acquire. Hence the only anthropogenic criteria used was land-use and land cover. The risk from the compiled database was examined using the following factors.

4.4.3 *Historical Flood Hazard.*

- **Flood Points**: For the flood points, the data was acquired manually from several reliable news sources which reported flooding occurrences within the study areas. The entire worksheet containing data on flood points was categorized by location according to latitude and longitude. In order to analyze the locations that had some records throughout the period of the flooding event, a grid of 250m was drawn on the map. To determine the size of the grid used, a careful examination of the perimeter of each street was taken into consideration. It was discovered that the area between each street ranges between 120m and 330m as shown in Figure 14.

Figure 14. Area per block in (a) Abeokuta South and (b) Lekki.



4.5 Risk Mapping for Floods

For both the management and protection of major flood occurrences, it is critical to map and identify risk areas. That is why GIS has been established and is frequently used to investigate spatial and temporal patterns of flood events with the primary goal of identifying relationships between geographical elements that cause floods (Ramlal and Baban, 2003; Romanescu and Stoleriu, 2014).

In flood risk assessment management studies, many authors have used multicriteria analysis (MCA) (Scolobig et al., 2008; Boroushaki and Malczewski, 2008; Meyer, 2009; etc.) and that is why this study is using the Analytical Hierarchy Process (AHP)-embedded ranking algorithms for the vulnerability/susceptibility variables. AHP is a multi-criteria decision-making process that offers a systematic method for evaluating and integrating the effects of different factors. It involves numerous layers of dependent or independent, qualitative as well as quantitative information.

In determining the spatial probability of flood risk of these cities, the environmental, anthropogenic, and historical flood points are factors identified which can affect flood occurrence based on a thorough literature review. Basin slope, elevation, distance from water course, drainage density, soil type and geology as criteria under the Environmental factor. Land use and land cover was selected as criteria under the anthropogenic factors and the location of past flood occurrences as the criteria under historical flood hazard. Each of these criterions under each factor were ranked according to each risk level.

4.5.1 *Ranking each factor*

The first step was to take each of the factors considered and rank them according to their susceptibility level. In this ranking approach, the factors were examined in order to determine the impact of each factor on flood susceptibility. After careful bibliographic review, the basin slope, elevation, distance from water course, drainage density, soil type, geology and land-use were classified as low, medium, high, and very high susceptibility. All susceptibility levels were given numbers of 1, 2, 3 or 4 which, respectively, range from extremely low to very high risk as shown in Table 6. In addition, the choice of this ranking is also adopted from a methodology document for the World Health Organizaion (WHO) on disaster risk which was authored by El Morjani (2011). The methodology can also be applied in other geographical locations, hence the adoption. Maps, each showing the respective rank given to each physical characteristic is then produced. Once the choice of ranking each factor was established, the next step was to determine how to assign what range of environmental characteristics falls within each rank.

Table 6. Susceptibility level and its importance.

Susceptibility Level	**Importance of factors class**
Low Susceptibility	1
Medium Susceptibility	2
High Susceptibility	3
Very High Susceptibility	4

4.5.2 *Choice of ranges assigned to each rank.*

In order to determine what range of environmental characteristics is suitable to each rank, the first thing was to take note of the difference in lowest and the highest value between each environmental characteristics of both study areas. The next step was to cross-reference the points of flood occurrences with each environmental characteristics with the exception of soil and geology. To achieve this, the value of each environmental characteristic was extracted onto each flood points.

A thorough assessment of the slope values present within each point of flood occurrence of both areas was carried out and it was observed that the range in the slope present in the flood points for Abeokuta South and Lekki were similar and within 0 to 12%. Hence a similar range difference was used for both study areas.

A similar approach of assessment was used for the elevation. Unlike slope, there was a huge difference in the lowest and highest value of elevation between the two cities. The lowest and highest point in Lekki is respectively -13 m and 31 m above sea level while for Abeokuta is 14 m and over 200 m above sea level. Also, the elevation of flood points differ greatly between both cities. Hence, different intervals was applied to both cities. Therefore, 50 m interval was applied for the city of Abeokuta while a 7 m interval was used for Lekki.

The same approach was applied for the drainage density and distance from the water course. The range in values of both environmental characteristics within the flood points of both cities were similar therefore the same range was used for both cities.

The classification in characteristics of the soil type used by Spaargaren (2007) which describes the texture of the soil of both studies was used in ranking each soil type. The same was used for the geology.

4.5.3 *Definition of weighable criteria to generate a risk map.*

The next step is to use the Saaty AHP scale as seen in Table 7 to assess the significance of a few chosen causal factors. Therefore, defining the choice problem is the first step. The development of the comparison matrix with the Saaty scale are used in the second stage to evaluate the components' relative importance. It also enables the principal components of these factors to be used to calculate the weighting coefficient. Depending on the significance of each element, a number between 1 and 9 was assigned to it. 1 indicates that the two variables under comparison are equally important. But if the number is 9, it signifies that the component in the row is significantly more significant than the factor in the column. In order to make this comparison between each factor, personal opinion as well as extensive literature was carried out (Tudunwada and Abbas, 2022; Patrikaki et al., 2018). The table used for this comparison shown in Table 8. The final stage is the normalization of the principal component values once the matrix has been created (Equation 3, 4 and 5). Each factor results in the application of a weight that establishes its significance in relation to the others. As a result, Table 9 lists the values attributed to the anthropogenic and environmental criteria as well as the weights assigned to them.

Table 7. Saaty AHP Scale

AHP Scale of importance for comparison pair (aij)	**Numerical Rating**	**Reciprocal (decimal)**
Extremely Important	9	1/9 (0.111)
Very strong to extreme	8	1/8 (0.125)
Very strong Importance	7	1/7 (0.143)
Strongly to very strong	6	1/6 (0.167)
Strong Importance	5	1/5 (0.200)
Moderate to strong	4	1/4 (0.250)
Moderate Importance	3	1/3 (0.333)
Equally to Moderate	2	1/2 (0.500)
Equal Importance	1	1 (1.000)

Source: Saaty T.L., 1980

$$Aw = \lambda_{max} w, \lambda_{max} \geq n \tag{3}$$

$$A = \{a_{ij}\} \tag{4}$$

$$\lambda_{max} = \frac{\sum ajwj-n}{w1} \tag{5}$$

Where: A = pairwise comparison; w = normalized weight vector; λ_{max} = the maximum principal component value of matrix A; a_{ij} = numerical comparison between the values i and j

Table 8. The matrix of pairwise comparison of causative criteria and calculation of the normalized weight of Environmental criteria.

	Slope	Geology	Relief	Soil	Distance from river	Drainage Density
Slope	1.00	4.00	1.00	2.00	2.00	1.00
Geology	0.25	1.00	0.33	0.50	0.50	0.25
Relief	1.00	3.00	1.00	2.00	1.00	1.00
Soil	0.50	2.00	0.50	1.00	1.00	1.00
Distance from river	0.50	2.00	1.00	1.00	1.00	1.00
Drainage density	1.00	4.00	1.00	1.00	1.00	1.00
Weights	**0.24**	**0.06**	**0.21**	**0.14**	**0.15**	**0.20**

Table 9. Groups of Risk factors with their respective weights.

Groups	Criteria	Weights
Environmental Criteria	Slope	0.24
	Geology	0.06
	Geomorphology/Relief	0.21
	Soil	0.14
	Distance from river	0.15
	Drainage Density	0.20
Anthropogenic Criteria	Land-Use and Land Cover	1
Historical Flood Hazard	No of Flooding Events	1

4.5.4 *Susceptibility mapping*

The susceptibility map based on the environmental criteria was achieved in accordance with the information in Equation 6 using the corresponding weights. Maps of each factor under the environmental criteria was created in the GIS environment. All the factors in vector format were then converted into raster format with 30 × 30 m. Using the reclassify tool in the Arc toolbox, each map was then reclassified based on the rank each physical/environmental characteristics fall under. These reclassified maps were then subject to a weighted overlay under the spatial analyst tool in the Arc toolbox with each map assigned its weight as shown in Table 9 and Equation 6 to create a flood susceptibility map.

$$C_{env} = 0.24 * slp + 0.21 * elv + 0.15 * dfr + 0.22 * dd + 0.14 * soi + 0.06 * geo \tag{6}$$

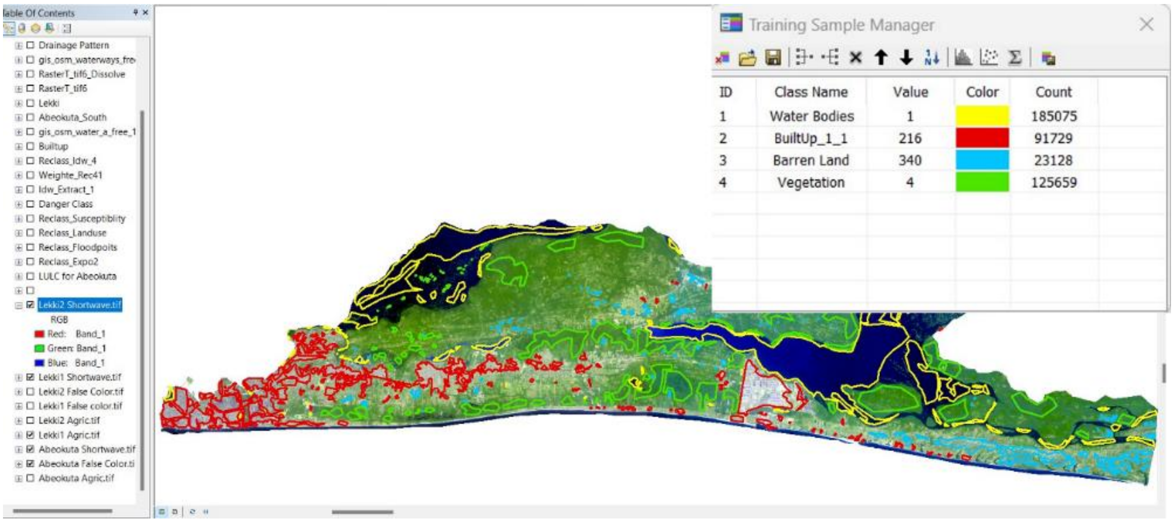
Where:

C_{env} = Environmental criteria; slp = Slope; elv = Elevation; dfr = Distance from river; dd = Drainage density; soi is Soil; geo = Geology.

4.5.5 ***Land-Use and Land cover mapping***

After achieving the Susceptibility map, the next step was to produce the land-use and land cover map. In order to classify the land-use and land cover pattern of the study areas, the Maximum Likelihood Classifier (MLC)-based supervised classification approach was used to classify the satellite images obtained. This approach is one of the most popular classification methods in remote sensing, and it assigns the correct class to the pixel with the greatest probability of being classified. The purpose of classification of images is to recognize and represent the elements present in the image in terms of the thing or type of land cover these elements really represent on the surface of the earth. Bands 5, 4, and 3 from Landsat 8 OLI were used as input bands to produce false-color composite images. The next step was to create a signature file by choosing pixels with homogeneous surface types. To achieve this an average of 100 training samples for each land-use and land cover class were chosen from the acquired composite images as seen in Figure 15 which were later merged to produce the four LULC classifications of built-up, vegetation, water bodies, and barren land.

Figure 15. Training sample selection and categorization of Lekki.



ID	Class Name	Value	Color	Count
1	Water Bodies	1	🟨	185075
2	BuiltUp_1_1	216	🟥	91729
3	Barren Land	340	🟦	23128
4	Vegetation	4	🟩	125659

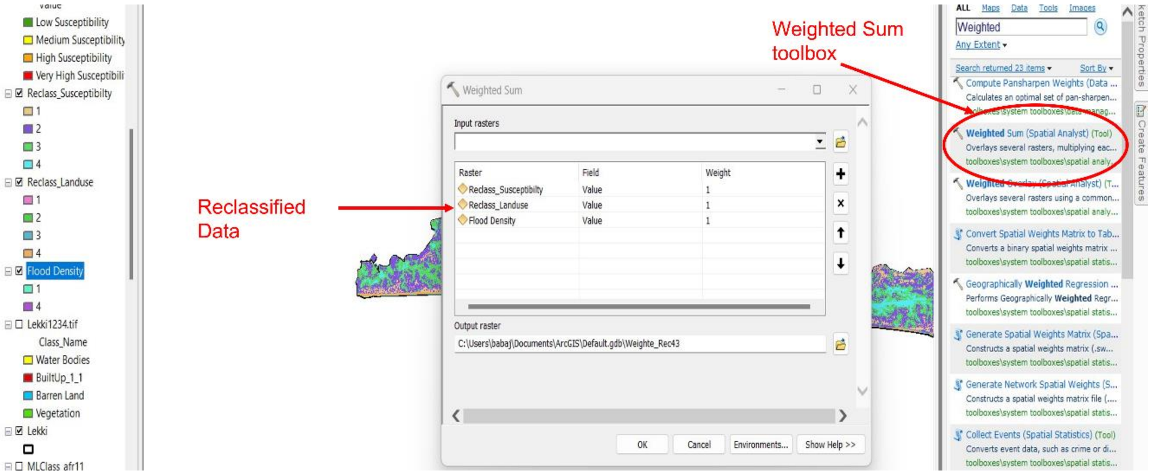
4.5.6 ***Flood Grid mapping***

The next step after achieving the land-use and land cover map is to create a flood grid map. To achieve this a 250m² grid is over lain on each study area. The number of points per grid are extracted unto each grid in order to create a flood grid map.

4.5.7 ***Flood Risk mapping***

Once the susceptibility map, land-use and land cover map has been produced, the next stage is to use these maps to produce a flood risk map. To achieve this, the reclassification toolbox is used to reclassify the susceptibility map where areas with low, medium, high and very high are classified into 1, 2, 3 and 4 respectively. The land-use and landcover map are also reclassified where vegetation, barren land, built-up and waterbodies are classified into 1, 2, 3 and 4 respectively. The reclassified maps are then combined with the flood density map using the weighted sum tool in the ArcGIS software to produce the flood risk map as shown in Figure 16. The following formula used to determine the resulting risk and produce disaster risk map is shown in Equation 7.

Figure 16. Weighted Sum Analysis



Weighted Sum toolbox

Reclassified Data

Weighted Sum

Input rasters

Raster	Field	Weight
Reclass_Susceptibilty	Value	1
Reclass_Landuse	Value	1
Flood Density	Value	1

Output raster

C:\Users\babaj\Documents\ArcGIS\Default.gdb\Weighte_Rec43

$$D = (C_{env} + C_{ant} + HFH) \tag{7}$$

Where C_{env} =Environmental criteria; C_{ant} =Anthropogenic criteria; HFH = Historical Flood Hazard.

5 RESULTS AND DISCUSSION

The criteria chosen for mapping the study areas' flood susceptibility interfere to different degrees and independently. Each factor is then separated into classes according to the level of effect of each class, and ratings are given to each class.

5.1 Slope map

The slope map of the research areas is displayed in the maps and tables. One of the key elements in floods is the slope of the land surface. Surface runoff and precipitation infiltration are influenced by slopes. Due to the slow surface runoff velocity, low sloped areas flood more quickly. On the other hand, areas with high slopes have a high runoff velocity which makes flooding impossible (Nsangou et al, 2021). Supporting this theory is shown in Table 10 and Figure 17b where 18 (47%) flood occurrences were reported in both slopes between 0 to 3% and slopes between 3.1 to 7%. While 1 (2.63%) flooding event each occurred in slopes between 7.1 to 11% and slopes above 11% respectively within the last 20 years.

For the city of Abeokuta south, 41.43% of the total area has a slope with a percent rise between 0 to 3% while 44.41% of the total area has a slope percent rise between 3.1 to 7%. This implies that the majority of the city are gently undulating and the flow of water on the surface of these areas will be slow. This will results in the accumulation of water in most areas of the city after a heavy downpour of rain. In addition, 9.57% and 4.59% of the total area has a slope percent rise between 7.1 to 11% and slope rise above 11% with the former having a medium susceptibility level and the latter having a low susceptibility level because the flow of water increase as the percent rise increases as shown in Table 10 and Figure 17.

Table 10. Abeokuta South Slope Susceptibility Level and Ranking.

Slope in percent rise	**Spatial Extent (km²)**	**Spatial Extent (%)**	**No. of Flood Events**	**Rank**	**Susceptibility Level**
0 - 3%	37.67	41.43	18	4	Very High Susceptibility
3.1 - 7%	40.38	44.41	18	3	High Susceptibility
7.1 - 11%	8.70	9.57	1	2	Medium Susceptibility
Above 11%	4.18	4.59	1	1	Low Susceptibility

For the city of Lekki, areas that have a percent slope between 0 to 3% and 3.1 to 7% cover about 53.78% and 34.68 % of Lekki with having about 12 and 15 flooding events occurring within this slope category respectively as shown in Table 11. While areas with the percent slope of 7.1 to 11% and areas above 11% cover a total of 8.58% and 2.96%, having recorded only 4 and 1 flooding event in each category respectively over the last 20 years. Despite the entire city of Lekki having a gently undulating surface, the low sloped areas have recorded more flooding occurrences over the years as shown in Figure 18.

Table 11. Lekki Slope Susceptibility Level and Ranking.

