SUITABILITY ANALYSIS FOR SITING CHECK DAMS IN FLOOD PRONE AREAS

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PLAGIARISM

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DEDICATION

I dedicate this project to JEHOVAH The Almighty God Through His Beloved Son Jesus Christ for His grace upon me and for seeing me through all the hurdles of the last five years and also to my beloved parents Mr and Mrs Igberaese for their support and guidance over the years.

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ABSTRACT

Flooding poses a significant challenge to Ugbowo and its environs, causing environmental degradation and socio-economic losses. This study aims to mitigate flooding through a comprehensive check dam suitability analysis using GIS and remote sensing techniques. Key criteria considered include land cover (21%), rainfall (18%), drainage density (16%), elevation (17%), slope (15%), and soil type (13%). Results indicate that 11.46% of the area is highly suitable, predominantly in the southeastern region, 87.32% moderately suitable, mainly in central and western areas, and 1.22% with low suitability in the northern section. The primary factors influencing suitability are land use/cover, rainfall patterns, and drainage density. Recommendations include structural elevation, runoff management, site-specific check dam design, and additional flood mitigation measures to enhance flood resilience and watershed management. This study provides a framework for optimizing check dam placement, thereby reducing flood risks and promoting sustainable water resource management in the region.

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ACRONYMS

UNIBEN - University of Benin

AHP - Analytical Hierarchy Process

MCDA - Multi-criteria design analysis

GIS - Geographic Information System

NOAA - National Oceanic and atmospheric Administration

NCGIA - National Centre of Geographic Information and Analysis

ESRI - Environmental Systems Research Institute

USGS - United States Geological Survey

NASA - National Aeronautics and Space Administration

LiDAR - Light Detection and Ranging

MCE - Multi-criteria Evaluation

NUC - National Universities Commission

DEM - Digital Evaluation Model LDD - Local Drain Direction

CN - Curve Numbers

CR - Consistency Ratio

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Check dams are crucial structures used in conservation efforts to address challenges posed by runoff and flooding. They play a vital role globally in preventing land degradation and boosting agricultural productivity (Polyakov et al., 2014; Piton et al., 2017; Abbasi et al., 2019; Pal and Galelli, 2019; Rahmati et al., 2019a). In numerous regions worldwide, check dams are primarily constructed to capture stormwater and support the sustainable management of natural resources (Abbasi et al., 2019; Haile and Suryabhagavan, 2019; Rahaman et al., 2019; Singhai et al., 2019; Vema et al., 2019). These dams act as barriers across streams and gullies to minimize runoff, enhance water infiltration, boost vegetation growth that helps slow down runoff, reduce lag times and peak river discharges, trap sediments, improve water quality, and reduce stream gradients (Abbasi et al., 2019). Moreover, check dams aid in restoring river channels by replenishing organic carbon and nutrients in the soil (Abbasi et al., 2019; Mongil-Manso et al., 2019). They also serve as flood control measures, capturing excess runoff that contributes to groundwater recharge (Abbasi et al., 2019; Rahmati et al., 2019a). By modifying sediment deposition patterns, check dams help maintain the stability of stream networks (Abbasi et al., 2019; Rahmati et al., 2019a). These structures are indispensable for curbing erosion, particularly in arid and semi-arid regions where gullies, ravines, and badlands are prone to develop (Castillo et al., 2007; Galicia et al., 2019; Nitheshnirmal et al., 2019).

Beyond their capacity to meet local needs, check dams have been widely used for decades due to their affordability and operational efficiency (Pal and Galelli, 2019). However, their performance varies depending on the location and specific site characteristics (Rahmati et al., 2019a). Therefore, accurately identifying and predicting suitable locations for check dam installation by considering spatial and environmental factors is crucial for conserving and managing natural resources.

Over time, numerous studies on site selection for check dams across different regions have employed traditional statistical methods combined with remote sensing (RS) and geographic information system (GIS) technologies (Huang et al., 2009; Ramakrishnan et al., 2009; Castillo et al., 2014; Dai, 2016). For instance, Padmavathy et al. (1993) utilized the weighted overlay technique to identify optimal locations for check dam construction. Several studies have also applied knowledge-based approaches, such as multi-criteria decision making (MCDM), to determine suitable sites for these structures (Ibrahim et al., 2019; Ildoromi et al., 2019; Mugo and Odera, 2019). Rahmati et al. (2019a, 2019b) integrated a Python-based site identification application with MCDM techniques to identify ideal check dam locations, validating their results with historical flood data using receiver operating characteristic-area under the curve (ROC-AUC) analysis. Ildoromi et al. (2019) employed fuzzy logic to pinpoint suitable check dam sites and validated their map through the locations of existing check dams and ROC-AUC measures. Recently, machine learning algorithms (MLAs) have gained traction in environmental sciences, proving to be more effective than traditional knowledge-based approaches (Khosravi et al., 2019; Chen et al., 2019). Al-Ruzouq et al. (2019) applied MLAs such as random forest (RF), support vector machine (SVM), and gradient boosted trees (GBT) to model dam site suitability. Despite these advancements, a comprehensive study utilizing MLAs to predict check dam locations in Iran has yet to be conducted.

1.2 Statement of the Problem

In many Areas in the Niger delta region is prone to erosion, flooding, and land degradation, the effectiveness of check dams in mitigating these issues will depend on its effective placement. However, the lack of comprehensive, data-driven methods for identifying suitable sites for check dam construction presents a big challenge. Traditional approaches often rely on limited environmental, hydrological, and topographical data,that often leads to ineffective outcomes in check dam performance. Therefore, there is an important need to develop and apply advanced spatial analysis techniques and technologies that includes Geographic Information Systems (GIS), remote sensing, and machine learning algorithms, to create an accurate and reliable suitability model for identifying the most appropriate locations for check dam installations. This will improve water conservation, reduce soil erosion, and improve land productivity in flood prone areas

1.3 Aim and Objectives

The aim of this research is to carry out suitability analysis for sitting a check dam in the study area.

The Specific Objectives Include

1. Estimate flood flow network density
2. Conditioning factors for flooding
3. Carry-out suitability analysis for check dams

1.4 Scope of Study

This study assess the impact of flooding on communities as well offer solutions to the flooding problem by the siting of check dams. This study covers the analysis for citing a check dam in flood prone area, the Geographical focus on where check dams can be sited to effectively manage flood, types of check dams materials and The hydrological and environmental impacts of sitting check dams.

1.5 Justification of the Study

The issue of flooding in the Niger Delta region of Nigeria is an unpleasant annually occurring problem that leads to the spending of millions of dollars, destruction of lives and properties, destruction of farmlands and roads that affects the socio-economic activities of the affected host communities and states. Hence this research on check dams is justified by their potential to address several environmental and water management challenges. Check dams reduce soil erosion, promote groundwater recharge, and support sustainable agriculture by slowing water flow and increasing infiltration.

CHAPTER TWO

LITERATURE REVIEW

2.1 Dams

A dam is a structure designed to obstruct or limit the flow of surface water or underground streams. The reservoirs formed by dams help control flooding and supply water for various uses, including irrigation, drinking water, industrial processes, aquaculture, and navigation. Additionally, many dams are paired with hydro power systems to generate electricity. They can also store and distribute water more efficiently across different areas. While the main function of a dam is to retain water, other structures like floodgates or levees (also called dikes) are typically employed to control or prevent water from flowing into specific regions.

Fig. 2.1: Hover dam which is the largest dam in the world

2.1.2 History of Dams

Ancient Dams

Early dam-building activities were concentrated in Mesopotamia and the Middle East. These structures were primarily used to manage water levels, especially in the Tigris and Euphrates rivers, which were crucial for agriculture and flood control. The oldest known dam, the **Jawa Dam** in Jordan, dates back to around 3000 BC. This gravity dam, located northeast of Amman, originally featured a stone wall 9 meters high and 1 meter wide, supported by a 50-meter-wide earthen rampart. Another ancient marvel, the **Lake Homs Dam** in

Syria, was built between 1319-1304 BC and is still operational. Meanwhile, in Egypt, the **Sadd-el-Kafara Dam** at Wadi Al-Garawi, dating back to around 2800-2600 BC, was constructed for flood control but was destroyed by heavy rains shortly after its completion.

The **Fayum Canal** system in Egypt, built during the Twelfth Dynasty (19th century BC), was an advanced irrigation project. It included two dams that retained water from the Nile, creating Lake Moeris (now Birket Qarun), which covered around 1,700 square kilometres.

By the third millennium BC, water management systems in **Dholavira, India**, were advanced, with reservoirs, dams, and channels for water storage. In **Yemen**, the **Great Dam of Marib**, initiated around 1700 BC, was an engineering feat that controlled irrigation for centuries, undergoing significant improvements over time, particularly by the Himyarites in 115 BC.

Other notable ancient dams include the **Eflatun Pınar**, a Hittite dam in Turkey dating back to the 15th century BC, and the **Kallanai Dam** in Tamil Nadu, India, constructed around the 2nd century AD. This stone dam is still in use today for irrigation purposes.

Roman Engineering

Roman dam-building techniques set a high standard for large-scale infrastructure projects. They introduced the concept of reservoir dams to ensure a continuous water supply during dry seasons. Using waterproof hydraulic mortar and Roman concrete, they built massive structures like the **Lake Homs Dam** and **Harbaqa Dam** in Syria.

Roman engineers also developed various dam types, including arch-gravity dams, buttress dams, and multiple-arch dams. They even constructed dam bridges, such as the **Bridge of Valerian** in Iran. In addition, Roman engineers were pioneers in using dams for hydropower, notably in **Dezful** and **Shustar** in modern-day Iran, where dams powered water wheels and mills.

Middle Ages

Dams continued to evolve during the Middle Ages. One example is the **Shāh Abbās Arch Dam** in Iran, built approximately 700 years ago and considered the thinnest arch dam globally. It stands 60 meters tall with a crest width of just one meter. In the Netherlands, low-lying areas relied on dams to control river water and prevent flooding, influencing place names like Amsterdam and Rotterdam, which began as river dams.

Industrial Revolution

The 19th century saw significant advancements in dam engineering. The first large-scale **arch dams** were built during this period. In 1804, **Henry Russel** of the Royal Engineers oversaw the construction of the **Mir Alam Dam** in Hyderabad, which is still operational. Another major project was the **Rideau Canal** in Canada, supervised by **Lieutenant-Colonel John By** in the 1820s, which included a series of masonry dams like the **Jones Falls Dam**.

In Australia, **Hunts Creek** near Parramatta was dammed in the 1850s, marking the first engineered dam in the country. Designed by **Lieutenant Percy Simpson**, it was influenced by advancements in dam engineering from India. France also contributed to dam engineering with **François Zola** designing the first modern French arch dam in Aix-en-Provence in the mid-19th century.

Modern Era

The 20th century saw the construction of massive dams, such as the **Aswan Low Dam** in Egypt (1902) and the **Hoover Dam** in the U.S. (1931–1936). These projects revolutionized dam construction with their scale and use of modern engineering techniques. The Hoover Dam, in particular, was an ambitious project that controlled floods, provided irrigation, and generated hydroelectric power, despite many technical and environmental challenges.

By 1997, an estimated 800,000 dams existed worldwide, with over 40,000 exceeding 15 meters in height. However, modern studies, like the one published by the University of Oxford in 2014, have raised concerns about the financial viability and environmental impact of many large-scale dam projects.

2.1.3 Types of Dams

Dams can be formed by human agency, natural causes, or even by wildlife interventions, such as those by beavers. Man-made dams are typically classified according to their size (height), intended purpose, or structure.

(a) By Structure

Based on structure and the materials used, dams can be classified into several types, including arch dams, gravity dams, arch-gravity dams, embankment dams, and barrages.

I. **Arch Dams**

An arch dam relies on a combination of arch action and gravity for stability. When the upstream face is vertical, the entire weight of the dam is supported by gravity, with hydrostatic pressure distributed according to the dam's stiffness. If the upstream face is sloped, this distribution becomes more complex. Arch dams are most effective in narrow canyons with steep, stable rock walls, as firm supports at the abutments are crucial.

There are two main types of single-arch dams: **constant-angle** and **constant-radius** dams. The constant-radius dam maintains the same curvature at all elevations, while the constant-angle dam keeps the subtended angle constant, adjusting the radii as necessary.

Examples of arch dams include:

Gordon Dam, Tasmania (arch dam)

Parker Dam, Colorado River (constant-angle arch dam)

Wildhorse Dam, Nevada (double-curvature dam)

Fig. 2.2: An Arch Dam

ii. **Gravity Dams**

A gravity dam is held in place by its own weight, counteracting the lateral forces exerted by the water. The design ensures that the resultant of the forces acting on the dam passes upstream of its toe to maintain stability. Gravity dams require a strong, impervious foundation to prevent uplift pressures that can destabilize the structure.

Examples include:

Grand Coulee Dam, Washington (solid gravity dam)

Braddock Locks & Da**m**, Pennsylvania (hollow gravity dam)

iii. **Arch-Gravity Dams**

An arch-gravity dam combines the characteristics of both arch and gravity dams, allowing for a thinner structure while still effectively managing large water flows. Example: Hoover Dam, Nevada (arch-gravity dam)

iv. **Barrages**

A barrage dam consists of a series of gates that can be opened or closed to regulate the flow of water. These structures are often used for irrigation and flood control. Tidal barrages, located at river mouths, help manage tidal flows and can also generate power. Example: Koshi Barrage, Nepal

iv. **Embankment Dams**

Embankment dams are constructed from compacted earth or rock and are categorized into two main types: rock-fill and earth-fill. Like gravity dams, they rely on their weight to resist water pressure. Example: Chatuge Dam, North Carolina (earthen embankment dam)

v. **Fixed-Crest Dams**

Fixed-crest dams are concrete barriers built across rivers, designed to maintain water depth for navigation. They can pose hazards to boaters due to their often-hidden presence and the induced currents they create.

2. **By Size**

Dams are classified into different size categories, which vary both internationally and within individual countries, such as the United States. The size of a dam influences its construction, repair, and removal costs, as well as the range and scale of its environmental impact.

i. **Large Dams**

The International Commission on Large Dams (ICOLD) defines a large dam as one that is at least 15 meters (49 feet) high from the lowest foundation to the crest. Additionally, dams between 5 meters (16 feet) and 15 meters in height that impound more than 3 million cubic meters (2,400 acre-feet) of water are also categorized as large dams. Dams that exceed 150 meters (490 feet) in height are considered "major dams."

Hydro power dams can be further classified based on height as either high-head dams (greater than 30 meters in height) or low-head dams (less than 30 meters in height). As of 2021, the ICOLD's World Register of Dams listed 58,700 large dams globally, with the tallest being the Jinping-I Dam in China, standing at 305 meters (1,001 feet).

i. **Small Dams**

Small dams serve various purposes such as hydro power generation, flood control, and water storage. They are particularly valuable for farms, where they can capture and store run-off for use during dry seasons. Unlike large dams, small dams often generate benefits without displacing populations, and decentralized small-scale hydroelectric dams are crucial for rural development in many developing countries.

In the United States, there are approximately 2 million or more small dams, many of which are not included in the National Inventory of Dams maintained by the Army Corps of Engineers. State regulatory agencies keep records of these small dams, leading to dispersed and uneven geographic information. Globally, small hydro power plants (SHPs) are gaining importance in national energy strategies. A study conducted in 2018 by Couto and Olden identified over 82,000 small hydro power plants either in operation or under construction worldwide. Definitions of SHPs, including their maximum generation capacity, dam height, and reservoir size, vary from country to country.

By Use

i. **Saddle Dam:** A saddle dam, also known as an auxiliary dam, is built to contain the reservoir formed by the primary dam. It serves to either increase water storage capacity or prevent overflow in certain areas. These dams are typically constructed in low-lying areas or "saddles" where the reservoir might otherwise escape. In some cases, dikes are built to prevent the reservoir from flooding nearby land, functioning similarly to levees.

ii. **Weir:** A weir, sometimes referred to as an "overflow dam," is a smaller dam used to create an impoundments in a river. This structure serves multiple purposes, including water abstraction and flow measurement. Weirs are also used to control the rate of water flow, either for irrigation or erosion control.

iii. **Check Dam:** A check dam is a small structure built across a waterway to reduce water flow speed and control erosion. Its primary function is to stabilize soil, prevent sediment accumulation, and promote water infiltration. Check dams are commonly used in areas prone to soil erosion, such as hilly terrain or regions with heavy rainfall.

iv. **Dry Dam:** Also known as a flood control or flood retention structure, a dry dam holds back water only during periods of high flow. The dam allows for normal water passage during non-flood periods but retains water when downstream flooding is imminent. This type of dam helps in managing flood risks in urban or agricultural areas.

v. **Diversionary Dam:** A diversionary dam redirects all or part of the water flow from its natural course into channels or tunnels, often for irrigation or hydroelectric power generation. The water may also be diverted to reservoirs for storage and future use. These dams play a key role in water management systems and energy production.

vi. **Underground Dam:** An underground dam traps and stores groundwater, allowing for its efficient use in regions with limited water resources. These dams prevent groundwater from flowing away and are often built in arid environments to preserve precious water resources. They are most common in areas such as north-eastern Africa, Brazil, and parts of Asia. There are two main types: sub-surface dams, which are built below ground, and sand-storage dams, which store water in accumulated sand layers behind the structure.

vii. **Tailings Dam:** Tailings dams are earth-filled embankments used primarily in mining operations to store tailings, the by-products of ore processing. Unlike traditional dams, tailings dams are continuously raised as the miners operation progresses. These structures need to manage the toxic chemicals present in the tailings, and modern designs include impermeable liners to prevent environmental contamination. The tailings dam design is chosen based on the geography, type of tailings, and other local factors, with upstream, downstream, and centreline construction methods being the most common.

2.1.4 Introduction to the uses of dams

It has been established that dams are natural or man-made structures that hold, increase the volume of water and restricts the flow of water in a water body. The important uses of dams have made it a matter of great concern for humans over the years. There are many dams in this civilized world. Although the main function of these dams is to hold water back, they often provide additional useful facilities. Major dam uses are discussed below.

Water Supply

1. Water stored in reservoirs of the dam is used to provide adequate amounts of quality freshwater to residential, industrial facilities and mining sites.

2. Dams can be used to regulate the flow of water in rivers. This is to say that water can be released from the reservoir to support wildlife and ecosystems downstream during a drought, and water can be released for agricultural uses during the same drought.

Example: Warragamba, a water supply dam of Australia, supplies water to more than 3.7 million people living in Sydney and the lower Blue Mountains.

i. Irrigation

Fig. 2.3: Irrigation

1. In many countries, cropland irrigation is done using water stored behind dams.
2. Example: Burrinjuck Dam, an irrigation dam of Australia, which was built as the main headwater storage for the Murrumbidgee Irrigation Area in New South Wales.

ii. Electrical Generation

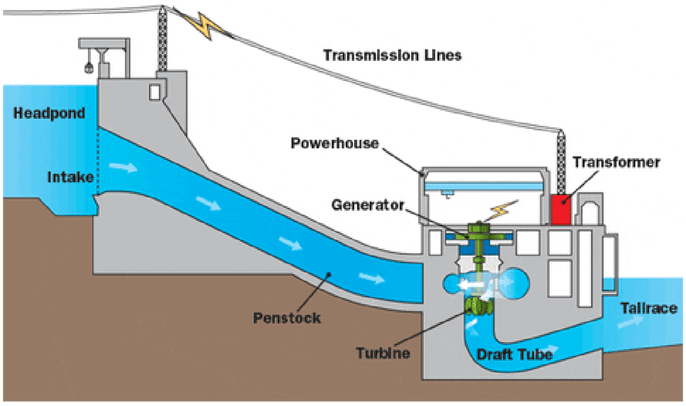


Fig. 2.4: Electrical Generation

1. To generate electricity in hydroelectric power stations
2. Hydro-power is considered clean because it does not contribute to global warming, air pollution, acid rain, or ozone depletion.
3. The United States is one of the largest producers of hydro-power in the world, second only to Canada. Dams produce over 103,800 megawatts of renewable electricity and meet 8 to 12 percent of the Nation's power needs.

4. Example: Itaipu Dam, a hydro-power dam in Brazil, is the largest hydro-electric power station in the world.

iii. Flood Control

Fig. 2.5: Flood control

1. For centuries, people have built dams to help control devastating floods. It helps to prevent the loss of life and property. Flood control dams impound flood-waters and then either release them under control to the river below the dam or store or divert the water for other uses.
2. Example: The Tennessee Valley Authority dams in the U.S.A., help to control floods on the Tennessee, the lower Ohio, and the lower Mississippi Rivers.

iv. Water Storage

1. Dams create reservoirs that supply water for uses, including industrial, municipal, and agricultural.
2. Water captured during the wet season can be stored for use during the dry season. Example: Corin Dam is a Water Storage dam of Australia which has a capacity of 19.9×109 gal.

v. Mine Tailings

1. It allows the mining and processing of coal and other vital minerals while protecting the environment.
2. There are more than 1,300 mine tailings impoundments in the United States. Mount Polley is a mine tailing dump of British Columbia, Canada.

vi. Debris Control

1. Dams provide enhanced environmental protection, such as the retention of hazardous materials and detrimental sedimentation.

vii. Navigation

1. Dams and locks provide for a stable system of inland river transportation throughout the heartland of the Nation.
2. Bonneville Dam of Washington, USA is a river navigation dam.

F) **Recreation**

1. Dams provide prime recreational facilities throughout the United States. Boating, skiing, camping, picnic areas, and boat launch facilities are all supported by dams.
2. Scrivener Dam is a recreation dam of Canberra, Australia.

Most of the dams are multi-purpose. Almost all dams have at least some flood mitigation effect in addition to their primary purpose. Flood control dams may have some of their storage capacity kept empty to store excess water inflow under flood conditions.

2.2 Introduction to check dams

Check dams are small structures built across streams or watercourses to slow water flow, reduce erosion, and improve soil and water conservation. Made from materials like loose rocks, concrete blocks, gabion baskets, or wood, they can be adapted to different environments such as seasonal streams, gullies, and mountain torrents. These dams play an essential role in managing watersheds by controlling both water and sediment movement. Over time, their popularity has grown, thanks to their simple construction and significant environmental benefits

2.2.1 History of check dams

The use of check dams has a history stretching back thousands of years. Ancient civilizations like the Nabataeans, in what is now modern day Jordan, built them to conserve water in dry landscapes. Over time, the idea of check dams spread across the globe, becoming a key tool for soil conservation, water management, and flood control. By the early 20th century, check dams became even more important as deforestation and farming practices led to increased soil erosion. These structures have been especially useful in mountainous and semi-arid regions, where heavy run-off and steep slopes can cause serious erosion and dangerous flash floods.

2.2.2 Functions and Applications

Check dams are transverse engineering structures of varying sizes and heights, constructed from materials like concrete blocks, loose rocks, gabion baskets, or wood. They are built across torrents, gullies, and streams, whether seasonal or permanent. These structures help control soil erosion, moderate water and sediment flow, and can enhance land productivity. Below are some of the functions and applications of check dams.

1. Erosion Control and Soil Conservation

One of the primary applications of check dams is to control soil erosion. By reducing the velocity of water flow, check dams encourages sediment deposition in upstream areas, which helps in reclaiming land that would have been lost to erosion . This function is important in regions with mountains, where unchecked water run-off can lead to the loss of nutrient-rich topsoil.

2. Water Retention and Flood Control

Check dams increase infiltration rates by slowing down surface run-off,in that way improving groundwater recharge. In flood-prone areas, they act as barriers that reduces the flow-rate of water which reduces the potential for downstream flooding . In semi-arid environments, this water retention capability is valuable for improving agricultural productivity and ensuring water availability during dry seasons.

3. Sediment Retention

Check dams can effectively trap sediments that is transported by water, preventing sedimentation in downstream reservoirs, rivers, and lakes. Over time, these accumulated sediments form the terraces can support vegetation growth and further stabilize the soil. However, sediment retention can also create challenges like the accumulation of sediments upstream of the dam may require constant removal to maintain the dam's design life.