Slope in percent rise	**Spatial Extent (km²)**	**Spatial Extent (%)**	**No. of Flood Events**	**Rank**	**Susceptibility Level**
0 - 3%	778.96	53.78	12	4	Very High Susceptibility
3.1 - 7%	502.35	34.68	15	3	High Susceptibility
7.1 - 11%	124.35	8.58	4	2	Medium Susceptibility
Above 11%	42.84	2.96	1	1	Low Susceptibility

Despite the difference in the range between the slope of both cities, they share similar characteristics when it comes to the frequency of flood occurrence within these slope range. It is evident that areas with a low slope percentage have experienced more occurrences in flood within the last two decades than areas with high slope percentage.

For the figures used to represent the slope, warmer colors were used in Figure 17a and Figure 18a to indicate the higher altitudes. But for flooding, the greatest level of susceptibility lies at the low altitudes, so in Figure 17b and Figure 18b, warm colors (red) was used to indicate areas with very high level of susceptibility. Hence allow the color gradient for both images to be reversed.

Figure 17. (a) General and (b) Reclassified Slope Map of Abeokuta South.

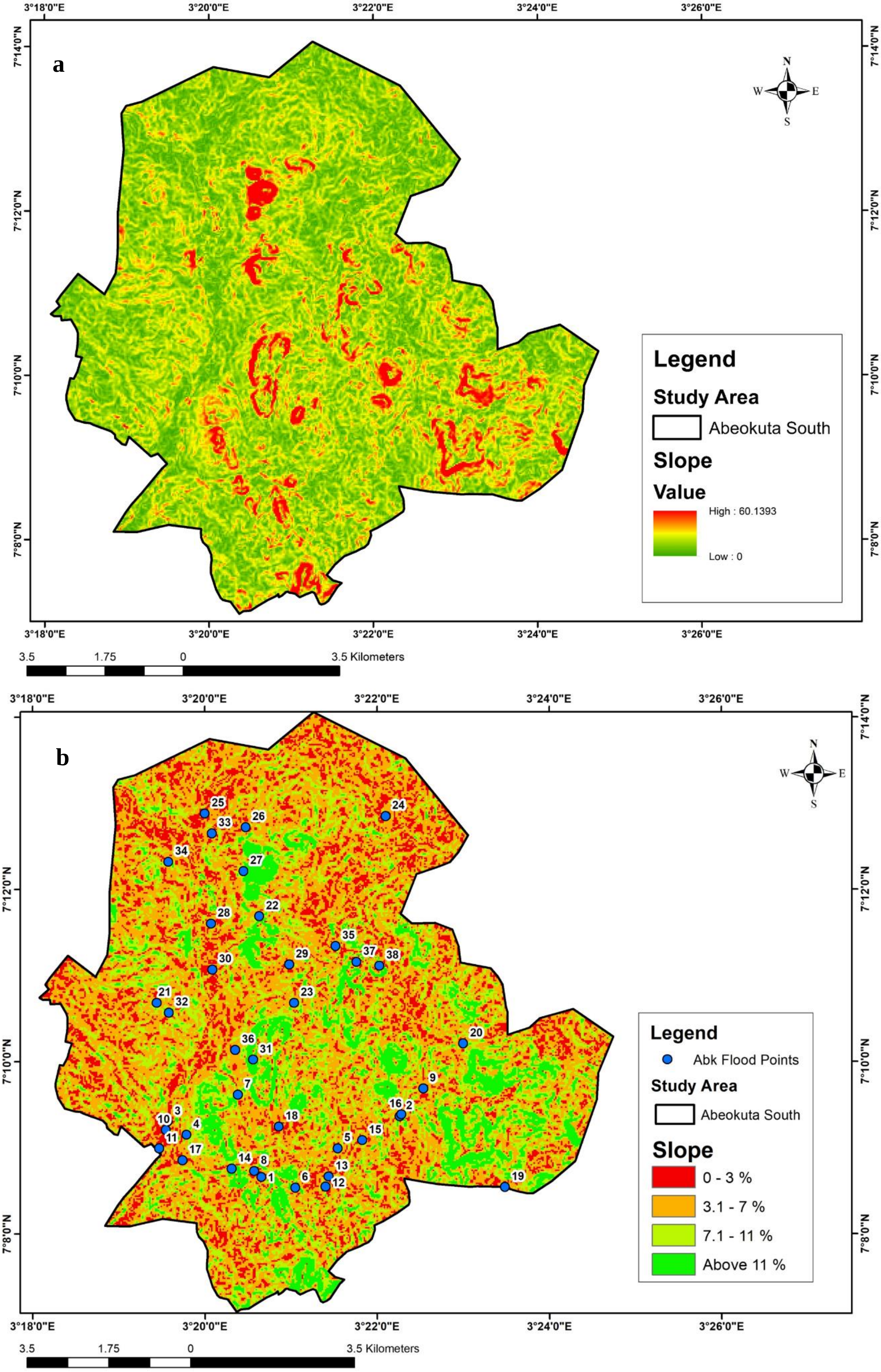
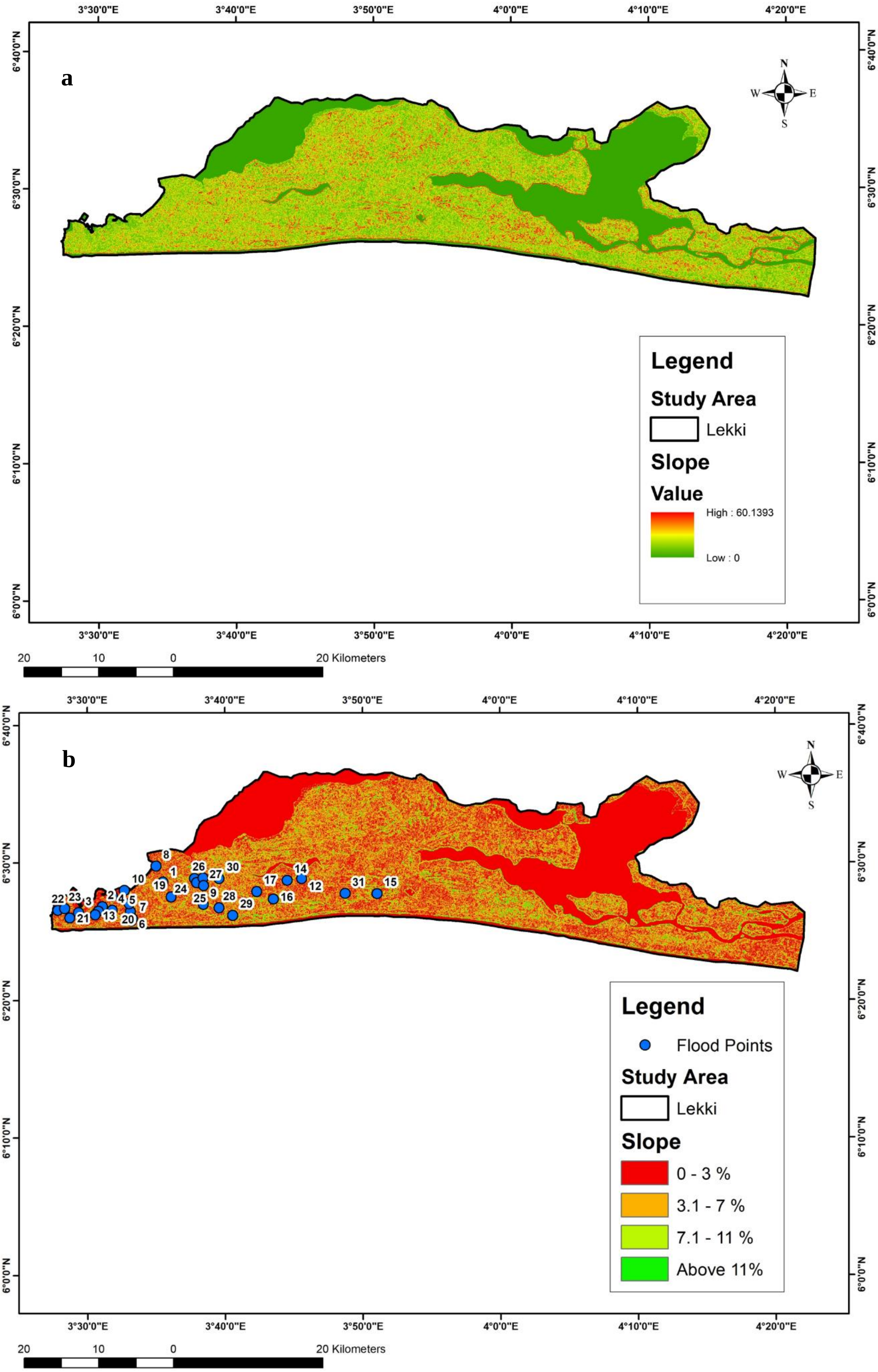


Figure 18. (a) General and (b) Reclassified Slope Map of Lekki.



5.2 Elevation map

The flood susceptibility level based on elevation is shown in Table 12 and Table 13, Figure 19a and b and Figure 20a and b. Elevation has a significant impact on how susceptible a region is to flood. Since low-lying places are where the many rivers join, the lower it is, the more likely it is that the area will flood (Nsangou et al., 2022). With about 39.5% (15 points) of the flood events occurring in elevations between 14 to 50m above sea level. While 55.3% (21 points) of the flooding events occurred in elevations between 51-100 m above sea level and 5.3% (2 points) of the flooding events occurred in elevations between 101 to 150 m above sea level. No flooding event occurred in elevations above 150m within the last 20 years.

The elevation pattern of Abeokuta shows that majority of the eastern part are above 100m from the sea level, with the highest point being above 200m. This would be attributed to the presence of rocks within the city. Majorly because of a major river called “Ogun river” which runs from the cities Northwestern part to the Southwestern part, areas very close to the river are below 50m of the sea level. Additionally, the elevation increase as the distance from this major river increases.

For the city of Abeokuta, it shows that the very high susceptible zone based on elevation was between 14 to 50 m above sea level which covers about 17.34% of the total area. The medium and high susceptible zones are between 51 to 100 m and 101 to 150 m above sea level, and they cover about 52. 98% and 25. 77% of the total area respectively. The very high susceptible zones were areas above 150 m and they only over 3.91 % of the total area.

Table 12. Abeokuta South Elevation Susceptibility Level and Ranking.

Elevation (m)	**Spatial Extent (km²)**	**Spatial Extent (%)**	**No. of Flood Events**	**Rank**	**Susceptibility Level**
14 – 50	15.78	17.34	15	4	Very High Susceptibility
51 – 100	48.19	52.98	21	3	High Susceptibility
101 – 150	23.45	25.77	2	2	Medium Susceptibility
Above 150	3.56	3.91	0	1	Low Susceptibility

For the city of Lekki, because the city is bordered by the Atlantic Ocean, and characterized with gentle undulating slopes, the elevation of entire city is between -13 to 50 m above sea level as shown in Table 13 and Figure 20a. Areas that are below 0 m are the inland waters found within this city, most especially the Lagos-Lekki lagoon. Areas below 0 m and areas between 0 to 7 m above sea level cover a total area of 27.91% and 27.64% of Lekki respectively as shown in Figure 20b, with 15 flood occurrences in the latter category. That is why no flood was recorded within these areas. Areas between 7.1 to 14 m above sea level cover 35.55% of the total area with 17 flood occurrences in the last 20 years. No flooding event occurred in areas 14 m above sea level.

Table 13. Lekki Elevation Susceptibility Level and Ranking.

Elevation (m)	Spatial Extent (km²)	Spatial Extent (%)	No. of Flood Events	Rank	Susceptibility Level
Below 0	404.3	27.91	0	4	Very High Susceptibility
0 – 7	400.42	27.64	14	3	High Susceptibility
7.1 – 14	514.85	35.55	17	2	Medium Susceptibility
Above 14	128.90	8.90	0	1	Low Susceptibility

Figure 19. (a) General and (b) Reclassified Elevation Map of Abeokuta South.

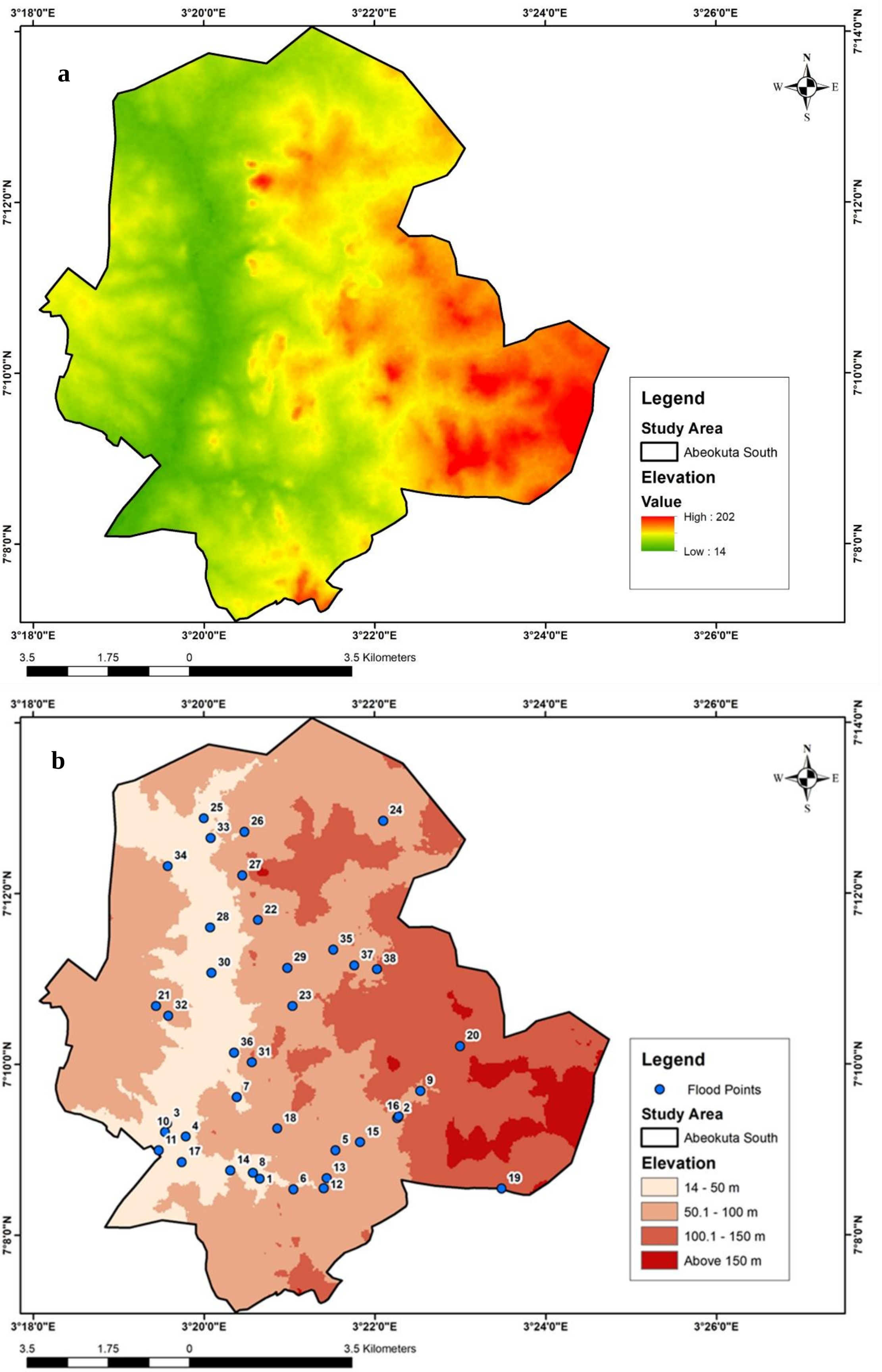
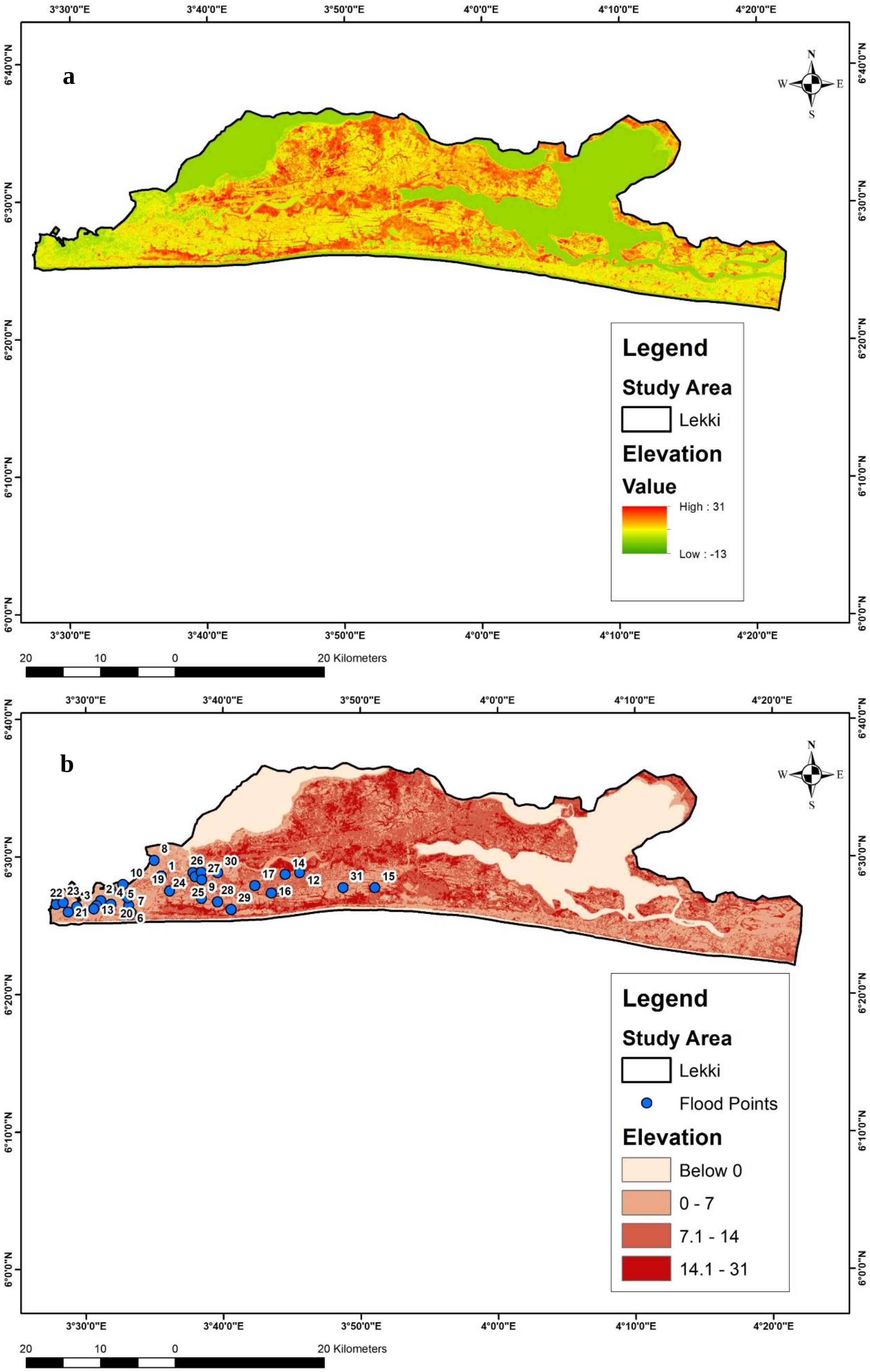


Figure 20. (a) General and (b) Reclassified Elevation Map of Lekki.