4. Ecological Restoration and Enhancement

Check dams also play a role in ecological restoration, particularly in degraded landscapes. By changing the hydrological and sediment dynamics, they create conditions that are conducive to the re-establishment of native vegetation and wildlife habitats. This ecological enhancement function is crucial in regions where land degradation has compromised biodiversity.

2.2.3 Design considerations for Check dams

Design considerations include actions and steps that are taken to ensure safety, efficiency, durability and cost effectiveness of the structures to be designed and constructed.

Design considerations in dams involves ensuring that dams are designed to completely ensure that standards are meant, that the adequate materials are used and they ensure that strength and quality of these dams are not compromised. Check dams are built using various materials, depending on factors such as local material source, cost of raw material,cost of design and construction, climate, amount of rainfall and environmental conditions. Common materials that are used in design and construction of check dams include:

1. **Loose rocks:** Clastic sedimentary rocks are made up of pieces (clasts) of pre-existing rocks loosened by weathering. These rocks have particles ranging in size from microscopic clay to huge boulders; their names are determined by the clast or grain size. The smallest grains are called clay, then silt, then sandClastic sedimentary rocks are made up of pieces (clasts) of pre-existing rocks loosened by weathering. These rocks have particles ranging in size from microscopic clay to huge boulders; their names are determined by the clast or grain size. The smallest grains are called clay,

then silt, then sand. This material is commonly used in rural or remote areas where transporting materials is difficult.

2. **Concrete blocks:** Concrete blocks are made from cast concrete (e.g. portland cement and aggregate, usually sand and fine gravel, for high-density blocks). They are easily obtainable and they have enhanced strength. The addition of steel reinforcement can greatly increase its structural performance for it to be able to be used in check dams designs. The compressive strength of concrete blocks and masonry walls varies from 3.4 to 3.45Mpa. Concrete blocks for areas with high water flow and significant erosion is a good material for the construction of check dams

3. **Gabion baskets:** Gabion basket is a cage, cylinder or box filled with rocks, concrete, or sometimes sand and soil for use in civil engineering, road building, military applications and in dam construction. A gabion wall is a retaining wall made of stacked stone-filled gabions tied together with wire. Gabion walls are usually battered (angled back towards the slope), or stepped back with the slope, rather than stacked vertically. The life expectancy of gabions depends on the lifespan of the wire, not on the contents of the basket. When filled with rocks, these combine flexibility and strength, allowing for deformation without failure. The Gabion basket in recent years have gained usage in the construction of check dams due to its durability, strength and increased water resistance.

4. **Wood:** Wood is an organic material, produced by a large number of woody plants and quite variable in properties. Among the many uses for wood are: Load-bearing structures including beams, columns, trusses, and piles, due to its high strength. The unfinished wood is utilised for short-term projects like scaffolding and lining up an arch, among others is used in the construction of furniture, roofing materials, door and window frames, and shutters as it is simple to cut and mould into any size and form. It is naturally suited for use as a flexural member

because of its extremely high strength to weight ratio, ability to transmit both tension and compression stresses, and capacity to do so and it is used in the building of boats and movable bridges. Wood is commonly used for low-cost, temporary check dams and in regions or areas where timber is readily available.

The design of check dams depends on local hydrological and geomorphological conditions of the areas or regions for which it is to be constructed upon. Smaller dams are often used in narrow gullies, while larger and bigger structures are constructed across wider streams. The size and placement of a check dam are very important in reducing erosion and improving water management where they are located. (Sheng and Liao, 1997)

2.2.4 Environment impact assessment of siting check dams

Climate change is one of the most challenging global issues today in the world, and dams generally have greatly contributed to this problem in no small measure by creating environments that aids the growth methane-producing microbes which is one of the leading producers of methane a major global warning gases. Also, dams divides the flow of rivers and disrupt their natural flow,as well as the survival of aquatic fauna, particularly migratory species. They also interfere with the biogeochemical cycles of river ecosystems, affecting their overall function and structure.

While check dams can provide many benefits for the regions they are designed to serve, they can also create negative environmental impacts. For example, many studies have shown that the downstream effects of check dams can sometimes increase erosion rather than reduce it (Lucas-Borja et al., 2018; Abbasi et al., 2019). By trapping sediments upstream, these structures can reduce the sediment load delivered to downstream areas, leading to channel fill ups and destabilization in those regions. Check dams may also alter the natural flow pattern of a river, thereby affecting aquatic ecosystems. The reduction in water flow downstream can destroy the habitats of fish and other aquatic organisms that rely on regular sediment and water transfer (Jin et al., 2012). in some instances, check dams may lead to water stagnation and the development of anoxic conditions, which can have harmful effects on water quality.

2.3 The issue of Flooding

Flooding is one of the most devastating natural disasters globally, it affects millions of people annually and causes very terrible damages to infrastructures of cities and countries, ecosystems, and economies. It occurs when water inundates land that is normally dry, overwhelming natural and human-made drainage systems. While flooding is a natural process, human activities and climate change are increasingly exacerbating its frequency and intensity.

Global Impact of Flooding

Effects of flooding on a global and local scale includes

i) **Human Toll:** Floods impact over 250 million people annually. They can lead to loss of life, displacement of populations, destruction of homes, and disruptions to livelihoods. In developing countries Like Nigeria, Pakistan, Ghana,etc. floods are particularly devastating due to poor infrastructure and limited emergency response capabilities.

ii) **Economic Losses:** The World Bank estimates that global flood damages amount to billions of dollars every year. These losses come from damaged infrastructure (e.g., roads, bridges), agricultural losses, property damage, and business disruptions.

iii) **Ecosystem Disruption:** Flooding can also severely disrupt ecosystems, causing habitat destruction, soil erosion, and water contamination. While some ecosystems, such as wetlands, are adapted to flooding, excessive flooding due to human activity can cause long-term ecological damage.

Below are global Examples of the dire effects of flooding:

i) **Asia:** The Asian continent is highly vulnerable to flooding, because of their climate, increased rainfall, increased deforestation, poor drainage systems and overpopulation particularly in countries like Bangladesh, India, China, and Pakistan. Monsoon rains and riverine floods regularly displace millions.

ii) **Europe:** Central and Western Europe frequently experience river floods, often worsened by urban development in floodplains. Flash floods have caused significant damage, as seen in recent floods in Germany and Belgium in 2021.

iii) **United States:** The U.S. faces riverine and coastal flooding, particularly in areas like the Mississippi River Basin and along the Gulf Coast, where hurricanes intensify the flood risks.

iv) **Africa:** Floods are common in sub-Saharan Africa, especially along major rivers like the Nile and Niger, often affecting millions through displacement and food insecurity

2.4 The Geographic Information System (GIS)

According to NCGIA, a GIS is a comprehensive system comprising hardware, software, and procedural components designed to facilitate the management, manipulation, analysis, modeling, representation, and display of georeferenced data. This integrated approach enables the resolution of complex problems related to resource planning and management (NCGIA, 1990).

Beyond this definition, numerous individuals and organizations have attempted to define GIS, underscoring the complexity and multifaceted nature of this field. Environmental Systems Research Institute (ESRI) provides an insightful analysis of the GIS acronym, breaking down its three letters to reveal the essence of GIS:

G: Geographic - implies an interest in the spatial identity or locality of certain entities on, under, or above the Earth's surface.

I: Information - implies the need to be informed to make decisions, where data or raw facts are interpreted to create useful information.

S: System - implies the need for staff, computer hardware, and procedures to produce information required for decision-making, encompassing data collection, processing, and presentation.

Various definitions of GIS underscore its multifaceted nature: GIS is defined as a computerized system for capturing, storing, retrieving, analyzing, and displaying spatial data describing land attributes and environmental features for a given geographic region, utilizing modern information technology (Thurgood, 1995).

GIS is a system of hardware, software, and procedures designed to support the capture, management, manipulation,analysis, modeling, and display of spatially referenced data, solving complex planning and management problems (Rhind, 1989).

Cowen (1988) defines GIS as a decision support system involving the integration of spatially referenced data in a problem-solving environment.

Burrough (1986) views GIS as a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data from the real world. Aronoff (1989) sees GIS as any manual or computer-based set of procedures used to store and manipulate geographically referenced data.

Carter (1989) defines GIS as an institutional entity, reflecting an organizational structure that integrates technology with a database, expertise, and continuing financial support over time.

In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e., data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system (United States Geological Survey - USGS).

2.5 GIS Applications in Flood Mapping

The applications of GIS in Flood Extent Mapping are as follows: 28

1. Flood Boundary Delineation

Flood boundary delineation is a critical application of GIS in flood extent mapping. It involves using GIS to create accurate flood boundaries, which are essential for emergency response planning, evacuation zones, flood insurance mapping, and infrastructure planning. GIS integrates remote sensing imagery, hydrological modeling, and terrain analysis to delineate flood boundaries. This process helps identify areas at risk of flooding, allowing for proactive measures to mitigate damage (Mason et al., 2007).

2. Flood Depth Analysis

Flood depth analysis is another vital application of GIS in flood extent mapping. By integrating LiDAR (Light Detection and Ranging) data, GIS estimates flood depths, inundation areas, and water volume. This information supports damage assessment, infrastructure design, flood mitigation planning, and emergency response. Accurate flood depth analysis enables authorities to prioritize response efforts, allocate resources effectively, and minimize damage (Schumann et al., 2016).

3. Flood Risk Assessment

GIS-based flood extent maps support flood risk assessment by identifying vulnerable populations, locating critical infrastructure, estimating economic losses, and prioritizing mitigation measures. Flood risk assessment informs urban planning, emergency preparedness, flood insurance pricing, and climate change adaptation. By analyzing flood extent maps, authorities can identify areas of high risk and develop targeted strategies to mitigate flood impacts (de Moel et al., 2015). 29

4. Emergency Response Planning

GIS enables rapid flood extent mapping for emergency response planning. This application supports evacuation planning, resource allocation, search and rescue operations, and damage assessment. By integrating real-time data from sensors, satellite imagery, and weather forecasts, GIS provides critical information for emergency responders. Rapid flood extent mapping enables authorities to respond effectively, reducing the risk of harm to people and property (Jonkman et al., 2018).

5. Hydrological Modeling

GIS integrates hydrological models to simulate flood events, predict flood extent, estimate water levels, and evaluate mitigation measures. Hydrological modeling supports flood forecasting, water resource management, climate change impact assessment, and infrastructure design. By analyzing hydrological models, authorities can develop effective flood mitigation strategies, optimize water resource management, and minimize flood risks (Bates et al., 2010).

6. Damage Assessment

GIS-based flood extent maps aid in damage assessment by estimating economic losses, identifying damaged infrastructure, prioritizing recovery efforts, and supporting insurance claims. Accurate damage assessment enables authorities to allocate resources effectively, prioritize recovery efforts, and minimize economic impacts (Sampson et al., 2012).

7. Floodplain Management

GIS supports floodplain management by identifying flood-prone areas, prioritizing mitigation measures, optimizing land use planning, and supporting floodplain regulations. Flood plain management involves balancing human activities with flood risk reduction. GIS helps authorities develop effective floodplain management strategies, reducing the risk of flooding and minimizing damage (FEMA, 2015).

8. Real-time Flood Monitoring

GIS integrates real-time data from sensors, satellite imagery, and weather forecasts to monitor flood extent. Real-time flood monitoring enables early warnings, emergency response planning, flood forecasting, and water resource management. This application supports proactive flood management, reducing the risk of harm to people and property (Schumann et al., 2018).

2.6 AHP Decision Hierarchical Structures Development

The fragmentation of a complex decision problem into smaller, more manageable pieces at multiple hierarchical levels/layers is referred to as a decision hierarchical structure. Figure 2.7 depicts a hierarchical tree with four levels. The objective or goal is at the top of the hierarchy, and the evaluation alternatives (options) are at the bottom, while the intermediate levels correspond to criteria and sub-criteria, depending on the project. Figure 3.4 shows a structure that is formed from the generalized notion seen in Figure 2.7.

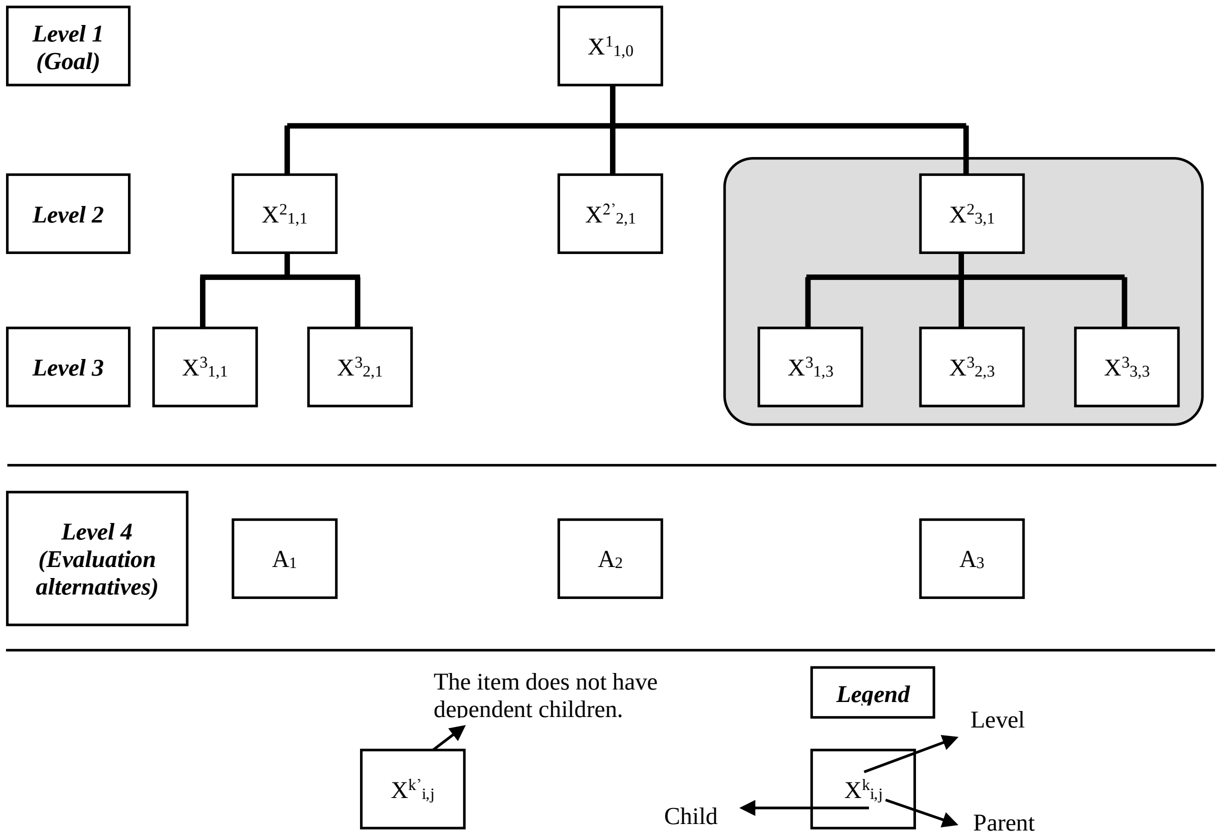


Fig. 2.6: A four-level problem decomposition with a decision hierarchical structure. Adapted from (Sadiq et al., 2004).

Depending on the complexity of the criterion parts, the levels can be decreased to 3 or increased to 4. The nomenclature used in Figure 3.4 for each item in the hierarchical model is Xki, j, where I am the child's order at level/layer k, and j is the child's parent (Sadiq, et al., 2004). For instance, X21,1 indicates that the item is at level k = 2, that it is the first child I = 1, and that its parent is j = 1. In the intermediate levels, each child is a criterion and sub-criterion that has an impact on the corresponding parent and child. Any intermediate item (element, factor, or sub-criterion) with an apostrophe, XK'I,j, indicates that the element has no dependent children. The derivation and discussion that follows are limited to the shaded items at levels 2 and 3. (i.e., X23,1, X31,3, X32,3, and X33,3).

To account for physical and socio-economic aspects in this case study, a three-level structure was used (Figure 3.5). These parameters are elevation from a digital elevation model (EL); slope estimated from a DEM (SP); land-use and land cover from a municipal zoning map (LU); rainfall (RF); soil types (SW); and stream or drainage networks (see Figure 3.5). (DN). In the analysis, the municipality boundary is employed as a constraint factor. When putting together an AHP hierarchy with a high number of pieces, the decision-maker should try to group them in clusters so that they don't diverge in extreme ways, as recommended by (Ishizaka, et al., 2011). AHP is utilized as a Multi-Criteria Decision Analysis (MCDA) in the multi-criteria decision-making process by arranging data in this way (Figure 3.5).

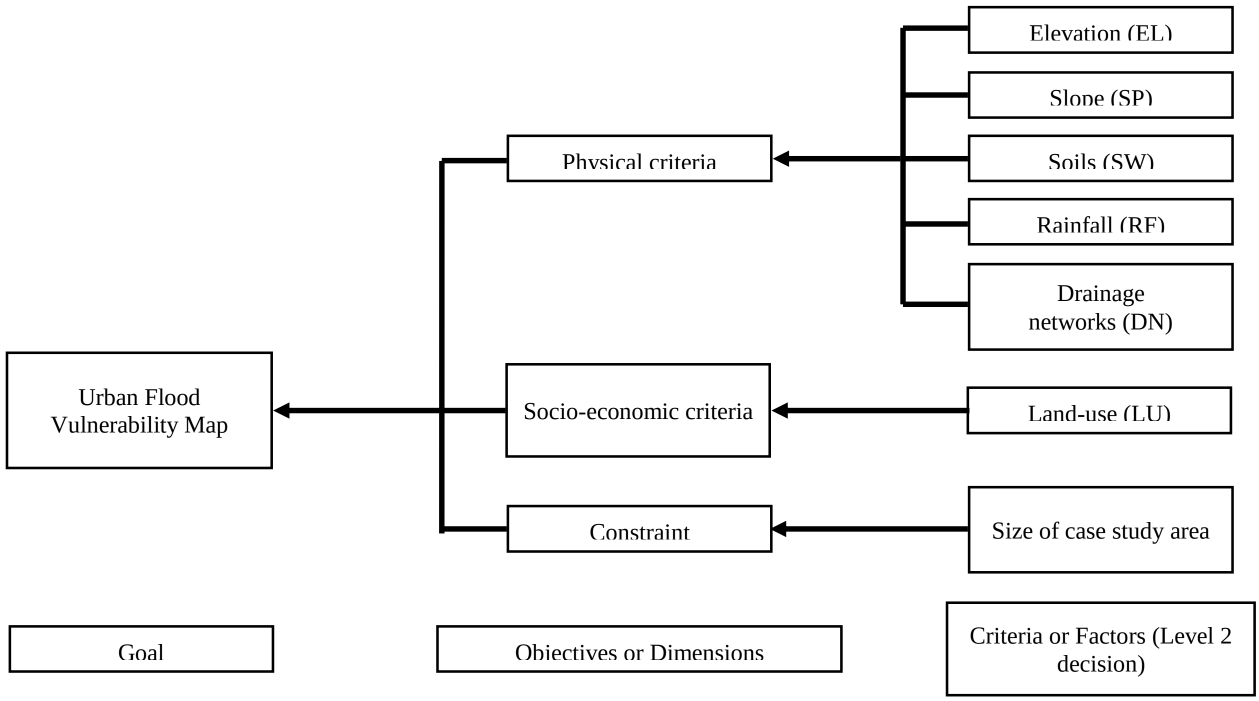


Fig. 2.7: depicts urban flood vulnerability as a three-level hierarchical structure of parameter features

2.6.1 ANALYTICAL HIERARCHY PROCESS (AHP) as a Tool for Multi-Criteria Decision Making

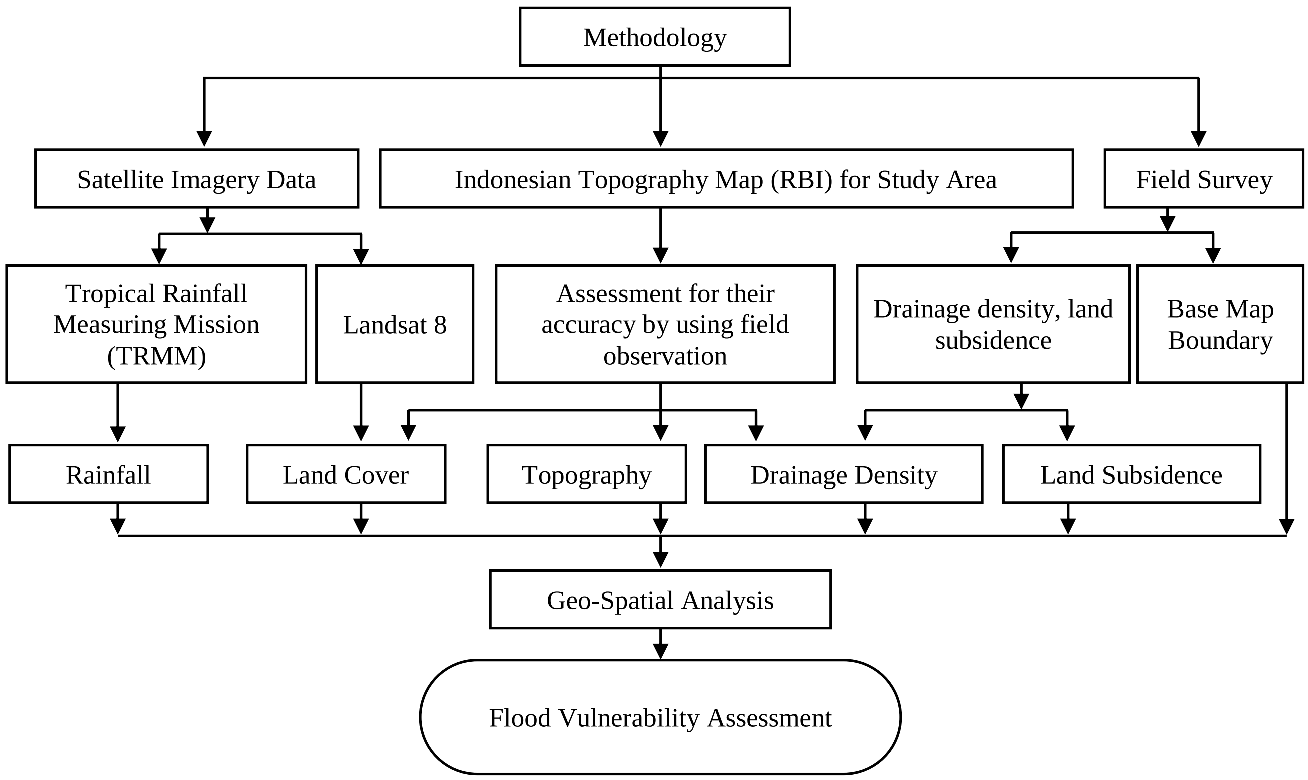


Fig. 2.8: Research methodology

In most decision-making processes, the expert works with the decision-maker(s) to structure the problem appropriately. When allocating weights, AHP has the advantage of allowing a hierarchical structure of the criteria, which allows users to focus more on specific criteria and sub-criteria. This is critical because a different structure could result in a different final ranking. Criteria with a large number of sub-criteria are given more weight than those with fewer sub-criteria. The analytic hierarchy process, which is a structured technique for dealing with complex decisions, was used to structure the flood causative factors in the application of multi-criteria decision analysis.

In theory, rather than prescribing a proper solution, the AHP assists decision-makers in identifying the one that best meets their needs and understanding the problem. As a result, AHP is a decision-making strategy based on people's genuine ability to make key decisions. It enables decision-makers to actively participate in the exploration of all available choices to thoroughly comprehend the underlying challenges before reaching an agreement or making a decision (Estoque, et al., 2010).

As a result, the goal of AHP is to evaluate the available options for a certain goal by establishing priorities for these options and the criteria that have been chosen.