5.3 Distance from River course

Combining the existing drainage network as seen in Figure 21a with a buffer zone tool in a GIS context led to determining the distance from the drainage network layer. Because the water overtops the river channel's incline and spreads across the surrounding area, river overflows may also result in a flood event. Because places closer to the river network are more susceptible to this hazard, the risk reduces as the distance grows. Figure 21b and Table 14 shows a recorded 22 (57.9%), 19 (26.3%), 1 (2.6%) and 5 (13.2%) flooding events occurred between 0 to 100 m, 101 to 200 m, 201 to 300 m, and areas beyond 300 m distance from the drainage network respectively within the last 20 years. This finding supports the theory that proximity to a water course affects the level of susceptibility as the number of reported flooding events reduces as the distance from the water course increases with the notable exception of areas over 300 m from water course. This would be as a result of residents dumping refuse into artificial drainage networks which could disrupt the flow of water during heavy downpours. Additionally, a lot of residents are prone to constructing houses and buildings very close to these water bodies which exposes them to a lot of risk.

In the city of Abeokuta, Ogun river is the major water body found in this city. Areas within a 100 m of this river and is tributaries cover about 26.68% of the total are and were regarded as zone that have very high susceptibility to flooding while the areas above the buffer zone 300 m cover 29.12% of the total area and are classified to be areas with low susceptibility. Table 14 provides the precise classification while Figure 21 shows the spatial distribution.

Table 14. Abeokuta South Susceptibility Level and Ranking based on proximity analysis.

Distance from Drainage Network	Spatial Extent (km²)	Spatial Extent (%)	No. of Flood Events	Rank	Susceptibility Level
100 m	24.27	26.68	22	4	Very High Susceptibility
200 m	21.84	24.01	10	3	High Susceptibility
300 m	18.37	20.20	1	2	Medium Susceptibility
above 300 m	26.48	29.12	5	1	Low Susceptibility

The major water bodies present in the city of Lekki is the Lagos lagoon which covers the northwestern part and the Lekki Lagoon and its tributaries which covers most of the eastern part of the city. Figure 22b shows that in the city of Lekki, a recorded 9 (29%), 8 (25.8%), 4 (12.9%) and 10 (32.3%) flooding events occurred between 0 to 100 m, 101 to 200 m, 201 to 300 m and areas beyond 300 m distance from the drainage network respectively within the last 20 years. 18.87% of the total land cover are within the buffer zone of 100 m and are classified to have a very high susceptible level as shown in Table 15. A total of 50.75% (which is about half of the total land cover of the area) have a distance from the drainage network of more than 300 meters and are classified to have a low susceptibility as shown in Table 15 which also provides the precise classification while Figure 22 shows the spatial distribution.

Table 15. Lekki Susceptibility Level and Ranking based on proximity analysis.

Distance from Drainage Network	Spatial Extent (km²)	Spatial Extent (%)	No. of Flood Events	Rank	Susceptibility Level
100 m	273.34	18.87	9	4	Very High Susceptibility
200 m	233.95	16.15	8	3	High Susceptibility
300 m	206.13	14.23	4	2	Medium Susceptibility
above 300 m	735.14	50.75	10	1	Low Susceptibility

Unlike Abeokuta South where the spatial distribution of past flooding events correlates with the distance from river network, the same cannot be said for the city of Lekki. More flooding events have occurred in the areas beyond 300 m from a river network than other individual categories. This could be as a result of the little range in the elevation and slope of the entire city with some of these places despite being relatively far from a river network, have a low slope rise and a low elevation. In addition, some of these areas that are relatively far from these river networks do not have artificial drainage systems and some that do have, practice dumping of waste into these drainage systems which also contribute to the past occurrences of floods.

Figure 21. (a) General Drainage Network and (b) River Buffer Map of Abeokuta South.

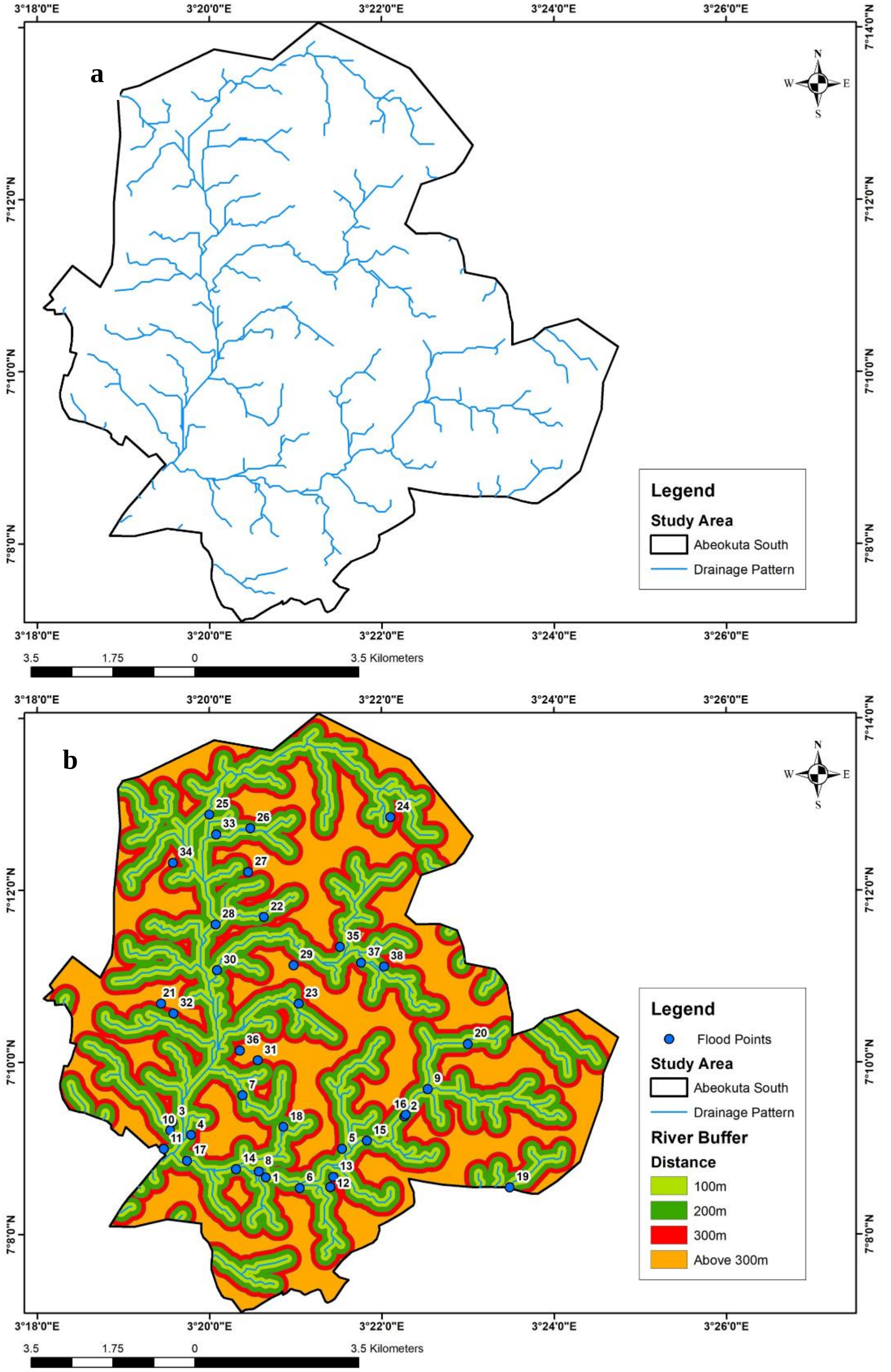
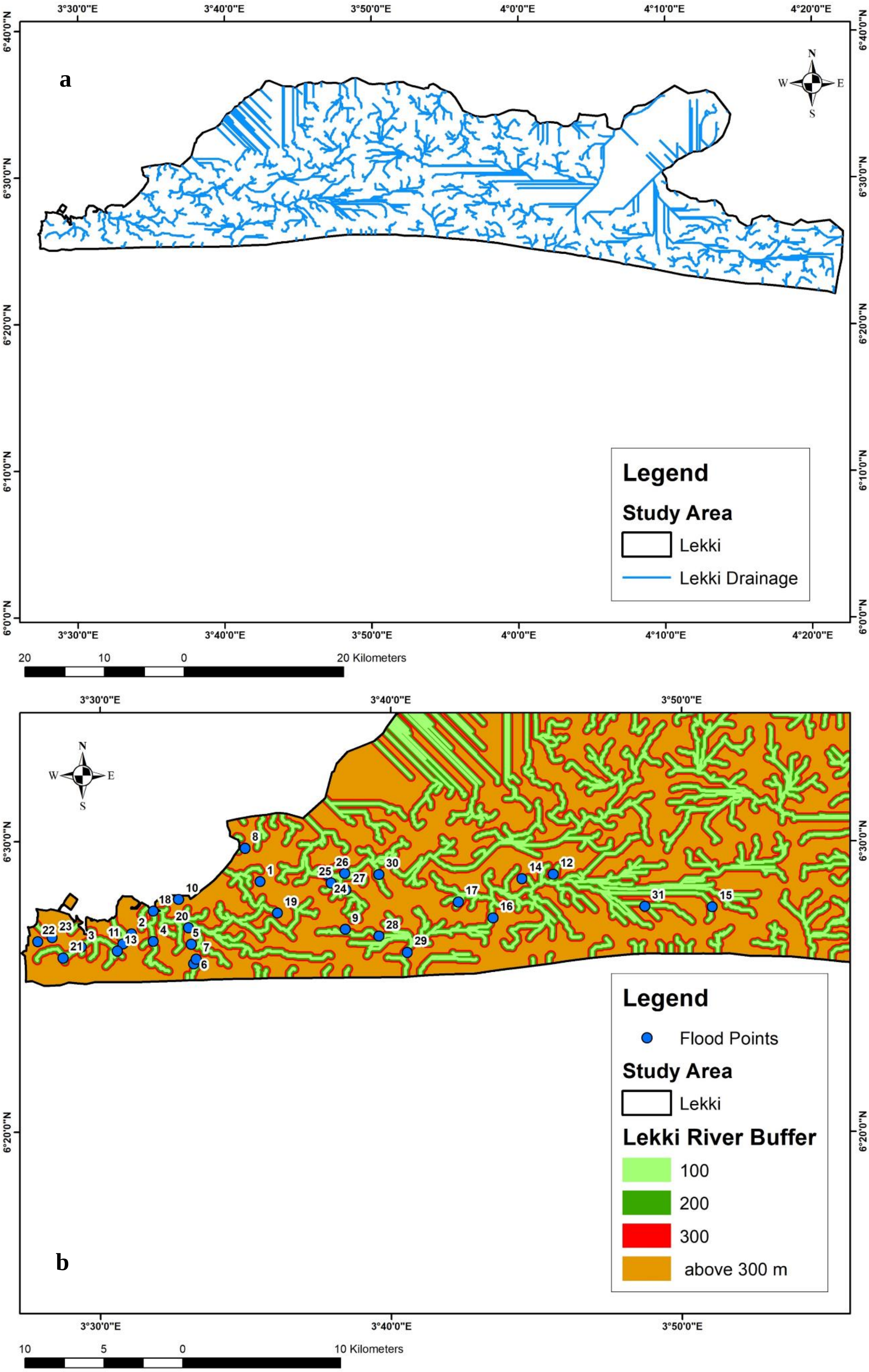


Figure 22. (a) General Drainage Network and (b) River Buffer Map of Lekki.



5.4 Drainage Density

The drainage density per km² for each grid of the study areas were calculated. This scale was selected because of the difference in size of both study areas. It was then converted into raster format of 100 x 100pixel size and ranked as illustrated in the maps and tables below. This method was adopted to track the drainage density or areas with respect to proximity to the drainage network. If there is a dense drainage network there, that location is more prone to experience flooding due to high flow buildup (Elkhrachy, 2015). This is shown in Figure 23 as no flooding event seems to have occurred between areas with the drainage density between 0 to 0.5. While 12 (31.6%), 11 (28.9%) and 15 (39.5%) flooding events occurred between areas with the drainage density of 0.51 to 1.5, 1.51 to 2.5 and areas with the drainage density above 2.5 respectively within the last 20 years.

The total area has a drainage density between 0 to 0.50 in Abeokuta covers about 19.33% of the total area, hence they are classified to be of low susceptibility. Just 13.54% of the total area of Abeokuta South has a drainage density above 2.50 which makes them prone to flooding and they are classified to be very highly susceptible as shown in Table 16 and spatially illustrated in Figure 23.

Table 16. Abeokuta South Susceptibility Level and Ranking based on Drainage Density.

Drainage Density (m/km^2)	**Spatial Extent (km^2)**	**Spatial Extent (%)**	**No of Flood Events**	**Rank**	**Susceptibility Level**
0 - 0.50	17.57	19.33	0	1	Low Susceptibility
0.51 - 1.50	32.11	35.33	12	2	Medium Susceptibility
1.51 - 2.50	28.90	31.81	11	3	High Susceptibility
above 2.50	12.30	13.54	15	4	Very High Susceptibility

For the city of Lekki, only 5 flooding events occurred in areas within 0 to 0.5 drainage density. 14 and 6 flooding events occurred in areas with drainage density between 0.51 to 1.5 and 1.51 to 2.5 respectively. While 6 flooding events occurred with areas having a drainage density above 2.5. Areas with drainage density between 0 to 0.50 are classified to have low susceptibility and cover 14.99% of the total area with only 9.69% under the classification of being very highly susceptible because of having a drainage density above 2.50 which is shown and spatially illustrated in Table 17 and Figure 24 respectively.

There is not a direct correlation between the drainage density for Lekki and the number of past flood occurrences. Since there is little difference between the elevation and slope of Lekki, local realities such as absence of artificial drainage systems and dumping of waste into some of these drainage systems would account for the past occurrences of flood within the areas with medium and high drainage density. While areas with very high drainage density have proper artificial drainage systems. Also, these areas with medium drainage density were formally waterlogged areas but were sand filled in order to construct buildings. During the rainy season, these water that were pushed away would push back and flood these areas, hence accounting for the high number of flooding occurrences in these areas.

Table 17. Lekki Susceptibility Level and Ranking based on Drainage Density.

Drainage Density (m/km²)	Spatial Extent (km²)	Spatial Extent (%)	No. of Flood Events	Rank	Susceptibility Level
0 - 0.50	217.06	14.99	5	1	Low Susceptibility
0.51 - 1.50	765.42	52.86	14	2	Medium Susceptibility
1.51 - 2.50	325.22	22.46	6	3	High Susceptibility
above 2.50	140.36	9.69	6	4	Very High Susceptibility

Figure 23. Drainage Density map of Abeokuta South.