A pairwise comparison technique is utilized in the AHP implementation to determine the priorities for the criteria in terms of their importance in attaining the aim. Similarly, the alternatives' priorities (i.e., the competing choices under consideration) are determined through pairwise evaluations of their performance against each criterion. As a result, AHP is founded on three principles: decomposition, comparison judgment, and priority synthesis (Saaty, 2008).

AHP provides an effective quantitative decision-making method for dealing with complicated and unstructured problems by arranging and assessing alternatives according to a hierarchy of multiple features, as shown in Figure 3.3. AHP provides a better, simpler, and more efficient framework for identifying selection criteria, calculating their weights, and analyzing the results (Bojovic, et al., 2008). As a result, the technique allows judgments on intangible qualitative factors to be combined with tangible quantitative criteria. The expert(s) and participants utilize AHP to establish priorities for all of the hierarchy's nodes once it has been established. By doing so, information from experts and participants is elicited and quantitatively processed. Priorities are allocated over a hierarchy based on the design, and their values are determined by the information submitted by process users, as shown in Table 1. Multiple pairwise comparisons in AHP are based on a nine-level standardized comparison scale (Table 1). The nine points were chosen because psychologists believe that nine objects are the maximum number of objects that an individual can compare and rank consistently. Pairwise decisions are made using the most up-to-date information and the decision maker's knowledge and experience.

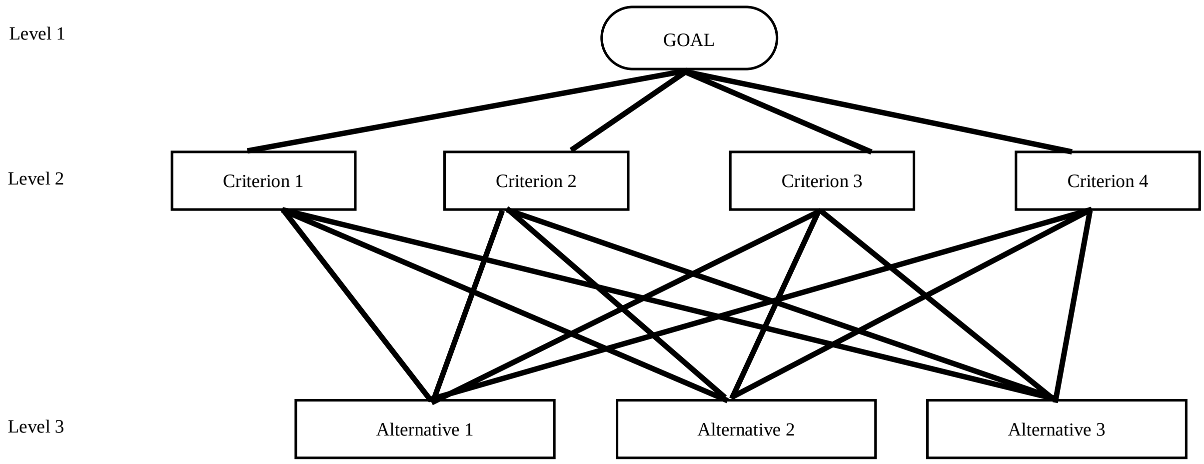


Fig. 2.9: The general structure of the analytical hierarchy process (AHP) for multi-criteria decision-making. modified from (Zahedi, 1986).

The goal is to choose among the competing alternatives 1, 2, and 3 based on a ranking score when judged individually against criteria 1, 2, 3, and 4.

Table 1. The nine-point intensity of importance scale was modified from (Schoenherr, 2008).

Intensity of importance	Definition	Description
1	Equally important	Two factors contribute equally to the objective.
3	Moderately more important	Experiences and judgment slightly favour one over the other
5	Strongly more important	Experiences and judgment strongly favour one over the other
7	Very strong more important	Experiences and judgment very strongly favour one over the other. Its importance is demonstrated in practice.
9	Extremely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals of above	If any element I have one of the above numbers assigned to it when compared with element j, then j has the reciprocal value when compared with i	-
Ratios (1.1-1.9)	If the activities (elements) are very close	May be difficult to assign the best value, but when compared with other contrasting activities (elements) the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities (elements).

CHAPTER THREE

METHODOLOGY

3.1 Study Area

Ugbowo is a prominent urban district within Benin City, the capital of Edo State, Nigeria. Based on available sources, Ugbowo is situated within the Oredo Local Government Area, one of the three LGAs that comprise the Benin City metropolis (the other two being Egor and Ikpoba-Okha). The district is an integral part of the city's urban fabric, contributing to the dynamic socio-economic and environmental landscape of the region. Benin City is geographically positioned between Latitude 6°21′N and 6°44′N and Longitude 5°35′E and 5°44′E. The city is characterized by fairly flat terrain, lying at approximately 8.5 m above sea level (Atedhor et al., 2011), and is located within a dense equatorial rainforest zone that experiences heavy rainfall. As of the 2006 National Population Census, Benin City had a population of 1,346,703, underscoring its status as a major urban centre in southern Nigeria.

The hydrology of the metropolis is significantly influenced by two major rivers. The Ikpoba River, a fourth-order stream situated within the rainforest belt (Efe, 2013), drains the northeastern portion of the city, while the Ogba River drains the southwest. These water bodies play a crucial role in the drainage and flood dynamics affecting Ugbowo and the surrounding areas.

Rapid urban development in Ugbowo has led to a marked reduction in the native evergreen rainforest vegetation, thereby altering natural water infiltration and runoff patterns. This study focuses on Ugbowo to assess flood susceptibility and to evaluate the suitability of check dam implementation as a flood mitigation measure, ultimately contributing to sustainable urban planning and water resource management within the region.

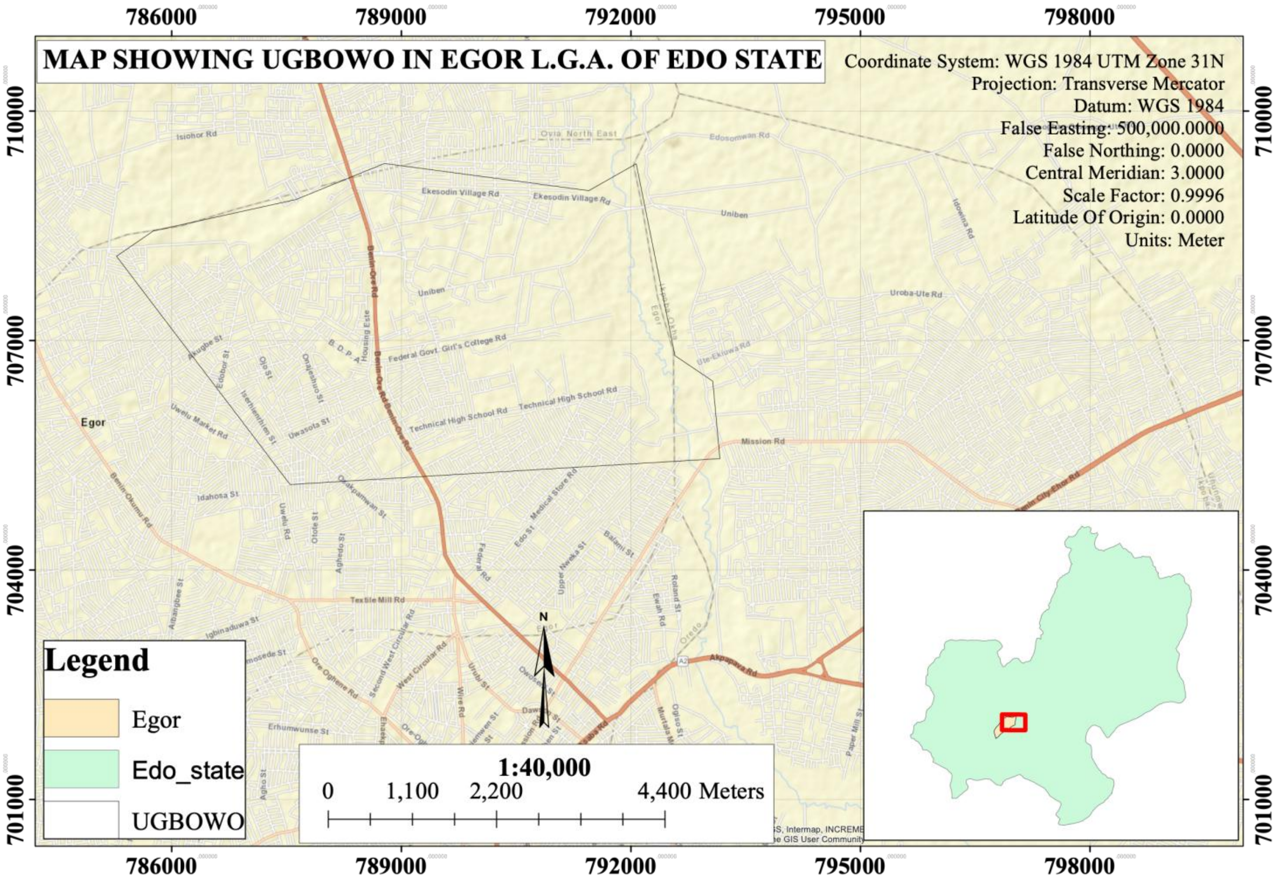


Fig. 3.1: Study area map.

3.2 Digital Elevation Map

Procedure for the above Map

Digital Elevation Model (DEM) was downloaded from the United States Geological Survey (USGS) website https://earthexplorer.usgs.gov and input into the ArcGIS environment, The shapefile of the study area which was created earlier was added to ArcGIS, A function "clip Raster" was used to clip the DEM into the desired shape, And "Reclassify" function was used to reclassify the DEM based on elevation level into five(5) group which was named: Very High, High, Moderate, Low, and Very Low respectively.

3.3 Map of Slope

Procedure for the above Map

A slope map was created from the DEM layer.

From ArcGIS System Toolboxes > Spatial Analyst Tools > Surface > Slope.

The output of the Topo to Raster tool is the input raster. The location of the output raster was specified. The output measurement was measured.

Click OK. A slope map is created from the DEM layer.

3.4 Soil Data Map

Procedure for the above Map

A scanned image of the soil map of Nigeria was georeferenced and digitized.

The study area layer was then used to clip the vector layer(digitized soil map)

And the vector soil map was then converted to raster, using the “Polygon to raster” feature in ArcGIS.

3.5 Map of Rainfall Data

Procedure for the above Map

Rainfall data was downloaded and interpolated using the inverse distance weighting (IDW) method for it.

Add DEM Map in ArcMap Software, then open ArcToolbox.

Already open ArcToolbox, select Spatial Analyst Tool > Hydrology, and perform 3 tasks one by one – (i) Fill, (ii) Flow Direction, and (iii) Flow Accumulation.

(i) Fill

Open Fill, select Input file- Dem Map, choose Output Destination and write the name, then click OK.

(ii) Flow Direction

Open Flow Direction, select Input file- Fill, choose Output Destination and write the name, then click OK.

(iii) Flow Accumulation

Open Flow Accumulation, select Input file- Flow Direction, choose Output Destination and write the name, then click OK.

Complete all 3 processes, Now open the Raster calculator to calculate Flow Accumulation.

Open the Search Box and search Raster Calculator. Raster Calculator window appears, double click Flow Accumulation Data (FLOW_ACCU) >=5000 (this value calculate for River Accumulation). Write-Output name and choose a destination and then click the OK Button.

You can see the calculated Flow Accumulation Result (flow_accu_cal) '0' and '1'. Value 1 mentions River Network.

Customize this Data to better understand River Network. Select flow_accu_cal data, Right-click, and choose Properties. Properties window appears value '0' choose to blank colour and click OK.

Stream Order

The next step is to perform the Stream Order. Open ArcTollbox > select Spatial Analyst Tool > Hydrology > Stream Order.

Stream Order window appears, Input stream raster – Flow Accumulation Calculate Data (flow_accu_cal). Input flow direction raster – Flow Direction Data and then choose Output and click OK.

The next important part converts Stream ordering into a Feature as well as Polyline Shapefile.

In the ArcTollbox > select Spatial Analyst Tool > Hydrology > select Stream to Feature.

Stream to Feature window appears, Input stream raster (streamj_order), then Input flow direction raster (FLOW_DIRECT) and choose Output and click OK.