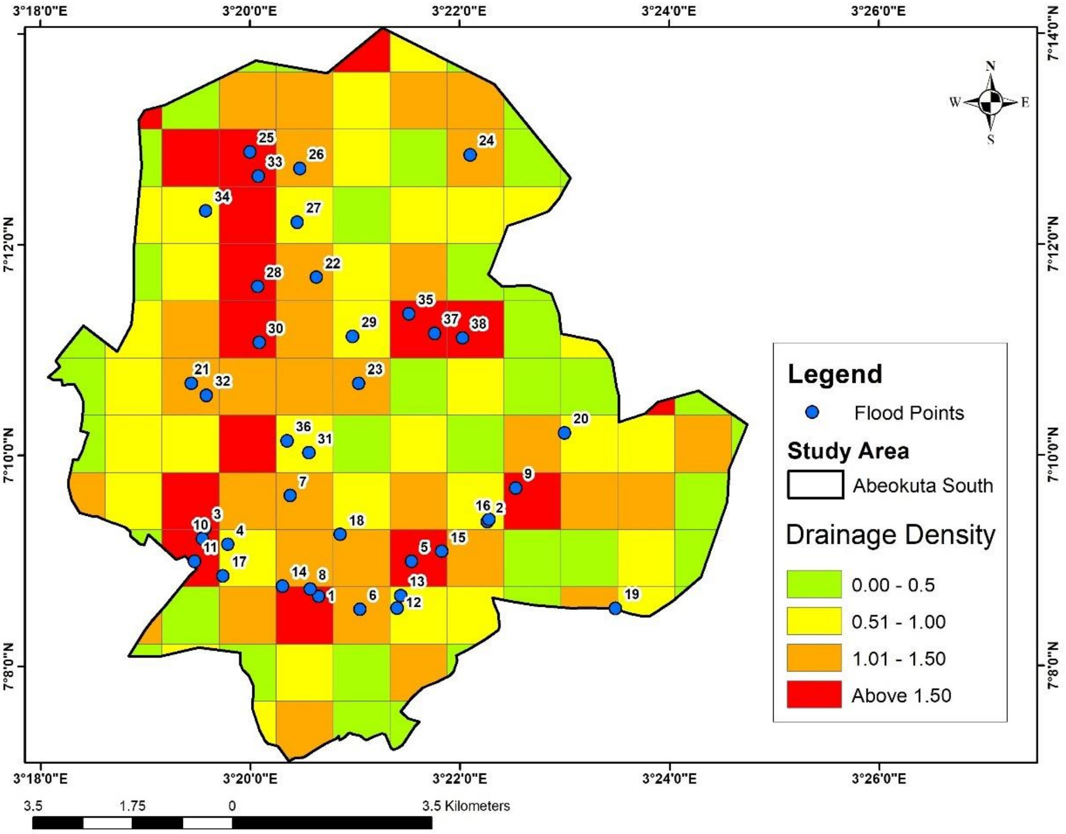
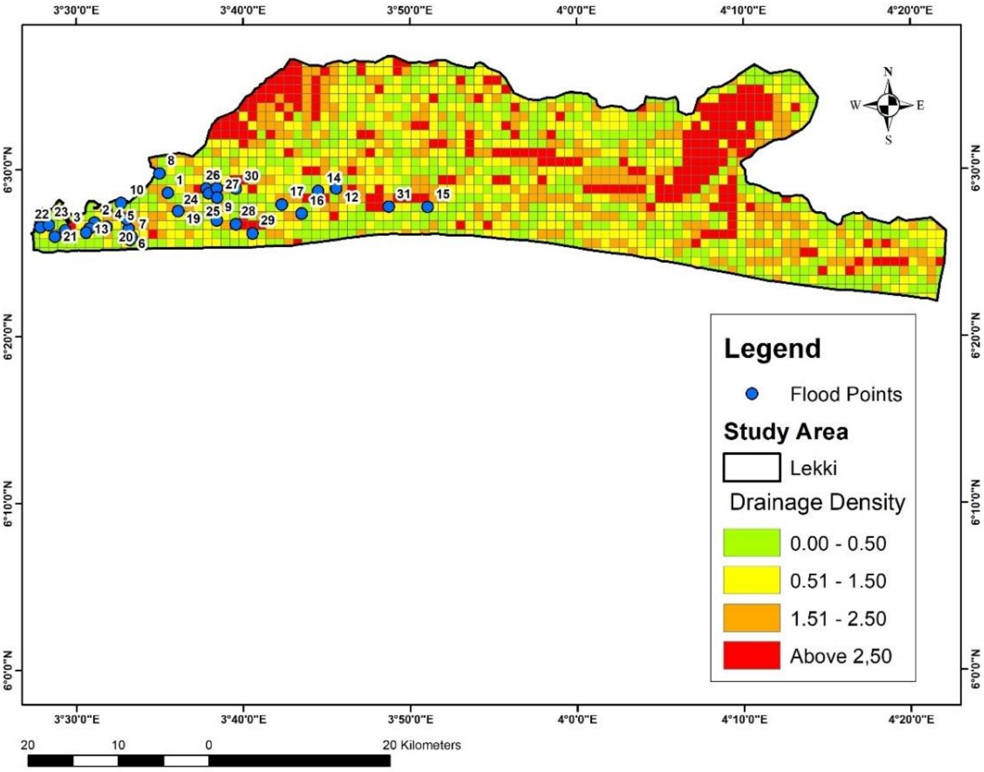


Figure 24. Drainage Density map of Lekki.



5.5 Soil map

For the city of Abeokuta South, about 99.36% of the entire area has a Ferric Lixisol soil type as shown in Figure 25a which according to the Spaargaren (2007) are strongly leached soils with weakly developed structure and are prone to erosion, hence areas within this soil type are classified to be highly susceptible to flood. Only about 0.46% and 0.18% of the total area are characterized to a Ferric Luvisol and Rhodic Nitosol soil type respectively. The Ferric Luvisol is characterized to be porous and well aerated but can be prone to topsoil erosion when on a slope, hence being ranked to be of medium susceptibility and the Rhodic Nitosol is characterized to have a good water holding capacity and is not prone to erosion, hence being ranked to be of low susceptibility as shown in Table 18 and Figure 25b.

Table 18. Abeokuta South Susceptibility Level and Ranking of Soil Type.

Soil Type	**Spatial Extent (km^2)**	**Spatial Extent (%)**	**No. of Flood events**	**Rank**	**Susceptibility Level**
Ferric Lixisols	90.37	99.36	38	3	High Susceptibility
Ferric Luvisols	0.42	0.46	0	2	Medium Susceptibility
Rhodic Nitosols	0.17	0.18	0	1	Low Susceptibility

For the city of Lekki, Eutric Fluvisols, Gleyic Arenosols and Rhodic Nitosols are the three soil types present with each covering 37.53%, 61.68% and 0.79% respectively as shown in Figure 26a and b. The Eutric Fluvisols are ranked to be very highly susceptibility because they are characterized to have a fine texture and easily erodible. The Gleyic Arenosols are ranked to be of medium susceptibility because characterized to be loamy sand and the Rhodic Nitosols are characterized to have a good water holding capacity and is not prone to erosion, hence being ranked to be of low vulnerability as shown in Table 19. In addition, Areas within the Eutric Fluvisols and Gleyic Arenosols have a recorded number and 12 and 19 flooding occurrences while areas within the Rhodic Nitosols have no recorded flooding occurrence between 2001 and 2020.

Table 19. Lekki Susceptibility Level and Ranking of Soil Type.

Soil Type	**Spatial Extent (km^2)**	**Spatial Extent (%)**	**No of Flood events**	**Rank**	**Susceptibility Level**
Eutric Fluvisols	540.98	37.53	12	4	Very High Susceptibility
Gleyic Arenosols	889.15	61.68	19	2	Medium Susceptibility
Rhodic Nitosols	11.45	0.79	0	1	Low Susceptibility

These two cities are shown to have different soil types with different characteristics, with the exception of the Rhodic Nitosols. Unlike the city of Abeokuta which has a dominant soil covering almost the entire city, the spatial distribution of the soil types in Lekki is distributed mainly between two soil types. This invariably means the soil type of Abeokuta will have little to no effect in the spatial distribution of susceptible areas unlike Lekki.

Figure 25. (a) General and (b) Reclassified Soil Map of Abeokuta South.

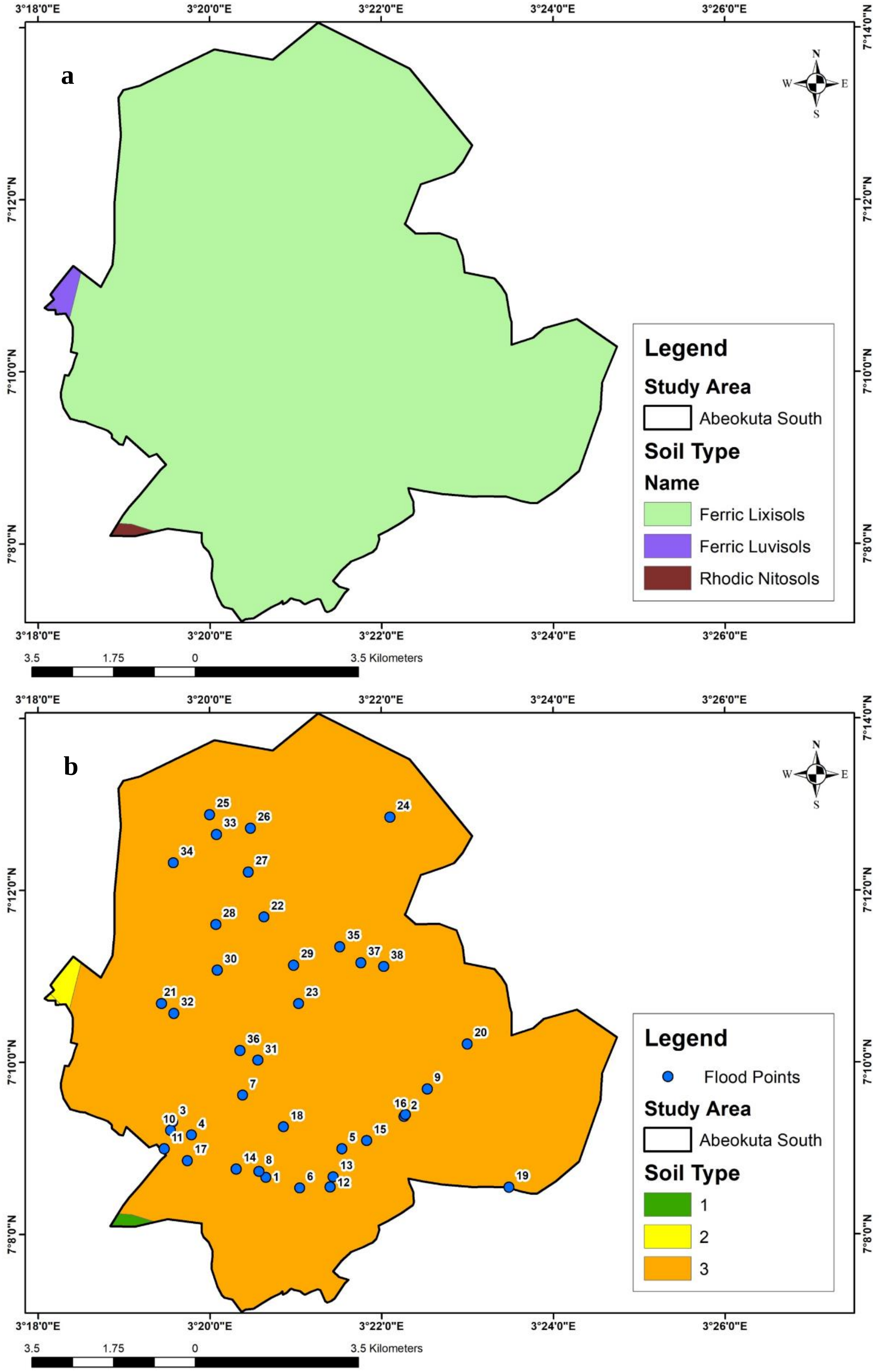
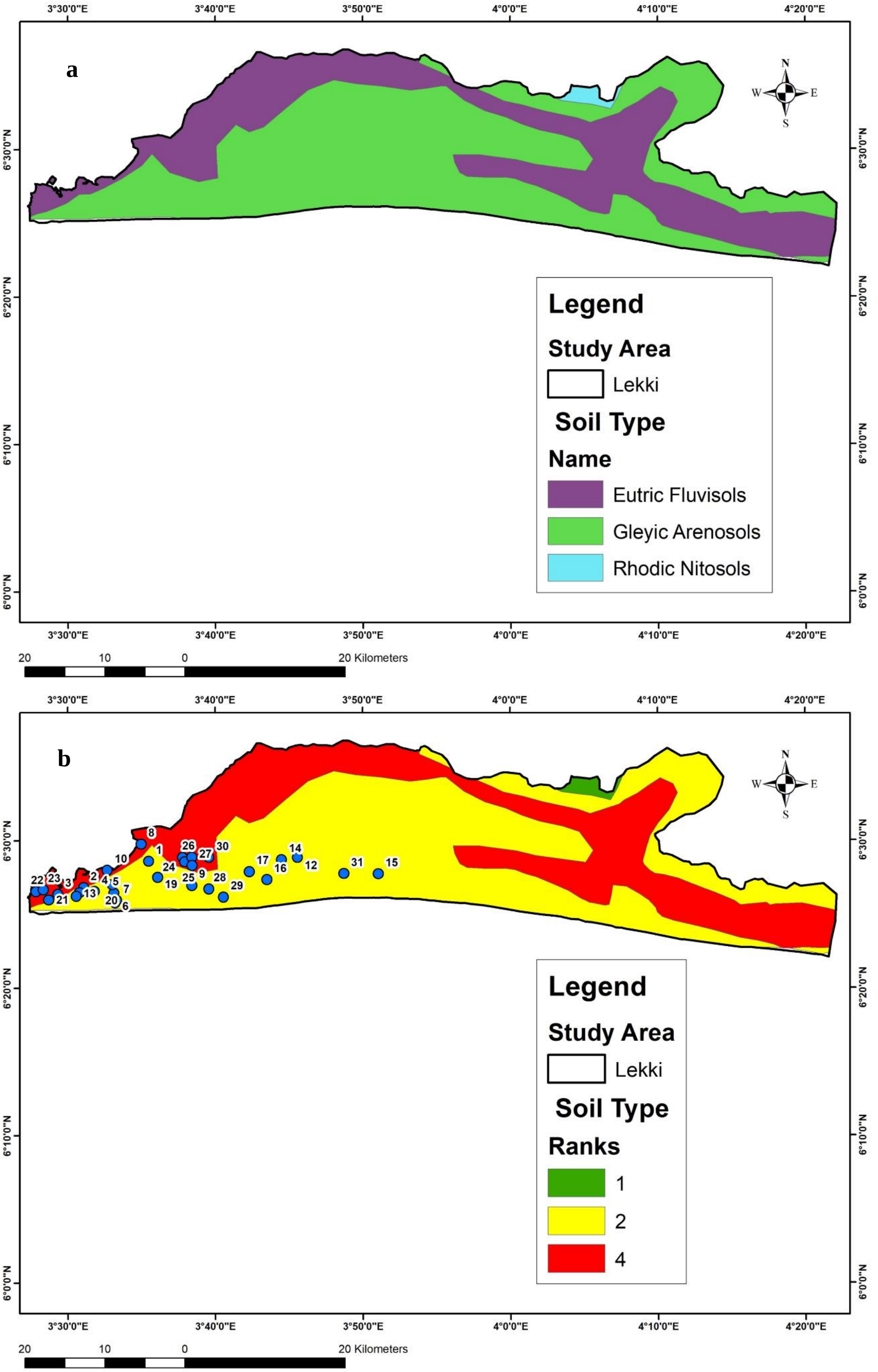


Figure 26. General and Reclassified Soil Map of Lekki.



5.6 Geology map

The spatial distribution and ranking of the geological formation present in the study area is illustrated in the Figures and Tables below.

The entire geological formation of Abeokuta South is made up of the Basement Complex Rock which is classified to be highly susceptible because it is characterized to be impermeable (Patrikaki et al., 2018 and Ozulu et al., 2021) as shown in Table 20 and Figure 27a and b.

Table 20. Abeokuta South Geology Susceptibility Level and Ranking.

Geology	Spatial Extent (km^2)	Spatial Extent (%)	No of Flooding events	Rank	Susceptibility Level
Basement Complex Rock	90.95	100	38	3	High Susceptibility

For the city of Lekki, about 65.69% of the total area is made of alluvium which are moderately drained and permeable, hence it is classified to have medium susceptibility. In addition, all the past flooding events recorded happened within areas of alluvium. About 7.28% of the total area is made up of coastal plain sands, characterized to be well drained and porous and classified to have low susceptibility as shown in Table 21 and Figure 28a and b.

Table 21. Lekki Geology Susceptibility Level and Ranking.

Geology	Spatial Extent (km^2)	Spatial Extent (%)	No of Flooding events	Rank	Susceptibility Level
Alluvium	946.88	65.69	31	2	Medium Susceptibility
Coastal Plain Sands	104.99	7.28	0	1	Low Susceptibility
Water Areas	389.58	27.03	0	4	Very High Susceptibility

Figure 27. (a)General and (b) Reclassified Geology Map of Abeokuta South.

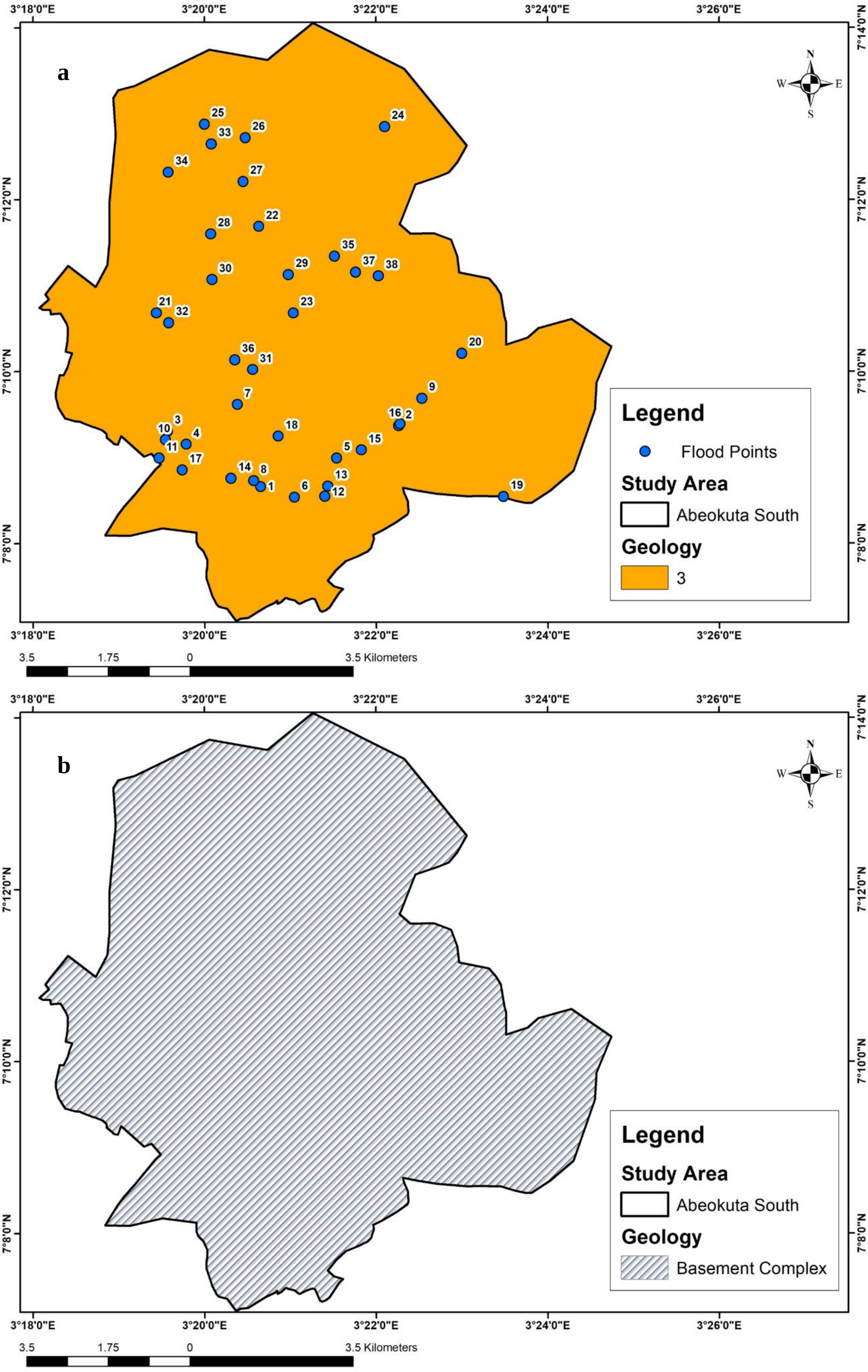
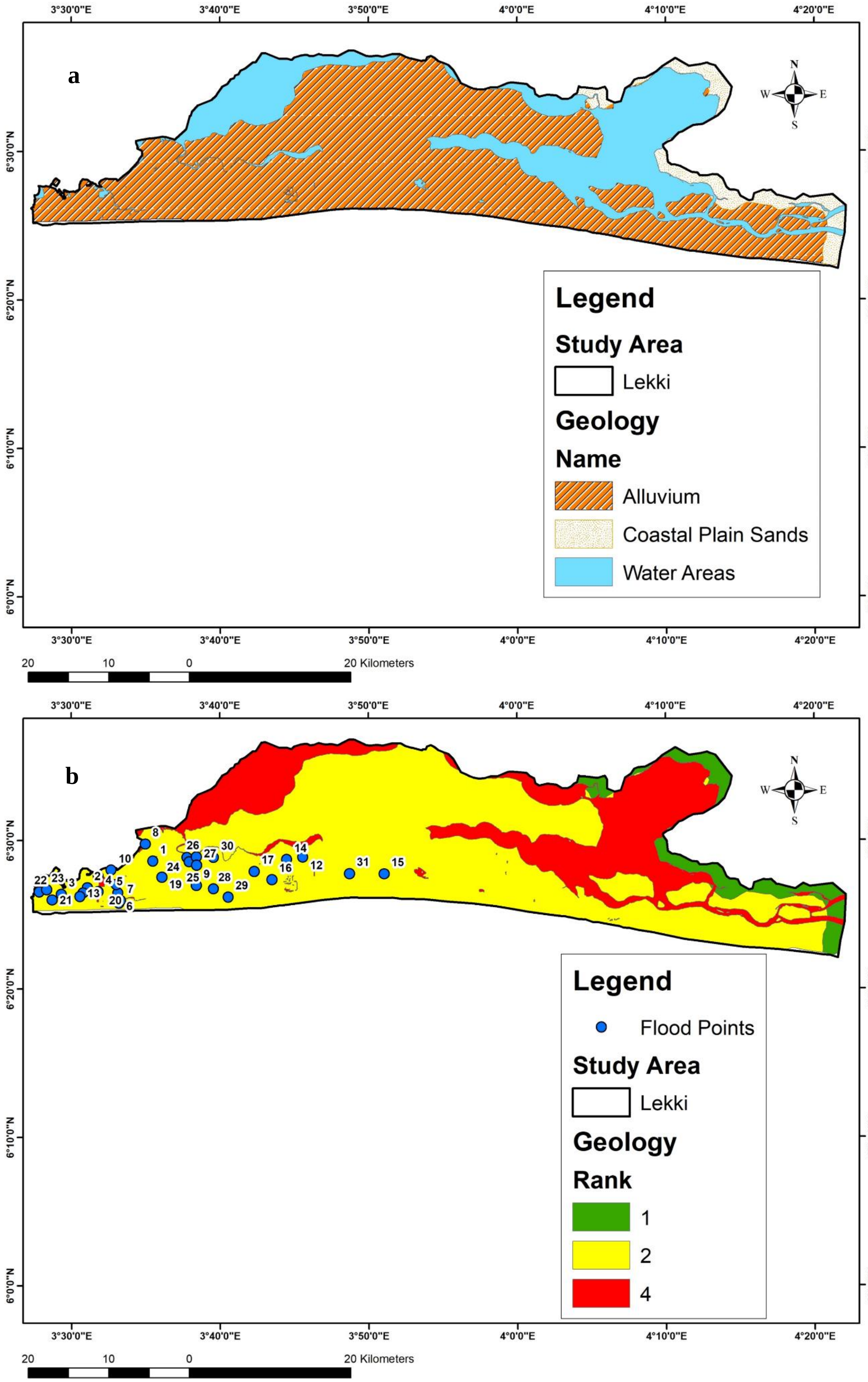


Figure 28. (a) General and (b) Reclassified Geology Map of Lekki.



5.7 Susceptibility map

Based on the 6 environmental criteria used, the following tables and figures presents the susceptibility levels and map of Abeokuta South and Lekki.

The analysis shows that in the city of Abeokuta South areas that have low susceptibility were only about 5.25 % of the total area, while the very high susceptible areas covered only 2.07%. Areas with medium susceptibility and high susceptibility cover 43.31% and 9.37% respectively as shown in Table 22. About 6 (15.79%) flood points fall under the Very High Susceptibility class, 17 (44.74%) flood points fall under the High Susceptibility class, 15 (39.47%) flood points fall under the Medium Susceptibility class as shown in Figure 29a and Figure 29b.

Based on the environmental criteria used, it was observed that the very highly susceptible areas tend to be those that are nearest to the drainage network. This was proven true when the drainage network was overlayed on the map as shown in Figure 29b. The most susceptible areas run from the southwestern part of the study area to the northern part of the study area. Most of the area with low susceptibility are in the southeastern part of the study area which are more than 300 m farther from the drainage network and are located over 150 m above sea level. Despite proximity to the drainage network being a major determinant of the susceptibility level, elevation also played an important role. With some of the areas despite being close to the drainage network fall under areas with low susceptibility as they are above 200 m from the sea level. This could be attributed to the presence of Rocks within the city.

Table 22. Susceptibility Level of Abeokuta South based on Environmental Criteria.

Susceptibility Level	No of Flood events	Spatial Extent (km^2)	Spatial Extent (%)
Low Susceptibility	0	4.76	5.25
Medium Susceptibility	15	39.23	43.31
High Susceptibility	17	44.71	49.37
Very High Susceptibility	6	1.87	2.07

For the city of Lekki, only about 13.69% of the total area fall within the areas will low susceptibility, while the very high susceptible areas cover less than 10% of the total area. The majority of the total area fall within the medium susceptibility and the high susceptibility zones which covers about 36.66% and 39.80% respectively as shown in Table 23 and Figure

30a. Just like the city of Abeokuta south, it was observed that the most susceptible places fall within the areas close to the drainage network as shown in Figure 30b especially the Lagos lagoon. The level of susceptibility reduces as the distance from the drainage network increases. Even though slope was used as a major criterion, it has little to no effect on determining the susceptibility of the region because the elevation of the entire area is between -13 m to 31 m above sea level with gentle undulating slopes. Hence the place could be characterized as a flood plain.

Table 23. Susceptibility Level of Lekki based on Environmental Criteria.

Susceptibility Level	**No of Flood events**	**Spatial Extent (km²)**	**Spatial Extent (%)**
Low Susceptibility	0	195.96	13.69
Medium Susceptibility	14	524.61	36.66
High Susceptibility	12	569.61	39.80
Very High Susceptibility	5	140.89	9.85

Figure 29. Susceptibility Map resulting from environmental criteria in the city of Abeokuta South.

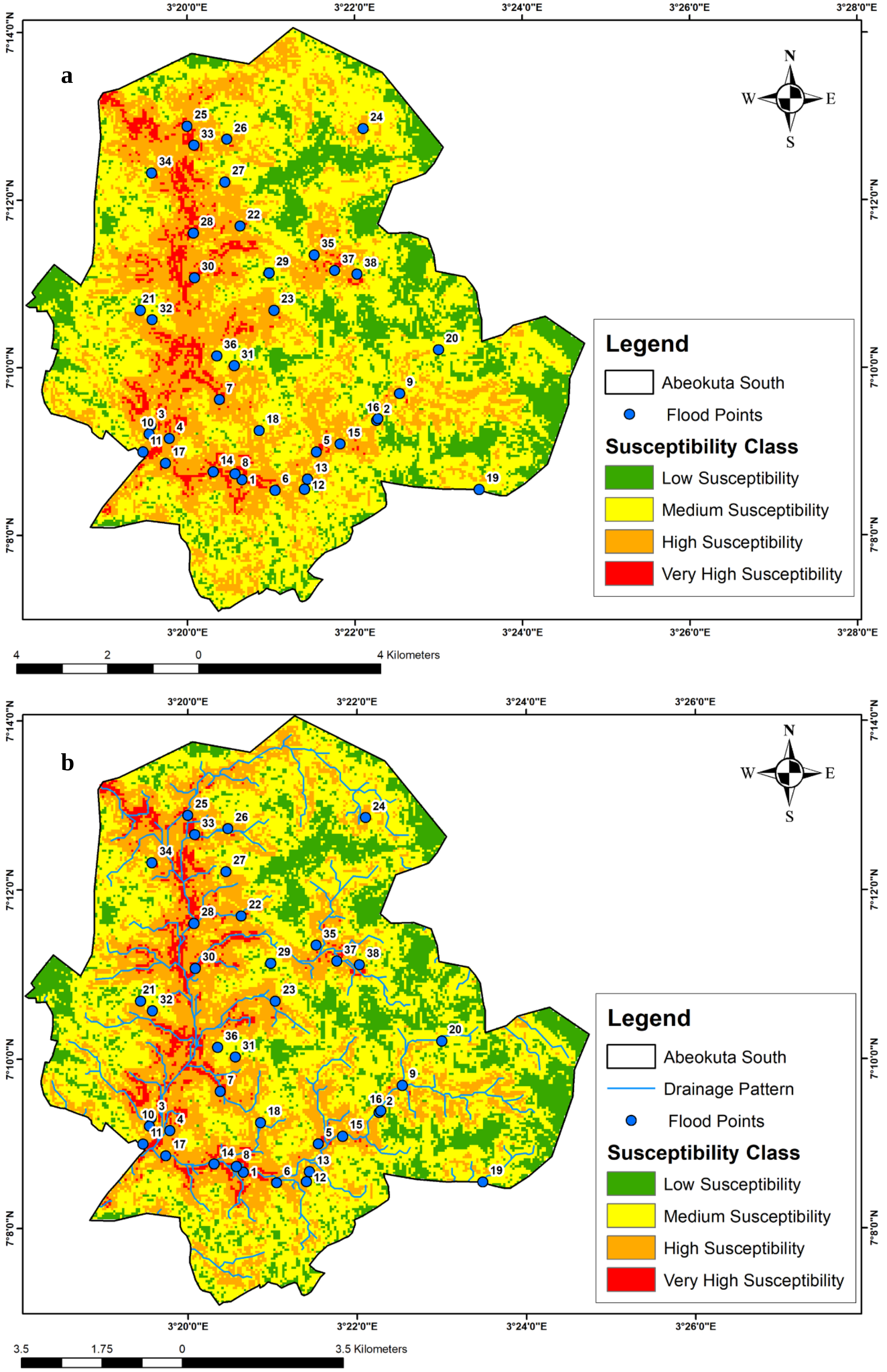
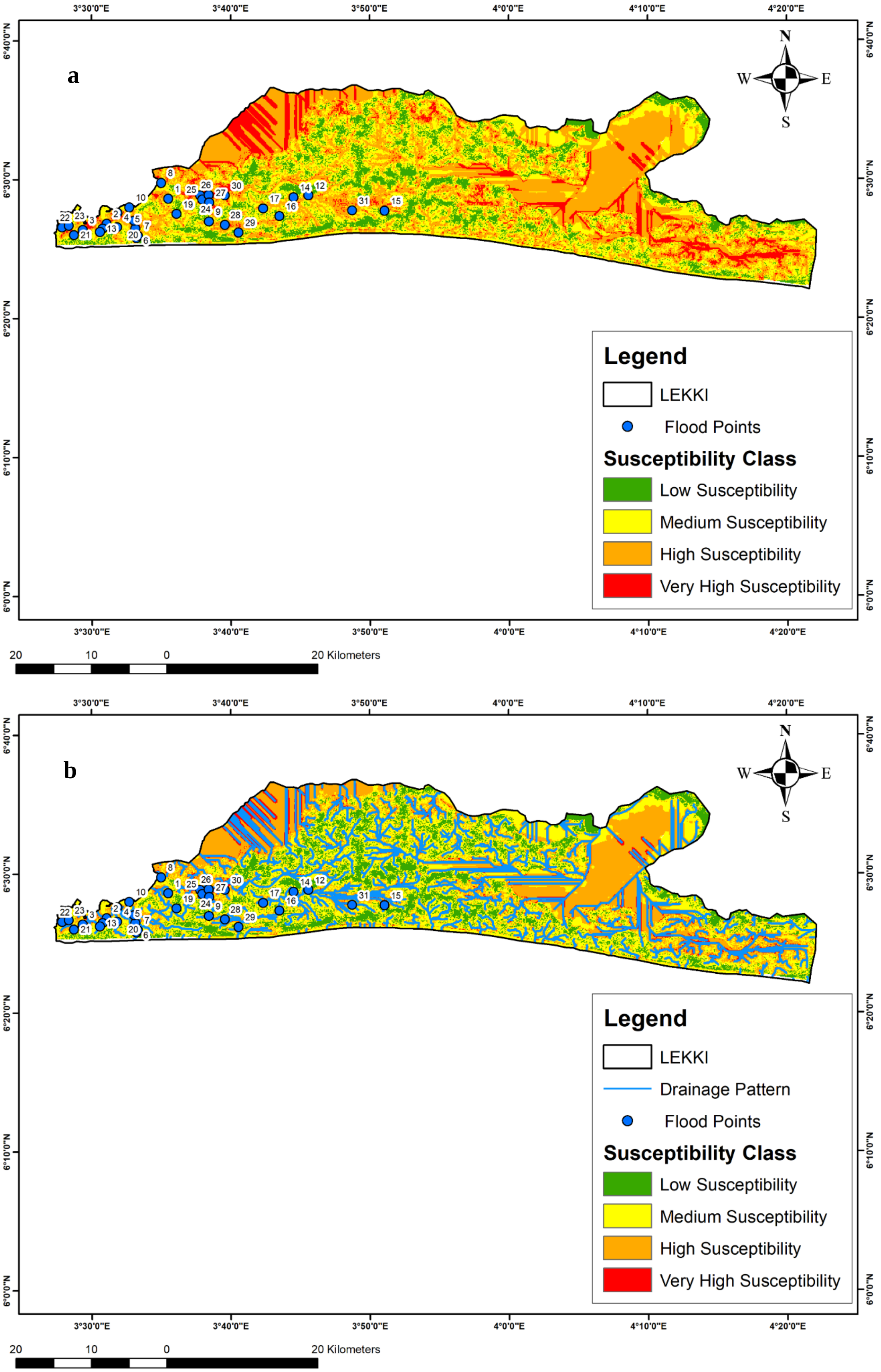


Figure 30. Susceptibility Map resulting from environmental criteria in the city of Lekki.