Customize Stream Network Feature Data, Right-click, and select Properties.

Stream Network Properties window appears, in the symbology group select Categories and choose GRID_CODE in the Value field option, and click Add all values.

You can also change colour, width, and Labels to Better Understand Stream Ordering. Complete all of the Processes click the OK button.

3.6 Land use Land cover Map

Procedure for the above Map

i. Data Gathering

The data are satellite imageries (Landsat 8) of the research region downloaded from the United States Geological Survey for the year 2023. (USGS).

ii. Satellite images will be imported.

The first step is to extract the layers and stack the separate bands after getting the satellite pictures in zipping and geo-Tiff files. The photos will then be loaded into ArcGIS vs10.7 environments from the file folder on computer hard disk C.

The following are the steps for combining the different bands into a single multispectral layer (colour composite):

a) Select Windows from the drop-down menu (a drag-down list appears).

b) Choose your image analysis (a window is displayed).

c) Select all of the bands that will be stacked.

d) Select "composite" from the drop-down menu.

iii. **Sub Setting (creating area of interest)**

The coordinates of the bottom left and top right of the study area approximately will be obtained using an identifier in the software; the region of interest (ROI) will be extracted from the whole satellite scene. This will be done by using the shape file contained in the boundary layer of the study area obtained for the study. This will then be used to sub-map the area of interest from all the bands on the images imported. This will be used to ensure the data quantity reduction and for focusing on the area of interest. The process (in ArcGIS; subsetting) will be repeated until all the bands are sub-settled.

The steps in the image subsetting are;

a) Go to the Arc toolbox (a drag-down list appears)

b) Click on Spatial Analyst (a drag-down list appears)

c) Select extraction (a drag-down list appears)

d) Select extraction by mask (a new window is displayed)

e) Provide the information requested and click OK.

iv. **Domain Definition**

The land use land cover classes identified in the study area to be used in the image classification includes bare surface, built-up area, rocks, and vegetation.

v. **Colour Composite**

Colour composites for 2023 images will be formed by combining the three formed subbands raster into a single map so that a better visual impression of the reality on the ground be obtained than by displaying one band at a time. This will help in visualizing land cover types without any enhancement work.

a) Go to windows on the toolbar.

b) Click on image analysis (already the single bands were brought to the ArcGIS environment then add them to have a single multispectral band).

c) Go to the composite band to combine the selected layers to form a temporary multispectral layer.

vi. **Creation of Sample Set**

The sample set of 2023 from the map list image of each period will be created. The domain classes such as; bare surface, built-up areas, rocks, and vegetation will also be created. The steps below show how to create training samples using the controls on the toolbar:

a) On the toolbar, choose an appropriate image layer in the layer list.

b) Click the draw button. Notice that there are three drawing tools available, polygons, circles, and rectangles.

c) In the map display, identify an area that belongs to a known class. Use the drawing tools to define training samples.

d) Once you finish drawing the training samples, a new class is created in the training sample manager with a default name, value, and colour. In the manager, change the class name, value, and colour if desired for the land, and repeat steps b-d to create a few more training samples to represent the rest of the classes on the image.

vii. **Image Classification**

This involves the location and delineation of selected cultural features and evidence of human activity or natural features. The identification of the imageries determines the class type of the study area. In this case, the classes that will be identified are; Built-up areas, bare surfaces, vegetation, and rocks. Image classification and analysis operations will be used to digitally identify and classify pixels in the data.

viii. **Classification Processes**

This will be done using ArcGIS software. You must first create "training areas" before the execution of the classification process. The classification process will be achieved through the following Steps;

a) The first step is to activate the spatial analysis extension in ArcGIS (customize> extensions>spatial analyst).

b) Generate clusters: this unsupervised classification example uses the iso-clusters unsupervised classification method (spatial analysis tools>multivariate>iso-clusters).

c) The next step was naming and selecting colours for each class that was generated by the iso-clusters output.

ix. **Post Classification Comparison**

In post-classification, the image of 2023 will be used to see the changes that occur within these periods. The classified image will then run for post-classification comparison to produce a change detection analysis. By using the change detection statistical tool of the post-classification, the matrix table of the ''from –to'' change class will be obtain obtained.

3.1 Map of Drainage Density Data

Procedure for the above Map

From the ArcGIS software, input the DEM of the study area and search “line density” input the necessary parameters, and press Ok. The drainage density of the area will appear .

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Result

All maps produced are in WGS84 UTM Zone 31 N coordinate system.

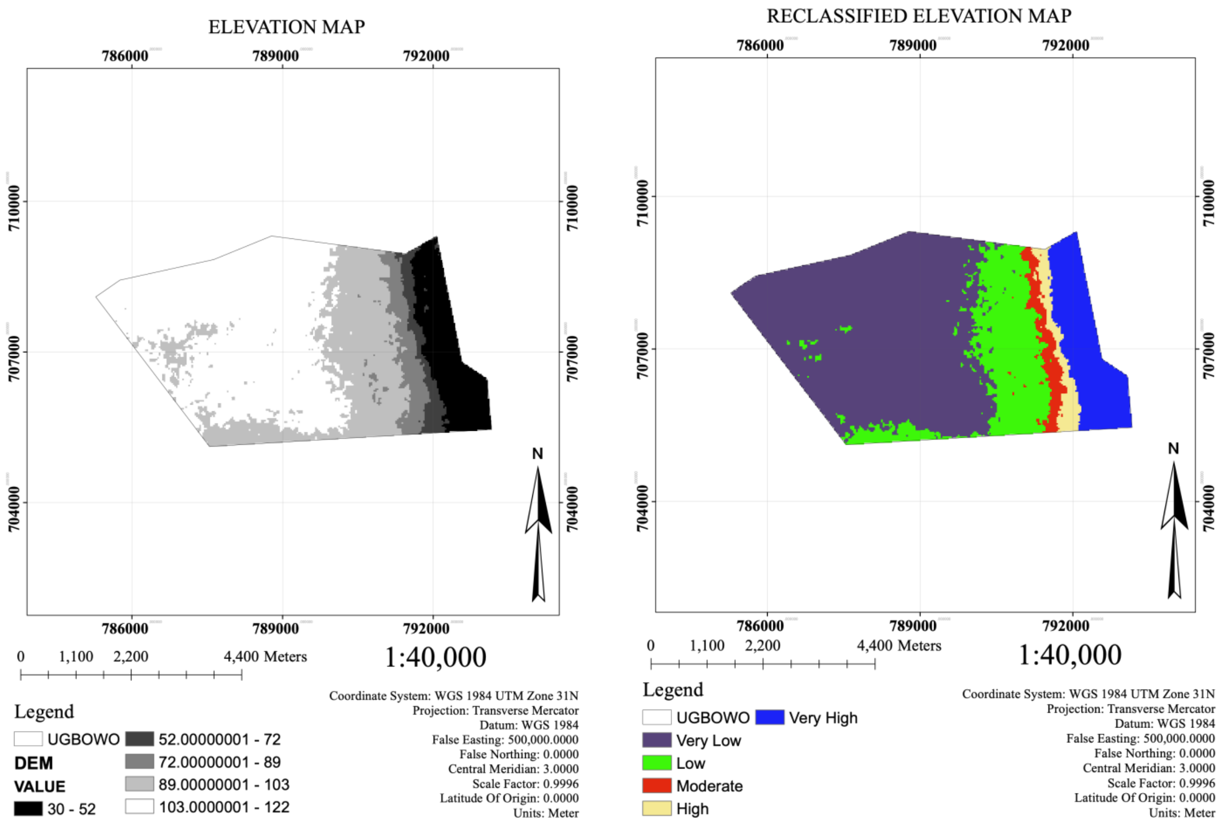


Fig. 4.1: Original DEM Map, Reclassified DEM Map

4.1.1 Slope Map

Elevation and slope are essential factors in determining a terrain's suitability for check dam construction. The slope influences the direction and volume of surface runoff that a check dam can effectively manage. The slope has a significant impact on the water retention capacity and structural stability of check dams. ,in this map areas with lower slopes (0-3.12 degrees) are given the highest ranking (5) for check dam suitability, while steeper slopes (14.59-33.22 degrees) receive the lowest ranking (1).

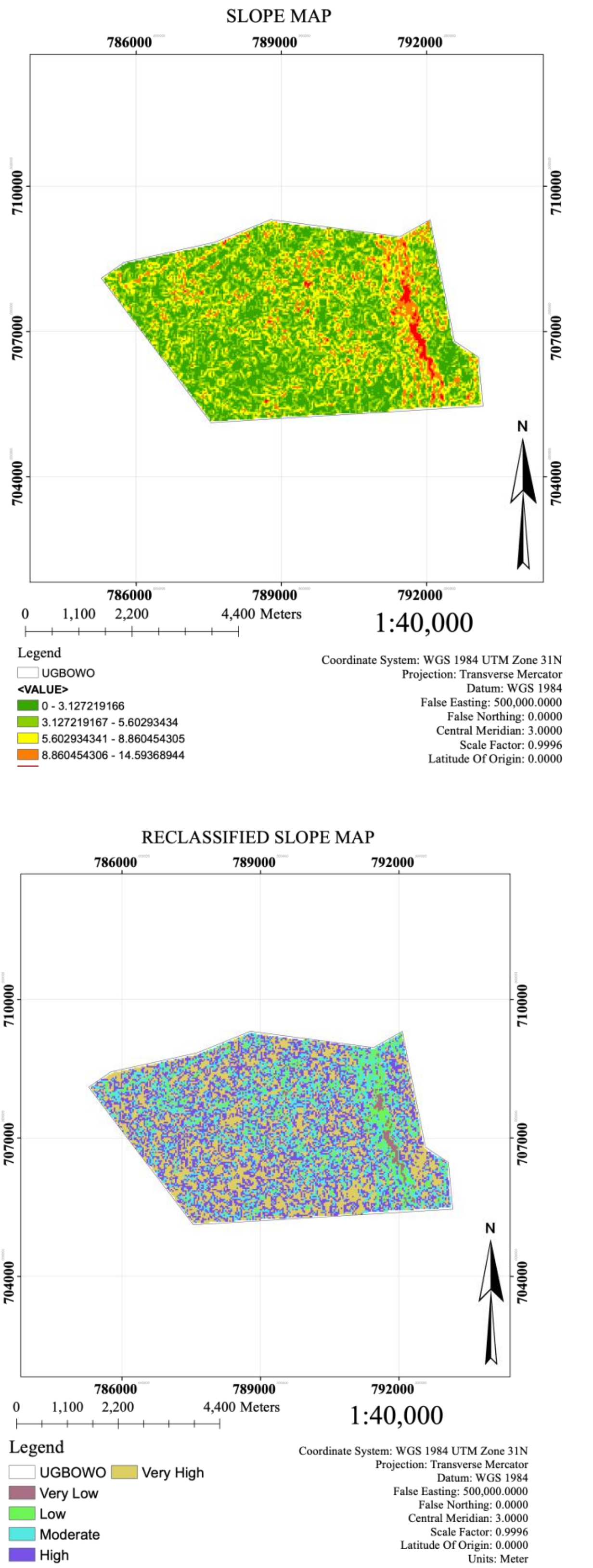
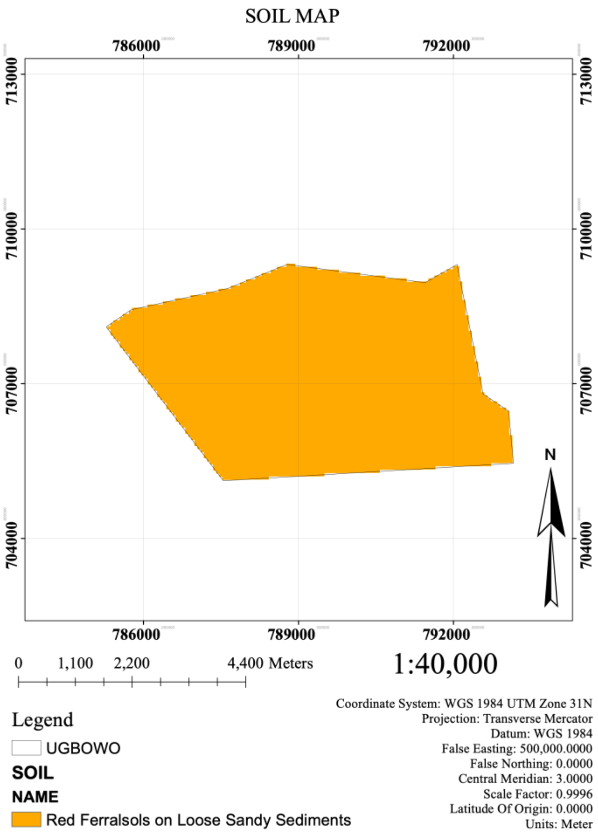


Fig. 4.2: **Original Slope Map, Reclassified Slope Map**

4.1.2 Soil Data Map

In the study area, Red Ferralsols on Loose Sandy Sediments are present, which received a ranking of 2, indicating moderate suitability for check dam construction.