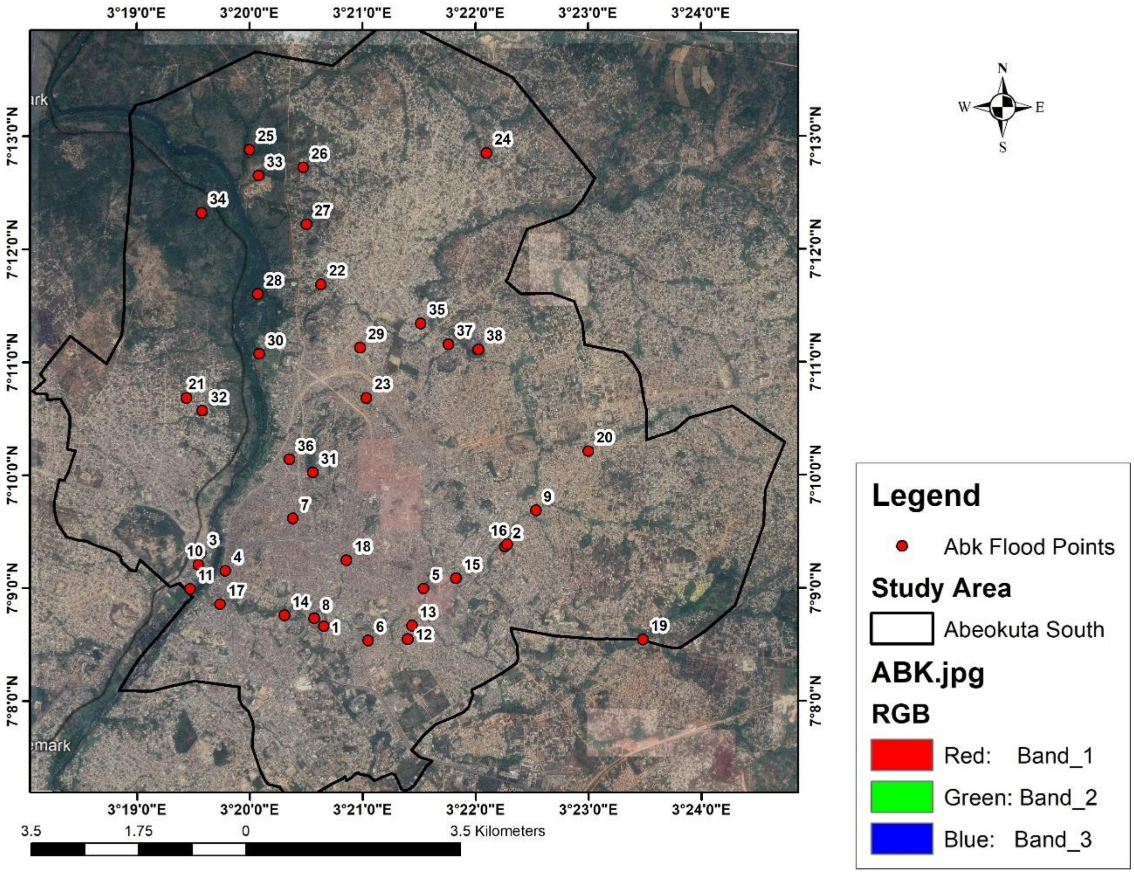


5.8 Susceptibility class and Anthropogenic characteristic of flood points.

5.8.1 Abeokuta

Each flood point has been labeled numerically for proper identification as shown in Figure 31.

Figure 31. Abeokuta South Map with spatial distribution of flood point.



Some of the flood points including points 6 shown in Figure 32 as well as 7, 28, 33, 37 and 38 can be found to be in the Very High Susceptibility Area.

Figure 32. Image of Flood Point 6 Located within the Very High Susceptibility Zones.

The location of flood point 28 is within a marshy/swampy area of Iberekodo, while the location of flood points 37 is in a rural environment within Ijemo with no drainage plan and the road being untarred. Point 38 is located within an abandoned mining site which is now currently used as an illegal dumpsite. Point 7 which is also within Very High susceptibility zone has old residential houses built beside a natural flowing river. Despite point 6 being in a less sloppy area than the rest, it is found to be located very close to a very heavy commercial environment called Kuto with little to no drainage plan also.

It is observed that the elevation of all the flood points found within the Very high susceptibility class are found to be below 100m above sea level. These points are also found to have relatively a high drainage density of over 2km/km² and a medium slope percentage. Taking into consideration the fact that the soil present in the study area is classified to be high susceptible because they are leached soils with weakly developed structure and are prone to erosion. This implies lower infiltration rates and higher surface flow velocity. Also, all but one of these flood points within the Very high susceptible zone are within 100m to a drainage network. The combination of these physical characteristics is what makes them very highly susceptible to flooding.

For the flood points found within the High susceptibility class, they all have either a medium or a high drainage density but with gentler slope compared to the points found within the Very high susceptible areas. This means a relatively lower surface flow velocity.

Figure 33. Image of Flood Points (a) 1 and (b) 12 Located within the High Susceptibility Zones.

The location of Point 12, 10 and 11 are within residential areas while point 17 is a commercial zone which are all very close to a major river in Abeokuta called “Ogun river”. This river is known to overflow, causing flooding in surrounding areas. These locations also do not have a proper artificial drainage system. Point 1 (Figure 33), 8 and 14 are located within the rural commercial zones of “Isale Igbein”. Most of the buildings here are also built quite close to a river.

Figure 34. Image of Point 21 which is located within a High Susceptible Area.

The location of Point 1, 5, 13, 15 and 21 can be found within residential zone with also no artificial drainage plan, roads are untarred as shown in Figure 34 and located close to a drainage network. In summary, the flood points located within the high susceptibility areas, most of them are located withing heavily residential areas than are located close to a drainage network.

Most of the flood points found within the Medium Susceptibility class are relatively more distant from any drainage network. Some of the exceptions are found to either have high elevations of over 100m above sea level or a low slope percentage. Most of these flood points also have a relatively low drainage density and much gentler slope compared to the rest which means the rate of surface flow velocity will be lower and infiltration would be higher.

Figure 35. Image of Point 18 which is located within a Medium Susceptible Area (a) before and (b) after heavy rainfall.

Points 2, 3, 9, 16, 18 and 20 are among the commercial zones that have a proper artificial drainage network, as illustrated in Figure 35, but are regrettably extremely close to a naturally occurring river that could occasionally overflow after a severe downpour.

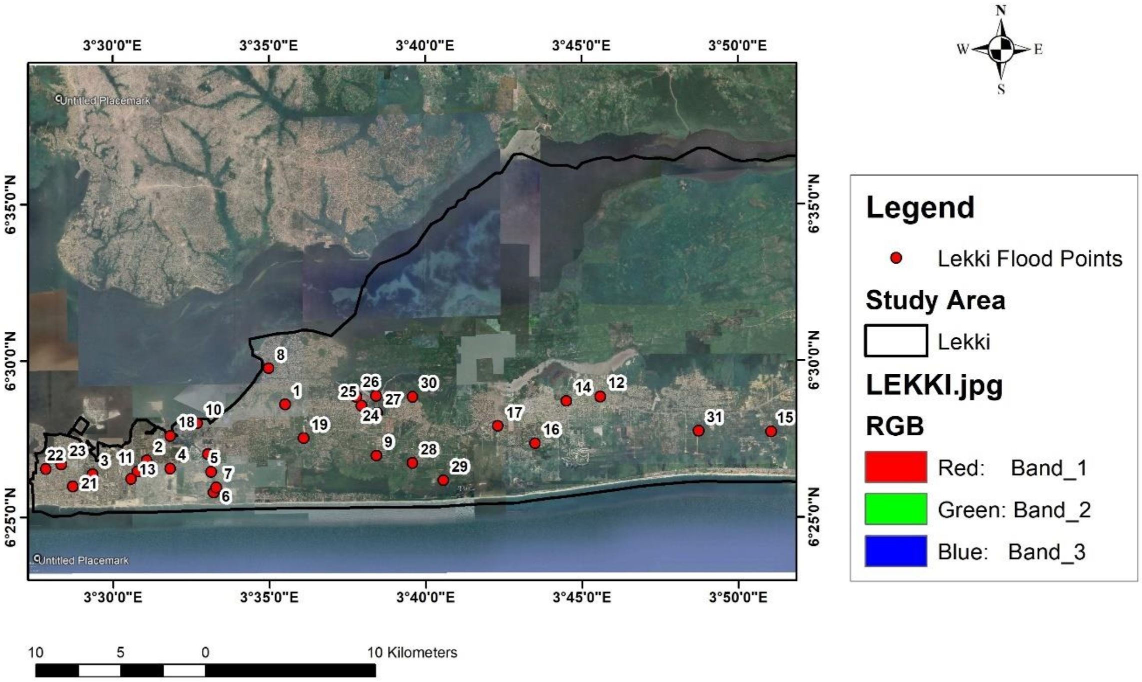
Figure 36. Image of Point (a) 22 and (b) 32 respectively which is located within a Medium Susceptible Area.

Point 22, 29, 32 and 35 are located in a residential area which is relatively far from any natural occurring drainage network but there seems to be little or no proper artificial drainage network and the road are untarred as seen in Figure 36.

5.8.2 Lekki

The same labelling technique was used for the city of Lekki, with each point where flood occurrences were reported are labeled in order for identification as shown in Figure 37

Figure 37. Lekki Map with spatial distribution of flood point.



About 5 (16.13%) flood points fall under the Very High Susceptibility class, 12 (38.71%) flood points fall under the High Susceptibility class, 14 (45.16%) flood points fall under the Medium Susceptibility class. It is observed that the elevation of all but one of the flood points found within the Very high susceptibility class are found to be at par with the sea level. They are also found to be either located within residential areas or very close to water bodies. Most of the flood points found in the Very high susceptibility class have a high drainage density.

Point 18, 24, 25 and 26 are located in residential zones with tarred roads and proper artificial drainage network that a located very close to a natural occurring drainage network. With the low elevation and the proximity to the river, these areas are very likely to be flooded after a heavy downpour.

Point 3, 17, 27 and 30 are located within residential areas that can be found within the highly susceptible areas. These areas are without artificial drainage networks and tarred riads as shown in Figure 38 which are relatively close to rivers. The proximity to these rivers and the absence of the drainage network makes them highly susceptible to flooding.

Figure 38. Images of Flood Point (a) 3 and (b) 17, residential areas located within the High Susceptible areas in Lekki.

Point 4, 22 and 23 are also residential areas found within the highly susceptible areas. Despite having tarred roads and drainage networks, these areas are very densely populated and some of the drainage networks are small and blocked due to garbage as shown in Figure 39. This makes them very susceptible to flooding. In Figure 40, point 13 is a commercial zone located very close to a naturally occurring drainage network that has been converted into a canal. But this canal has garbage being dumped into it which allows the surrounding areas to get flooded after heavy downpour.

Most of the flood points found within the high susceptible areas are relatively farther to the drainage network than the flood points found within the very high susceptible areas. Most of these flood points are also found to have medium drainage densities.

Figure 39. Image Flood Point 22, residential area located withing the High Susceptible areas in Lekki.

Figure 40. Image of Flood point 13, commercial area located withing the High Susceptible areas in Lekki.

Despite the elevation of the flood points found within the medium susceptibility zones being within just 0 to 10 m above sea level, they are all found to be relatively distant from any drainage network with most of them also having a low drainage density which reduces the likelihood of flooding.

Most all these flood points like 2, 5, 7 and 10 are found to be in very densely populated residential areas, but with proper artificial drainage networks. These drainage networks are covered to avoid dumping of garbage into them as seen in Figure 41. These areas are also observed to be resident to high income earners.

Figure 41. Images of Flood points (a) 5 and (b) 7, residential area located within the Medium Susceptible zones.

a

Other flood points within this zone are also very densely populated with narrow streets, no artificial drainage network and the roads aren’t paved as seen in Figure 42. The residents living in these areas are also observed to be medium and low-income earners.

Figure 42. Images of Flood Points (a) 14, (b) 8 and (c) 1 which is located within the Medium Susceptibility zones.

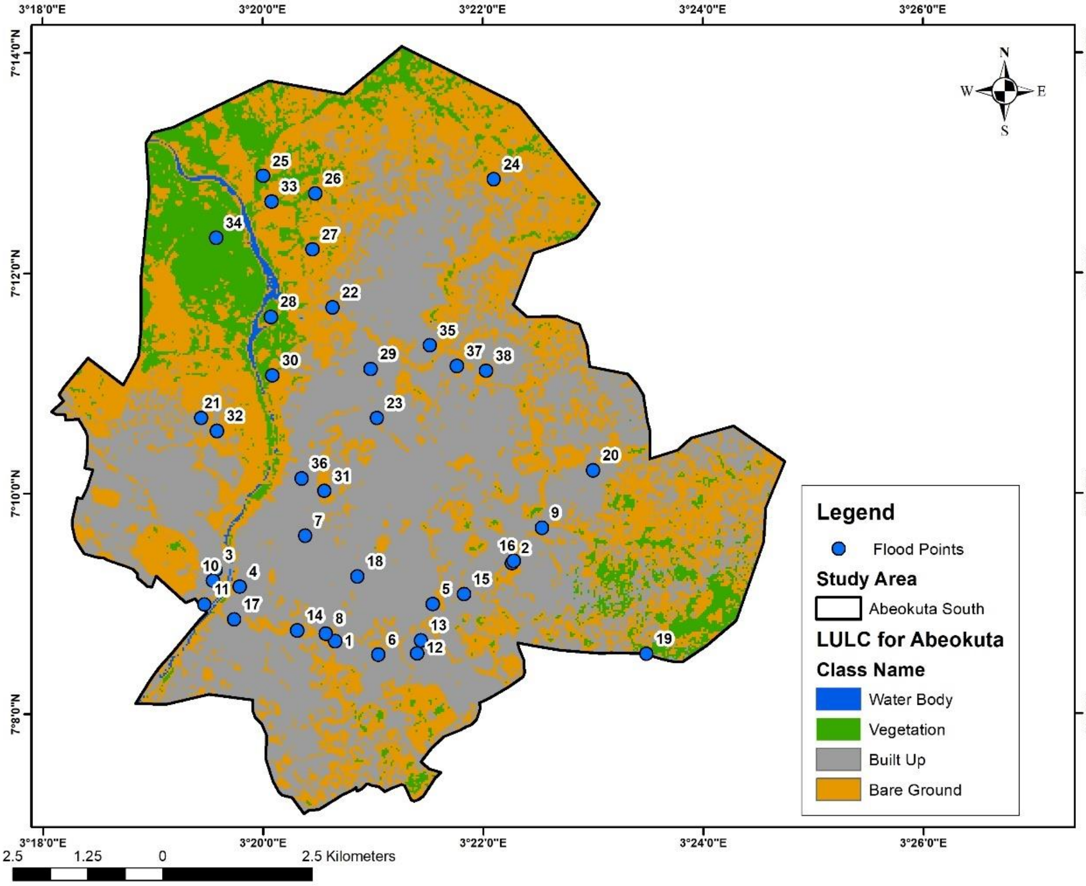
5.9 Land-use and Land cover map

The Land-Use and Land cover pattern of Abeokuta South as shown in Table 24, indicates that the built-up areas cover over 45% of the total area with 23 flooding events occurring in this category. This suggests the presence of high anthropogenic activities as well as the conversion of land-cover types such as vegetation to buildings and paved surfaces. This in turn accounts for the high amount of flooding occurrence in this land-use type. Only about 12 flooding events occurred in Barren land areas which cover about 38.49%. Vegetative areas which cover about 11.07% of the total area have had 3 flooding events occurring within the last 20 years as shown in Figure 43. While water bodies cover less than 1% of Abeokuta south.

Table 24. Land-use and Land cover Ranking of Abeokuta South.

Land-Use Land Cover	Spatial Extent (km²)	Spatial Extent (%)	No of Flood events	Rank	Susceptibility Level
Vegetation	10.06	11.07	3	1	Low Susceptibility
Barren Land	34.98	38.49	12	2	Medium Susceptibility
Built-Up	45.31	49.85	23	3	High Susceptibility
Water Body	0.54	0.59	0	4	Very High Susceptibility

Figure 43. Land-use and Land cover pattern along with the Flood points of Abeokuta South.

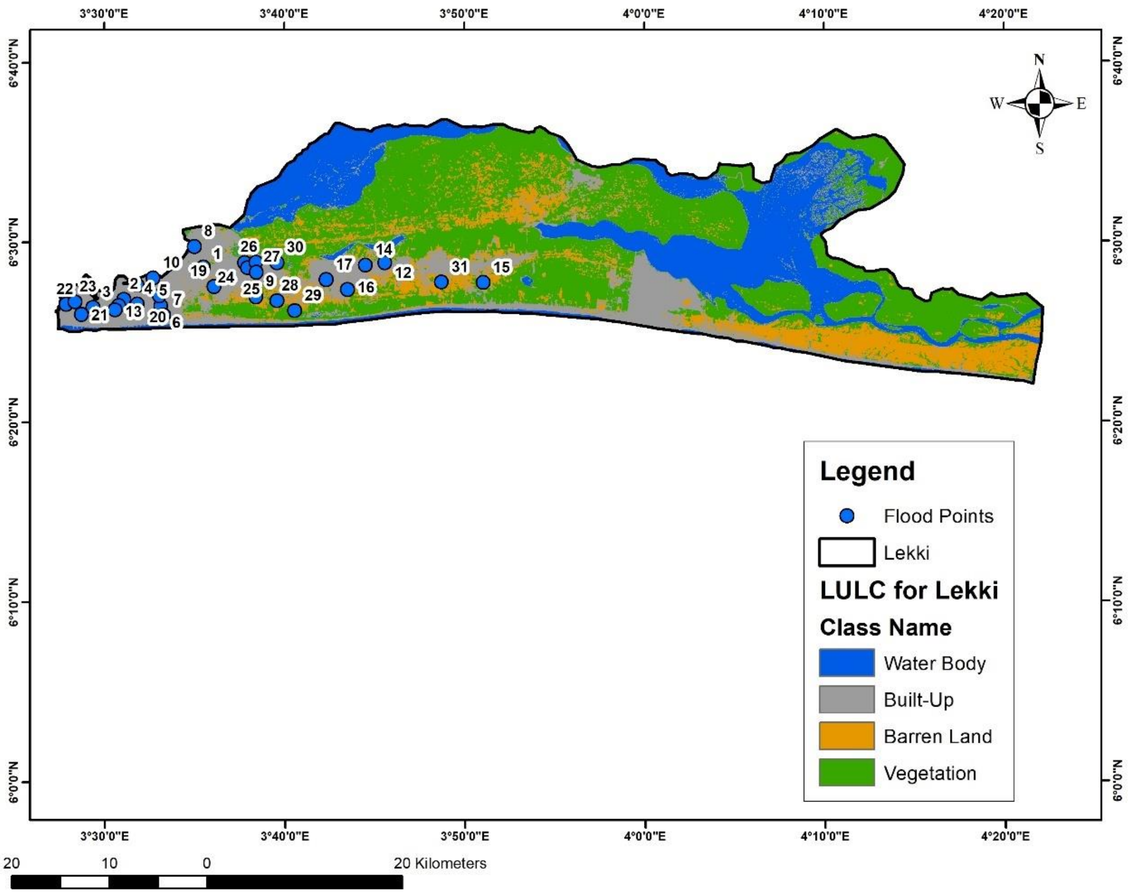


For the city of Lekki, Table 25 shows that vegetation take up most parts of the city, accounting for 47.85% of the total land cover of Lekki. 4 flooding events occurred on vegetative land cover which are surrounded by built-up areas. Water bodies and barren land take up about 25% and 10.9% of the total area, with 4 flooding events occurring on the latter. The built-up areas are found to be clustered to the western part of the city and take up about 16% of the total area of Lekki, with 23 out of the recorded 32 flooding events occurring in built-up areas as shown in Figure 44.

Table 25. Land-use and Land cover Ranking of Lekki.

Land-Use Land Cover	**Spatial Extent (km²)**	**Spatial Extent (%)**	**No of Flood events**	**Rank**	**Susceptibility Level**
Vegetation	693.15	47.85	4	1	Low Susceptibility
Barren Land	157.82	10.90	4	2	Medium Susceptibility
Built-Up	233.98	16.15	23	3	High Susceptibility
Water Body	363.51	25.10	0	4	Very High Susceptibility

Figure 44. Land-use and Land cover pattern along with the Flood points of Lekki.



5.10 **Flood Risk map**

Four major classes of flood risk, ranging from low class to very high class, are highlighted in the flood risk map created by thematic mapping combined with AHP and then categorized based on natural break algorithm in the ArcGIS environment as shown in Figure 45 and Figure 46.

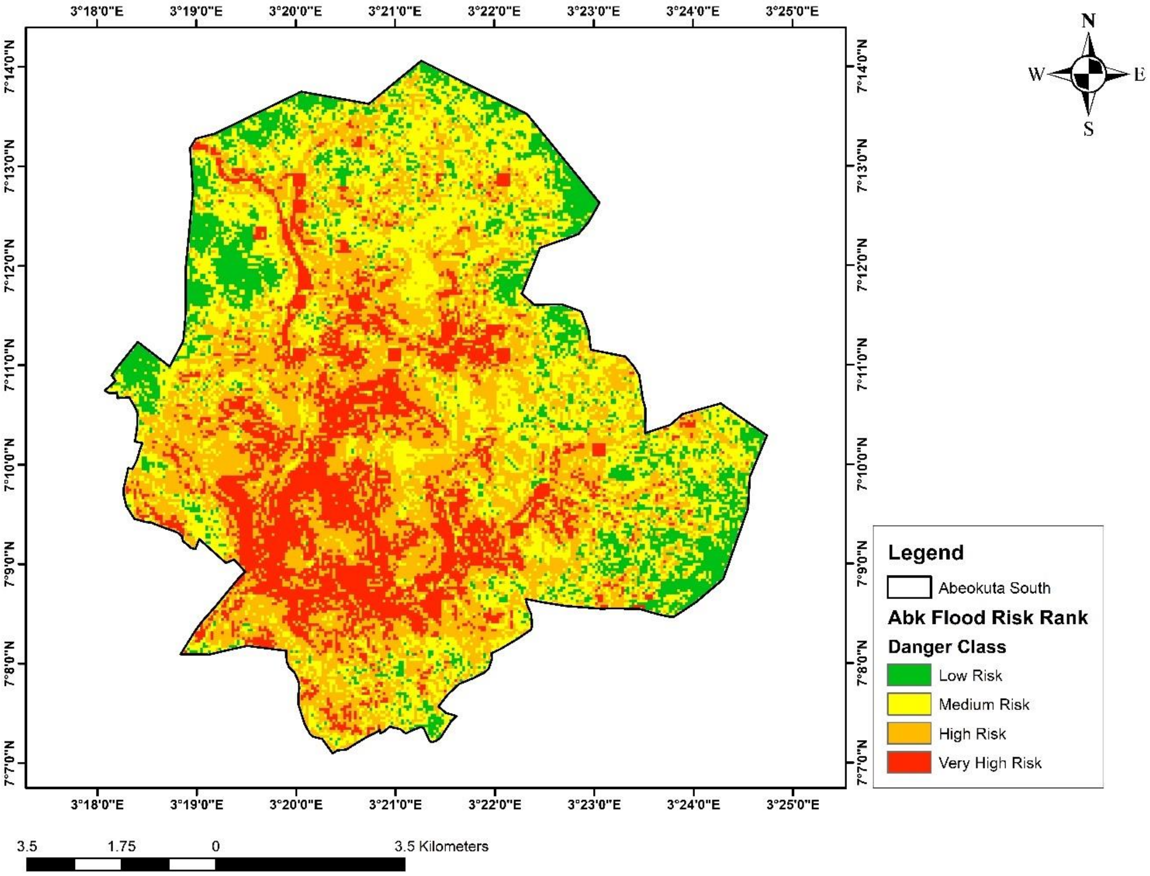
For the city of Abeokuta south, about 36% and 19% of the total land area fall under the high and very high-risk areas while the low and medium risk areas cover about 13% and 31% respectively as shown in Table 26. The very high-risk areas cover the southeast and south-central part of the city which is the core location of the urban areas. The low-risk areas located around the outskirts of the study area where vegetation is prominent and is distant from any drainage network as shown in Figure 45. From this result, land use, elevation, and distance from the drainage are elements that have shown to have a significant impact on the flood phenomenon. Some of these factors were highlighted by Kazaski et al (2015) who conducted his research in Greece's Rhodope-Evros region. Among the 7 factors employed to generate the flood susceptibility map for his study, flow accumulation, distance from the drainage network and elevation were the most significant factors influencing the flood susceptibility level. Just like Das and Gutpa (2021) in their study in the Subarnarekha basin, geology is also found to be the least influential factor on flooding in the city of Abeokuta and this is primarily because the entire city is covered by the same geology formation. This is in contrast to the study carried out by Nsangou et al (2021), who found geology to be amongst the top 3 factors influencing flooding in the Mfoundi watershed. This would be connected to the impermeable rock outcrops spread across the Mfoundi watershed, especially on the hillsides, riverbanks, and their beds that encourage rapid flood runoff and water stagnation with subsequent flooding occurrences.

Anthropogenic activities such as unregulated dumping of waste close to artificial drainages and in rivers, irregular and unplanned constructions of buildings (especially close to rivers) and the absence of artificial drainages in most of the parts in the urban areas also contribute to the very high risk of flooding in this city.

Table 26. Flood Risk Ranking of Abeokuta South.

S. No.	**Risk Level**	**Spatial Extent (km^2)**	**Spatial Extent (%)**
1	Low	11.79	13.04
2	Medium	28.30	31.29
3	High	32.94	36.42
4	Very High	17.41	19.25

Figure 45. Flood Risk Map of Abeokuta South.



In the city of Lekki, the very high-risk and high-risk areas cover about 30% and 35% of the total area of the city with the medium and low risk areas covering about 23% and 11% respectively as shown in Table 27. The very high-risk and high-risk zones are found to be located within the urban areas and areas very close to the drainage network as seen in

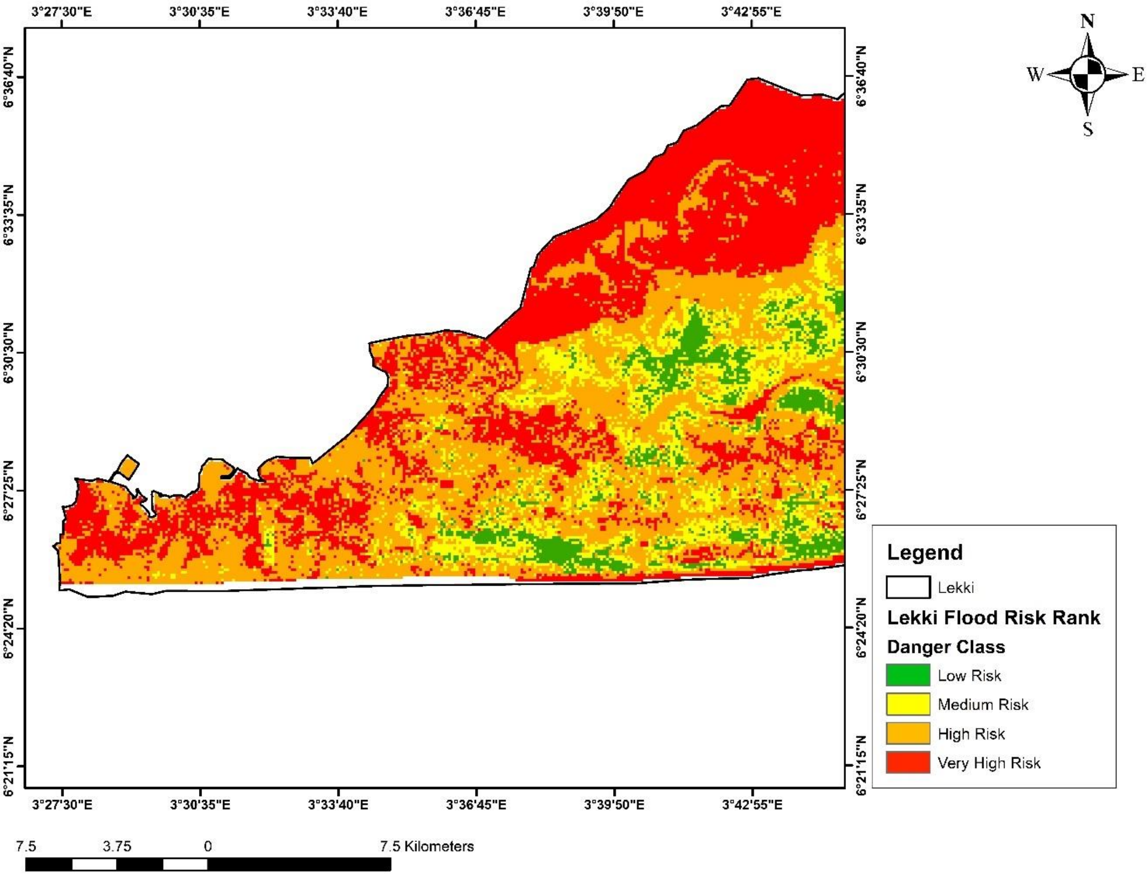
Figure 46. The elevation and slope has little to no effect in the flood risk of this city.

The anthropogenic characteristics and the local realities of this city play a major role in the flood risk. The presence of numerous drainage networks, geology and soil type has conditioned the built-up regions to be clustered to the eastern part of the total area. This clustering as well as the irregular dumping of waste puts a lot of pressure on the artificial drainages. In the city of Lekki, areas that were formerly water bodies are being sand filled in order to construct buildings. This results in blocking natural drainage systems and causing flooding during the rainy season.

Table 27. Flood Risk Ranking of Lekki.

S. No.	Risk Level	Spatial Extent (km^2)	Spatial Extent (%)
1	Low	163.65	11.48
2	Medium	323.88	22.73
3	High	499.67	35.06
4	Very High	437.99	30.73

Figure 46. Flood Risk Map of Lekki.

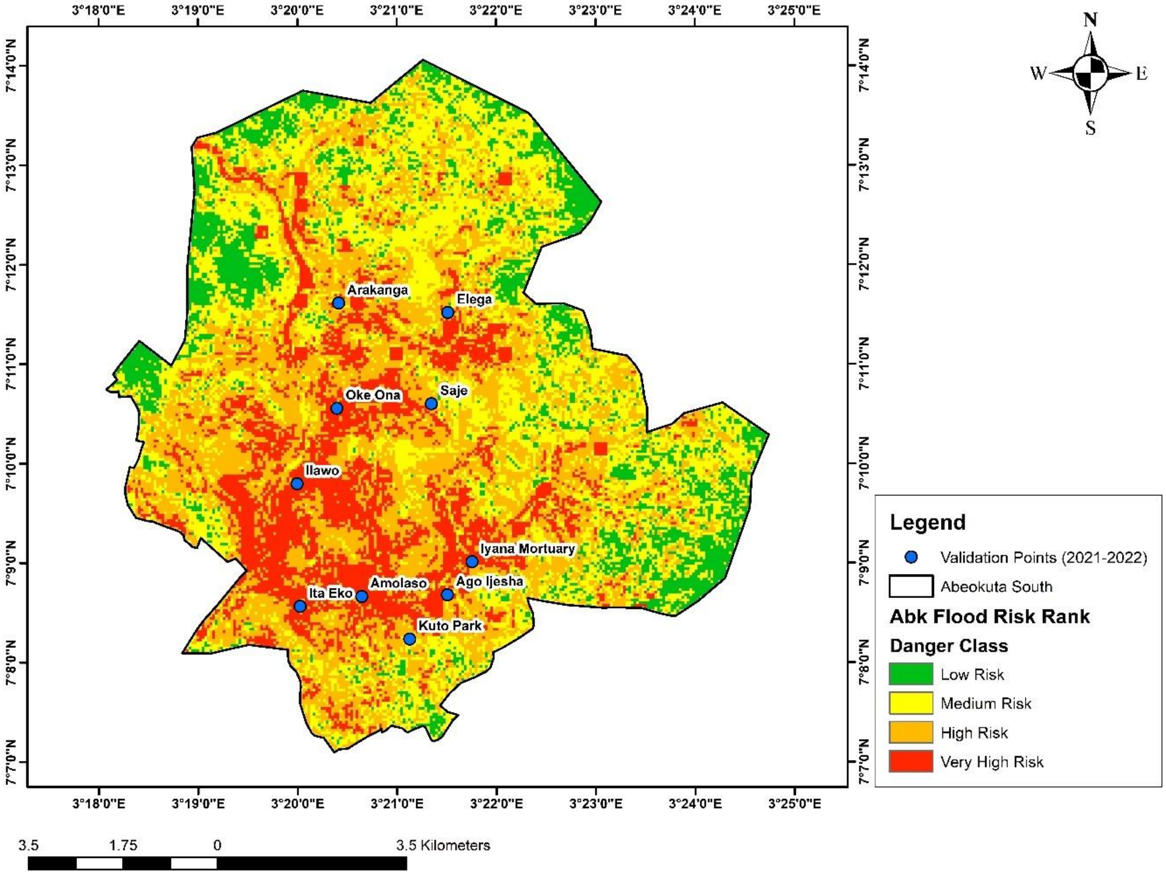


The research's methodology can be used in various environments. The sole distinction is that each environment's unique characteristics and local realities should be considered when evaluating the parameters that would be used in this flood risk mapping.

5.11 Validation

The areas of past flood occurrences between 2021 and 2022 were gathered from various news outlets, who gave pertinent data on 10 flooding sites, in order to validate the conclusions of the Abeokuta South and Lekki flood risk map. These historical flood locations were overlaid on the model's output. According to the projected outcomes, every historical flood site collected is situated in a zone with a high or very high probability of flooding as shown in Figure 47 and Figure 49, demonstrating the accuracy of the flood risk model utilized in this study.