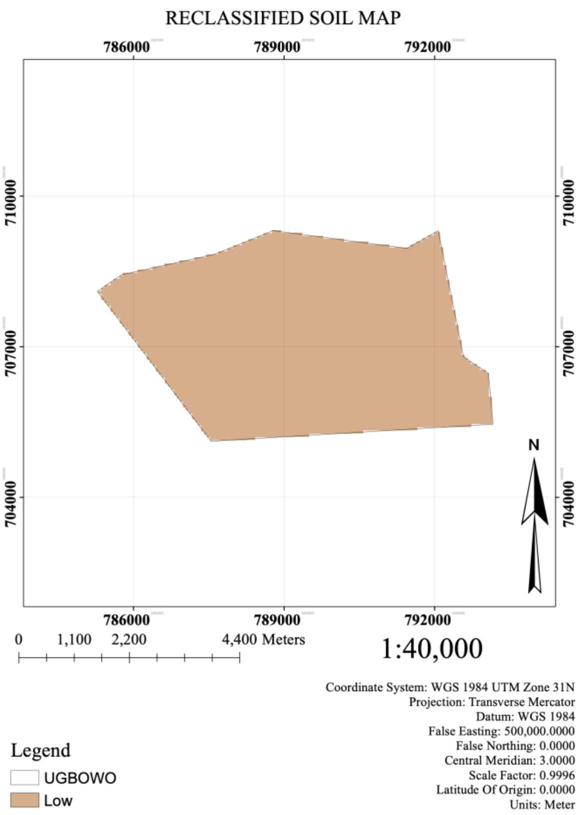


Fig. 4.3: **Soil Data Map, The Reclassified Soil Map**

A scanned image of the soil map of Nigeria was georeferenced and digitized.

4.1.3 Rainfall Data Map

The study area experiences rainfall ranging from 1,267mm to 2,407mm annually. Areas with higher rainfall (2,179-2,407mm) receive the highest ranking (5) for check dam suitability, as these areas have greater potential for water harvesting. Conversely, areas with lower rainfall (1,267-1,495mm) receive the lowest ranking (1).

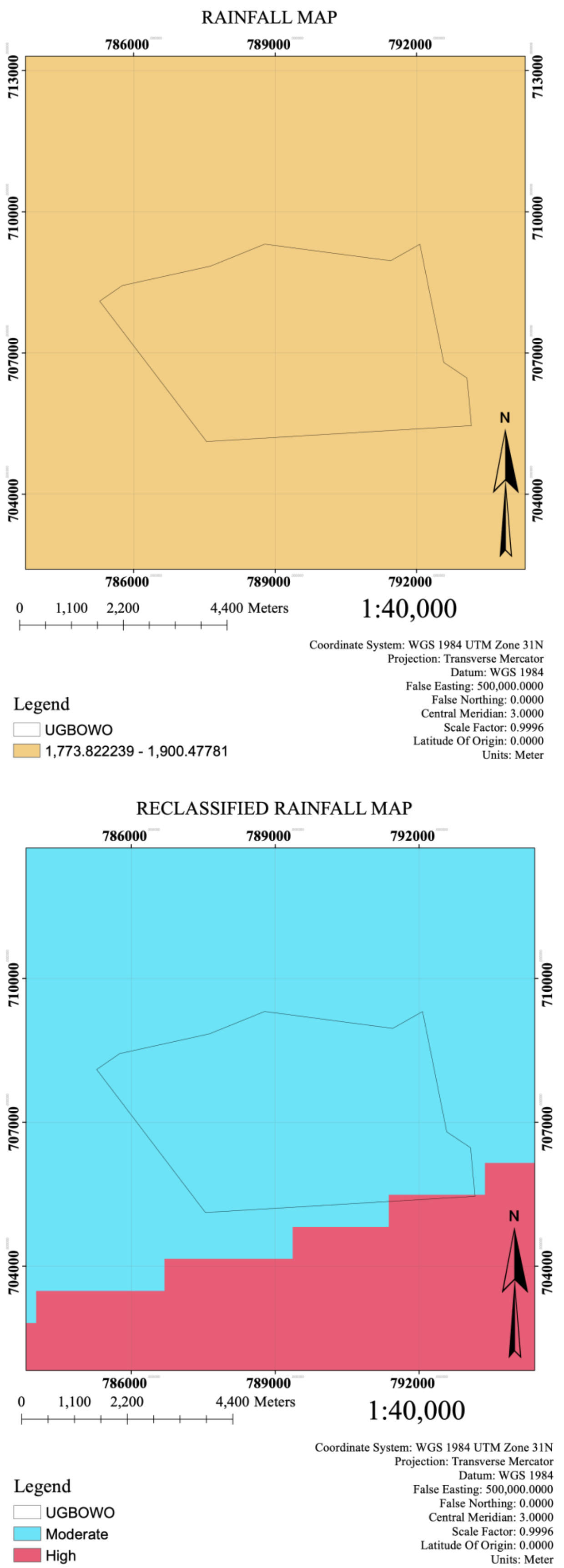
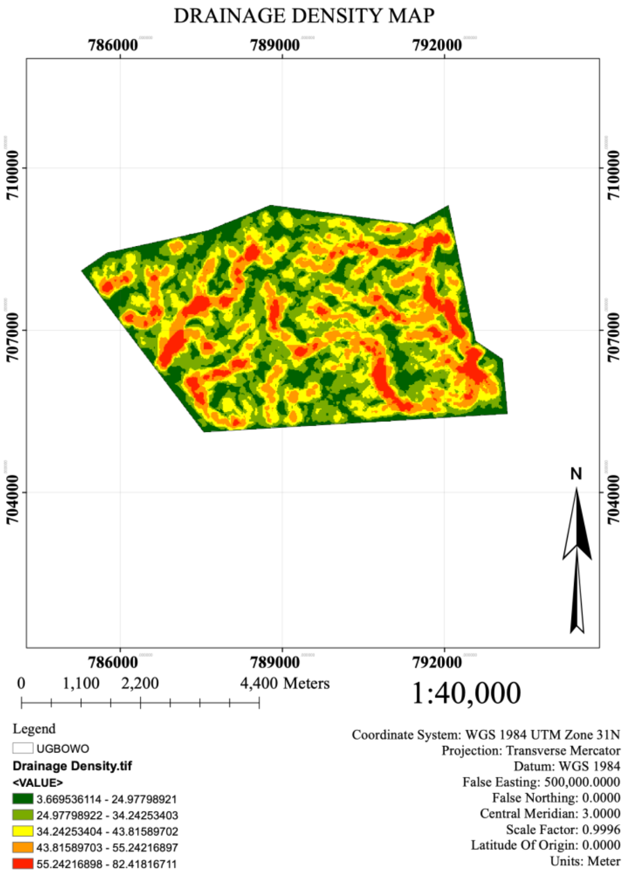


Fig. 4.4: **Rainfall Data Map, Reclassified Rainfall Data Map**

4.1.4 Drainage Density Map

Figure 4.5 shows the two major rivers in the research area derived from the flow accumulation: The Ikpoba and Ogba Rivers. Figure 4.6 illustrates the classified drainage density distribution, where areas with varying drainage density levels are ranked according to their suitability for check dam construction.

R



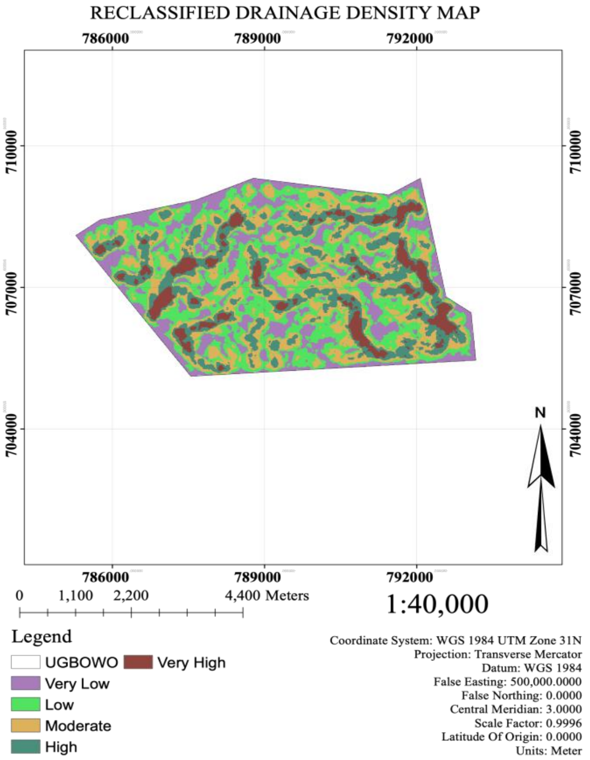
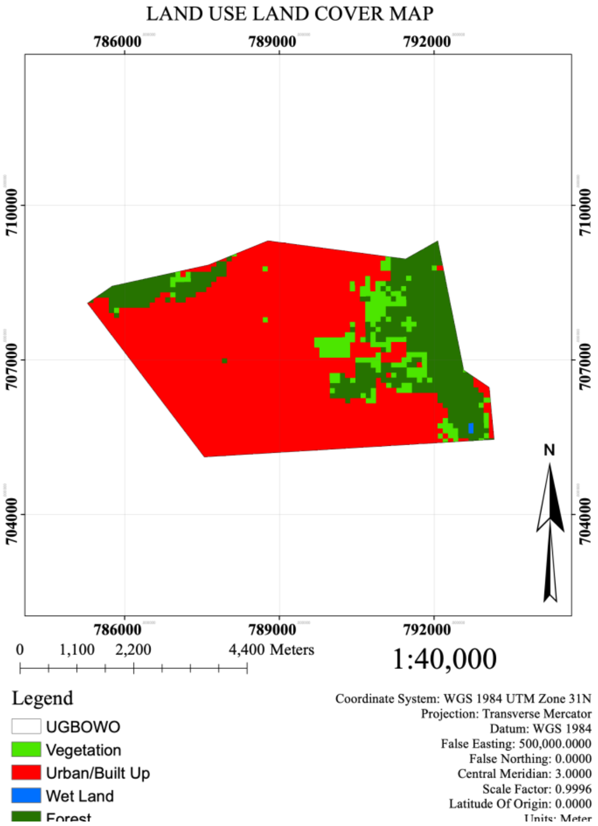


Fig. 4.5. **Drainage Density Data, Reclassified Drainage Density Data**

4.1.5 Land Use Land Cover Map

Figure 4.6 shows that Forest areas receive the highest ranking due to their soil stability and reduced erosion risk, making them more suitable for check dam construction. Urban areas receive a moderate ranking due to accessibility considerations, while vegetation areas receive lower rankings due to potential land-use conflicts. Figure 4.7 depicts the findings of the land-use/land-cover data analysis,