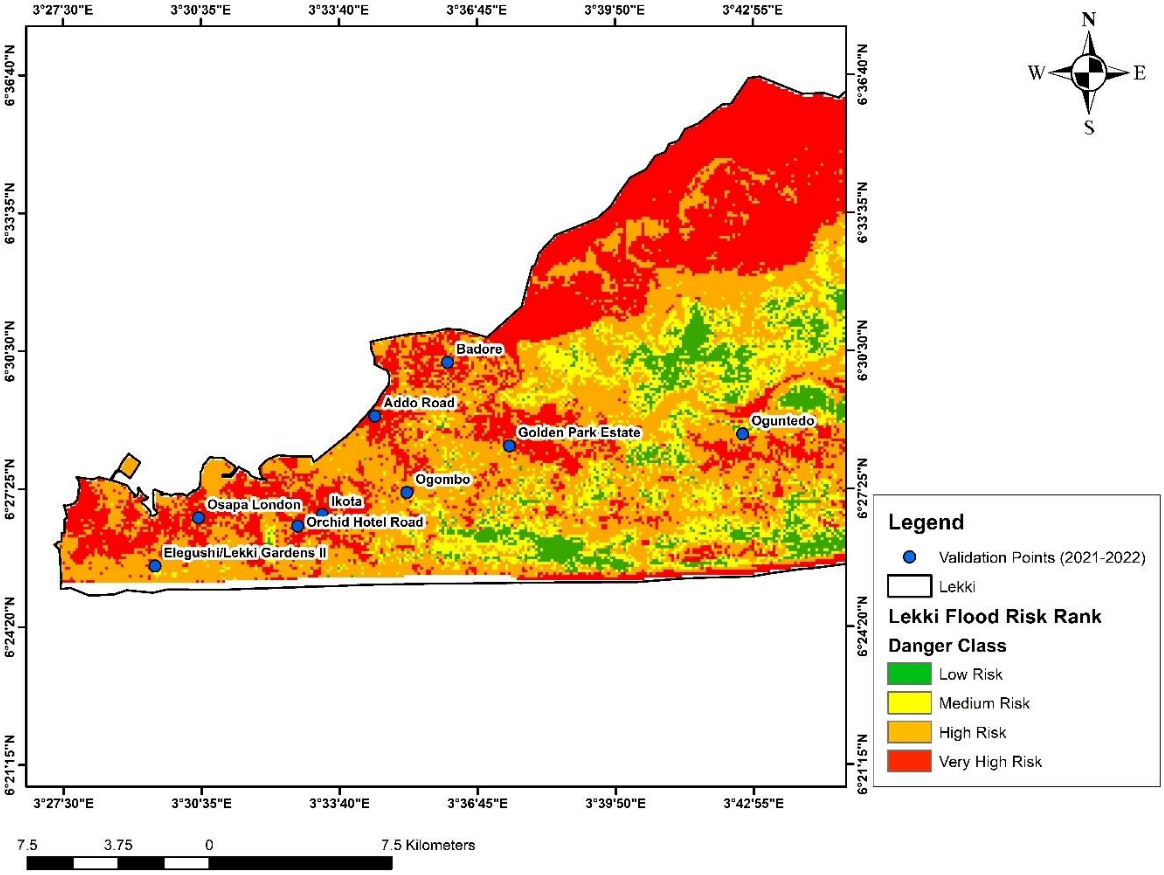
Figure 47. Flood Risk Map of Abeokuta South with Validation Points.



The flood points for Abeokuta south reveals that floods affect the build-up areas located near water bodies, without artificial drainage and are not well planned as in the case of Saje and Ago Ijesha shown in Figure 48.

Figure 48. (a) Saje and (b) Ago Ijesha community.

Figure 49. Flood Risk Map of Lekki with Validation Points.



The flooding history of Lekki revealed that the flood also affects build up areas located near water bodies especially areas like Addo located in near proximity to the Lagos lagoon. In other cases, like Paradise estate where these locations have proper drainages, they still experience floods because those locations were previously waterlogged or swampy areas and were sand filled to allow construction of buildings as shown in Figure 50 and Figure 51.

Figure 50. Images of Addo vicinity.

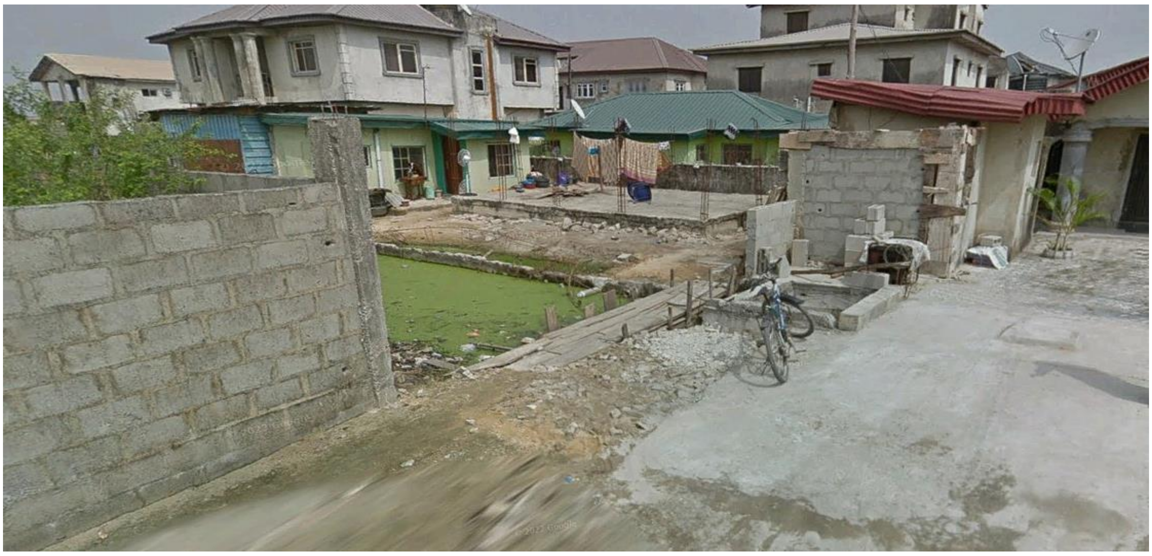


Figure 51. Images of Paradise Estate

5.12 Limitations

Some of the limitations encountered in this research was the data unavailability of certain factors like the rainfall distribution and the population density of each ward within the city. This is due to the absence of pluviometer around the cities to measure the actual precipitation on ground rather than depending on radar images which do not accurately reflex what is happening on ground and also the lack of a proper census count since 2006.

Despite some of these limitations connected to this current study, The flood risk maps of the cities obtained constitute a true instrument for development, planning, and decision-making by the government agencies and the fragmented territorial communities with authority. The outcomes of this effort will surely help to improve the quality of life for those who live in this densely populated area, where the issue of environmental management and sanitation represents a major obstacle. Notwithstanding, it would be necessary to incorporate these missing factors in later work and, at the very least, test out more effective models that could minimize error margins.

6 CONCLUSIONS AND RECOMMENDATIONS

Although flooding is a perennial issue in Nigeria, the negative effects can be reduced with good management. From the analysis carried out, maps of areas susceptible and at risk to flooding based on the environmental criteria, anthropogenic criteria and past flooding events were produced using GIS tools and multicriteria analysis techniques. The maps created using ArcGIS software for the cities of Abeokuta South and Lekki serves as an example of the value of the geoprocessing employed in this study. Data from many social and environmental factors can be cross analyzed using this method.

6.1 Specific

The first specific objective was achieved by using the environmental criteria that described and depicted the varying physical characteristics of both study areas to develop a susceptibility map. From these maps, it was observed that elevation and distance from the drainage network are the main factors that affect the susceptibility of areas in the city of Abeokuta South. The level of susceptibility reduces as the distance from the drainage network increases but there were exception in some cases as some of the areas despite being close to the drainage network fall under areas with low susceptibility because they are above 200 m from the sea level. It was majorly the distance from drainage network that affects the susceptibility of areas in Lekki. Even though elevation differences play an important role in flood susceptibility, it makes little difference when it comes to the city of Lekki. This is because the elevation of the city of Lekki because the elevation of the entire area is between -13 m to 31 m above sea level with gentle undulating slopes.

The second objective was achieved by assessing the Susceptibility maps of both study areas alongside the anthropogenic activities of the location of points with recorded flood incidents between 2001 and 2020. All the points of recorded flood incidents occurred within areas of very high, high, and medium susceptibility. The common anthropogenic activity observed in both study areas are the lack or absence of proper artificial drainage network, construction of buildings very close to water bodies and dumping of waste into these artificial drainages. These practices along with the level of susceptibility of these areas have contributed to the flood incidences over the last 2 decades.

The third objective of this study was to map the areas at risk of a flood disaster in the city of Abeokuta South and Lekki for better environmental management based on using the susceptibility maps, the land-use and land cover maps and the flood density map to produce a flood risk map. In addition to distance from drainage network, land-use and land cover plays a major role in determining areas at risk of flooding for both cities. In Abeokuta south, the lack of proper construction planning seems to be common due to the common absence of artificial drainage networks and construction of buildings close to natural water bodies which put a lot of lives and properties at risk. In Lekki the sand filling of the lagoon and other drainage networks sends water back to land and greatly contributes to flooding.

The achieved results represent a true decision-making intervention tool for development and planning by government authorities and decentralized local authorities. In addition, it has been demonstrated that GIS and remote sensing techniques are quite helpful for identifying areas at risk of flooding and creating maps of flood susceptibility. It would be necessary to incorporate some missing factors in later work and, at the very least, test out more effective models such as Height Above the Nearest Drainage (HAND) that could minimize error margins in elevation models.

6.2 Recommendations

The absence of statutory policies and Flood Risk Management frameworks in Nigeria at all tiers of government indicates a lack of concern for the increasing risk of flooding (Echendu 2020). The government has traditionally been more likely to distribute funds in the wake of disasters than in advance to avoid or ameliorate the issue, placing a greater emphasis on post-disaster response. Now, with the identification of susceptible and areas at risk of flooding within these cities, proactive and preventive strategies combining both physical and non-structural interventions must be established and put into action to reduce the threat of floods. Some of these interventions include;

- Provision of avenues to be able to acquire research-backed climate information as well as land data should be made available in order to enhance areas such as risk assessment, enhanced reporting procedures (possibly involving citizen scientists), sustainable monitoring and warning services, information dissemination, building capabilities for mitigation and sustainable response strategies. This is due to the incomplete records on previous flood disasters and knowledge gaps in particular disaster-prone locations, there is a knowledge gap (Egbinola, Olaniran, and Amanambu, 2017). And It cannot be emphasized enough how important research is to provide hydrological data, modeling information, flood warnings, risk analysis, simulations, predicting, and adaptation (Kreibich et al. 2017; Liu et al. 2018).

- Establishment and proper enforcement of town planning regulations forbid the construction of structures or other activities in flood-prone areas.
- Establishment of gauge stations in the rivers that cross these cities. So as to allow the flow and level of the rivers to be measured. As without this data, a hydrologic or a hydraulic modelling (HEC-HMS and HEC-RAS, for instance) cannot be performed.
- Provision of adequate drainage facilities along with the construction of roads.
- Proper periodic inspection and monitoring of drainage systems to spot any problems and make repairs. Additionally, it is important to guard against the sedimentation and littering of drainage systems, and vegetation like trees whose root systems have a history of undermining the drainage system should be cut down or removed.
- Adequate education should be provided to those who are frequently affected by flood threats to encourage them to adopt environmentally sound practices like properly disposing of their waste rather than into drainage channels because improperly disposed waste, such as discarded plastic, shoes, clothing, and other items, also clogs drains, particularly at their narrowed ends or points. This also causes the storm water to overflow or pour into the sewers, which can cause flooding that can enter houses and farms and harm crops and household goods.
- Effective and lasting environmental and resource management methods to assist people in disaster-prone locations so as to experience less risk and vulnerability.
- Building partnerships amongst local communities, NGOs, volunteer organizations, and local and international donor organizations in order to manage floods.

7 BIBLIOGRAPHIC REFERENCES

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8 ANNEXES

ANNEXE A: DATA OF ABEOKUTA ANALYZED TO DETERMINE RANGE FOR EACH CLASSIFICATION.

Flood Point	Elevation (m)	Slope (%)	Drainage Density	Distance from Water course (m)	Susceptibility Class
1	44	3.102878	2.521465	68.372378	High Susceptibility
2	87	1.040991	0.923738	59.931065	Medium Susceptibility
3	30	0	2.958929	121.209843	Medium Susceptibility
4	30	4.56408	1.368502	105.530712	High Susceptibility
5	59	3.43311	2.779652	145.839379	High Susceptibility
6	62	7.270731	2.368818	91.526682	Very High Susceptibility
7	46	6.021525	2.004187	51.56857	Very High Susceptibility
8	37	1.357181	2.521465	52.503664	High Susceptibility
9	98	0	2.727182	24.771004	Medium Susceptibility
10	27	1.316674	3.01857	25.608272	High Susceptibility
11	24	2.001791	3.01857	171.256899	High Susceptibility
12	57	2.303343	1.251454	184.439679	High Susceptibility
13	60	1.645679	1.251454	191.550904	High Susceptibility
14	39	4.703212	2.005792	54.213531	High Susceptibility
15	61	3.239049	2.779652	16.350349	High Susceptibility
16	88	1.86173	0.923738	58.843762	Medium Susceptibility
17	30	0.658424	1.368502	9.562836	High Susceptibility
18	66	0.931111	1.806012	9.830315	Medium Susceptibility
19	115	4.882449	2.384268	32.670412	Medium Susceptibility
20	117	2.081294	1.176652	93.730538	Medium Susceptibility

21	75	4.408316	1.571214	302.998125	High Susceptibility
22	62	6.755693	1.690283	76.403735	Medium Susceptibility
23	68	3.288647	2.039699	78.200979	High Susceptibility
24	85	4.408316	2.240197	144.388633	High Susceptibility
25	42	1.645679	2.765198	92.561822	High Susceptibility
26	52	2.810654	1.768161	51.134747	High Susceptibility
27	66	7.491977	0.7043	234.77880	Medium Susceptibility
28	36	2.107127	2.928339	47.997656	Very High Susceptibility
29	87	2.569616	1.295311	334.5823	Medium Susceptibility
30	31	1.472021	3.142184	55.909444	High Susceptibility
31	95	3.616679	0.640276	286.184313	Medium Susceptibility
32	54	3.556552	1.571214	199.810495	Medium Susceptibility
33	43	3.748401	2.765198	57.627198	Very High Susceptibility
34	49	3.958102	1.153673	311.17287	Medium Susceptibility
35	81	2.372728	2.710624	131.732024	Medium Susceptibility
36	43	4.157111	0.640276	331.046153	Medium Susceptibility
37	94	6.91132	2.710624	88.131268	Very High Susceptibility
38	86	6.030386	2.681581	102.933278	Very High Susceptibility

ANNEXE B: DATA OF LEKKI ANALYZED TO DETERMINE RANGE FOR EACH CLASSIFICATION.

Flood Point	**Elevation (m)**	**Slope (%)**	**Drainage Density**	**Distance from Water course (m)**	**Susceptibility Class**
1	10	4.90946	1	775.459782	Medium Susceptibility
2	0	1.81707	0.41147	431.644303	Medium Susceptibility
3	0	2.87304	1.731191	27.71209	High Susceptibility
4	5.256	7.49198	1.48076	111.078251	High Susceptibility
5	0	4.0631	1.084678	471.229601	Medium Susceptibility
6	9.453	5.13945	0.737011	298.744072	Medium Susceptibility
7	10	2.29843	1.05574	529.757467	Medium Susceptibility
8	8.981	0.81262	0.12772	468.82206	Medium Susceptibility
9	10	5.45121	0.040531	194.998195	Medium Susceptibility
10	0	6.70103	0.258874	470.389114	Medium Susceptibility
11	0	2.56973	0.84519	385.229302	Medium Susceptibility
12	10	4.14356	2.509542	188.326779	Medium Susceptibility
13	0	2.36917	0.816551	67.800295	High Susceptibility
14	10	3.49521	0.736249	393.649053	Medium Susceptibility
15	10	7.19982	1.155357	91.67192	High Susceptibility
16	10	6.21534	1.66849	115.724673	Medium Susceptibility
17	10	2.56973	1.23146	114.34333	High Susceptibility
18	0	0	1.374888	21.129176	Very High Susceptibility
19	10	6.34676	0.026077	307.300279	Medium Susceptibility
20	0	0.81262	3.028784	269.065044	Medium Susceptibility
21	0	4.48784	1.779603	140.950928	Very High Susceptibility
22	10	6.94302	0.82364	681.524578	High Susceptibility
23	8.341	2.92994	0.82364	235.527714	High Susceptibility
24	6.966	11.6349	3.997713	84.324595	Very High Susceptibility
25	0	7.49198	3.997713	37.591778	Very High Susceptibility
26	0	1.28486	3.758964	98.305597	Very High Susceptibility
27	10	6.10817	2.03302	298.753455	High Susceptibility
28	9.837	4.90946	3.179045	24.656771	High Susceptibility

29	10	1.14922	1.605971	127.86479	High Susceptibility
30	4.494	4.59687	1.162501	179.248552	High Susceptibility
31	10	8.22714	1.792388	5.188189	High Susceptibility