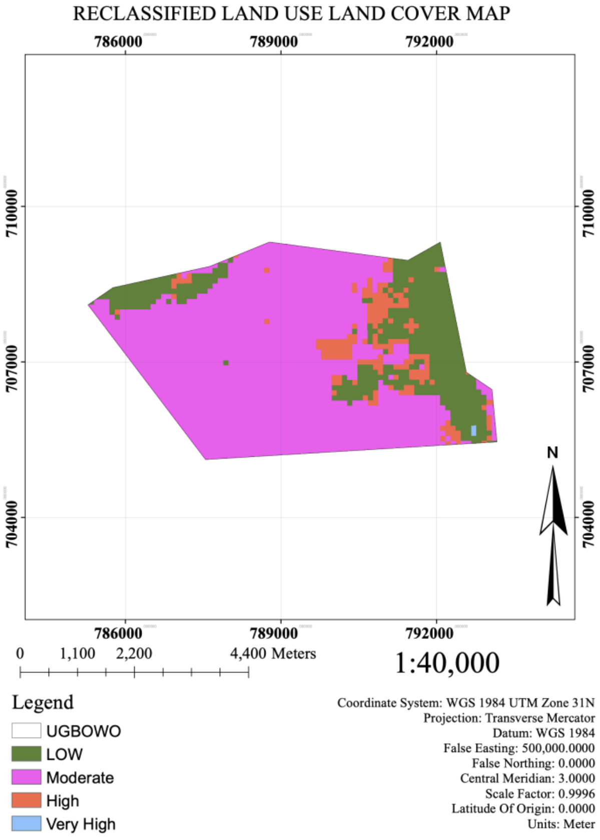


Fig. 4.6: **(N) Land Use Land Cover Map, (O) Reclassified Land Use Land Cover Map**

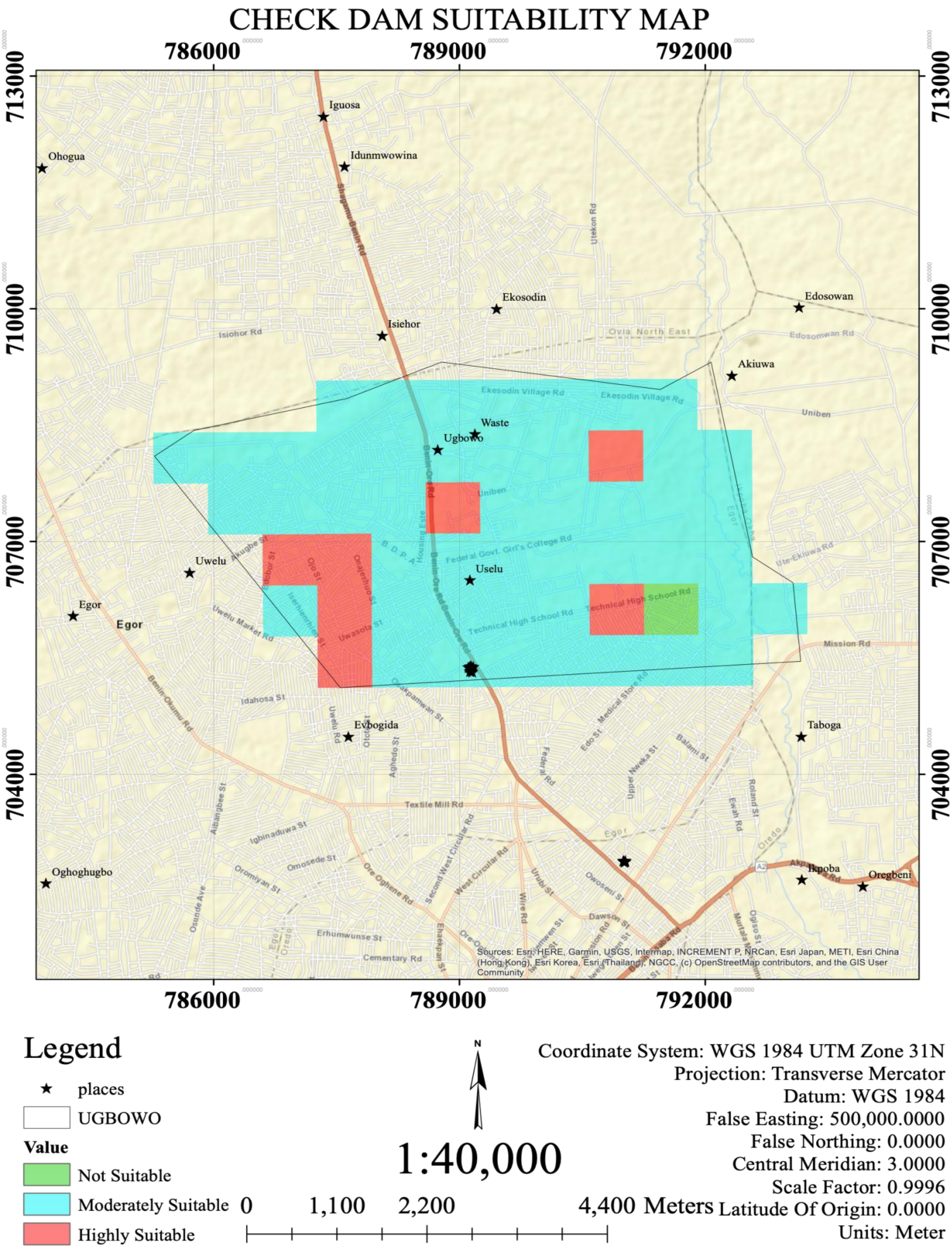


Fig. 4.7: **Dam Check Suitability Map**

From the result above it is observed that the Ikpoba river area has a high vulnerability to flooding than other areas because it is a major river channel where all upland soil is been washed by erosion.

Or you can explain it by saying the area toward the northern part of the map is less vulnerable compared to the southern part.

4.1.6 Criteria for Flood Mapping Ranking

The basic goal of AHP-based multi-criteria decision-making is to rank and prioritize options. The effectiveness of available resources, which is, in most situations, the primary assessment of the decision-maker, is directly influenced by the quality of priority-setting. Hydrologists and engineers commonly rely on heuristic and experiential assessments from the public, who are the end-users, when making decisions.

In this study, sixteen experts were asked to give their assessments and judgments regarding the variables related to flooding and their significance in terms of weights, out of the six factors analyzed, to determine the objectives and formulate the decision-making process. The experts included four hydrologists, four engineers, and eight end-users. End-users are those who are affected by the phenomenon and are represented in this case study by representatives from community leaders, the area chief, and the sub-chief. Experts or decision-makers are those who have the technical skills and know-how to solve a given problem, whereas end-users are those who are affected by the phenomenon and are represented in this case study by representatives from community leaders, area chiefs, and sub-chiefs. In three rounds, each expert participant assigned weights to the objective elements, each round using a different approach and consisting of the following rounds:

Round 1: Assign each aim or factor percentage to reflect its weight.

Round 2: Assume the relevance scale among the objectives is linear, and use round 1 to identify the lowest priority.

Round 3: Objectives should be graded on a scale of one to five, with one being the least significant and five being the most important.

The eigenvector is used to weigh the standardized raster layers to highlight the importance of each element in comparison to the other criteria in the resulting flood hazard. Table 3 shows the results of the pairwise comparison and ranking of the criterion. Table 4 shows the normalized matrix transformed to per cent contributions and Table 5 shows the consistency of the matrix which was used to compute $\lambda_{max.}$

Table 2: Ranking of urban flood-causing criteria.

Ranking of Flood Vulnerability Parameters						
Criteria	Land-use	Rainfall	Drainage	Elevation	Slope	Soil
Land-use	1	1	2	2	1	1
Rainfall	1	1	1	1	1	2
Drainage	0.5	1	1	2	1	1
Elevation	0.5	1	0.5	1	2	2
Slope	1	1	1	0.5	1	1
Soil	1	0.5	1	0.5	1	1
Total	5	5.5	6.5	7	7	8

Table 3: Normalizing the criteria columns to obtain the normalized matrix.

Criteria	Land-use	Rainfall	Drainage	Elevation	Slope	Soil	Criteria Weight	Per cent (%)
Land-use	0.200	0.182	0.308	0.286	0.143	0.125	0.207	21
Rainfall	0.200	0.182	0.154	0.143	0.143	0.250	0.179	18
Drainage	0.100	0.182	0.154	0.286	0.143	0.125	0.165	16
Elevation	0.100	0.182	0.077	0.143	0.286	0.250	0.173	17
Slope	0.200	0.182	0.154	0.071	0.143	0.125	0.146	15
Soil	0.200	0.091	0.154	0.071	0.143	0.125	0.131	13
Total	1	1	1	1	1	1	1	100

Table 4. Calculating the Consistency of the criteria columns to obtain the λ_{max}.

Consistency Matrix									
Criteria	Land use	Rainfall	Drainage	Elevation	Slope	Soil	Weighted Sum Value	Criteria Weight	
Land-use	0.207	0.179	0.330	0.346	0.146	0.131	1.338	0.207	6.5
Rainfall	0.207	0.179	0.165	0.173	0.146	0.261	1.131	0.179	6.3
Drainage	0.104	0.179	0.165	0.346	0.146	0.131	1.069	0.165	6.5
Elevation	0.104	0.179	0.082	0.173	0.292	0.261	1.090	0.173	6.3
Slope	0.207	0.179	0.165	0.086	0.146	0.131	0.914	0.146	6.3
Soil	0.207	0.089	0.165	0.086	0.131	0.131	0.809	0.131	6.2

From Table 4,

A consistency Index (CI) of 0.07 and a Random Index (RI) for 6 (Six) parameter computations yielded a final value of 1.24. The maximum permitted values for CI and RI are 0.1 and 10%, respectively. The CI and CR values in this investigation were 0.07 (CI 0.1) and 5.5 per cent (CR 10 per cent, respectively, to ensure that they met the highest criteria allowed. These are the values:

Table 7: Weighted flood hazard Values.

N		6

Lambda (λ_{max})	(6.5+6.3+6.5+6.3+6.3+6.2)/6	6.3

CI	$(\lambda_{max}-n)/(n-1)$	0.07
CI	$(\lambda_{max}-n)/(n-1)$	0.07

RI		1.24
RI		1.24

CR	CI/RI	0.055

CR%		5.5

Once the relative importance of each element had been established, a multi-criteria analysis was carried out using a GIS technique to create a flood-vulnerable region.

The results of flood vulnerability mapping in the Study Area are shown in Figure 4.8. The vulnerability of flood areas is categorized into 5 (five) criteria, namely "Very high vulnerable", "High vulnerable", "Moderate vulnerable", “Low vulnerable”, and “Very low vulnerable”.

4.1.7 Model Input Factors Weighting and Ranking

The pairwise comparison matrix and the factor maps are employed in the weight and ranking computation stage. To obtain the best fit to the weight set, the primary eigenvector of the pairwise comparison matrix is calculated. Priorities are represented by weight values, which are absolute numbers between zero and one. When using a weighted linear combination, the weights must add up to one. Table 5 shows a summary of the flood causative factors or variables development, including the numerous components, their relative weights, and how they are placed in terms of their influence on flood episodes in the research area. The sub-factors (j) in Table 5 are the deciding factor I ranges that contribute to the choice ranking values. Table 5 shows how the three-level hierarchical structure is divided, as well as how the ranking decision for vulnerability and risk mapping is made.

The factors with a greater weight value have higher importance or impact in the study than those with a lower weight value. The soil cover, which is characterized by infiltration, has the highest weights, meaning that it contributes more to flooding in the area than the other components or elements, according to the factor weights identified for this study area. This component has an impact not only on the bare soil surfaces but also on the overall material that covers an area.

Table 6: Weighted flood hazard ranking for the case study.

Parameter	Relative Weight (%)	Reclassified Parameter	Ranking
Urban land-use	21	Vegetation Urban/Built Up Wet Land Forest	2 3 4 5
Rainfall (mm)	18	1,267.199951 - 1,495.17998 1,495.179981 - 1,723.16001 1,723.160011 - 1,951.140039 1,951.14004 - 2,179.120068 2,179.120069 - 2,407.100098	1 2 3 4 5
Drainage density (km/km^2)	16	3.669536114 - 24.97798921 24.97798922 - 34.24253403 34.24253404 - 43.81589702 43.81589703 - 55.24216897 55.24216898 - 82.41816711	1 2 3 4 5
Elevation (meters)	17	30 - 52 52.00000001 - 72 72.00000001 - 89 89.00000001 - 103 103.0000001 - 122	5 4 3 2 1
Slope (degrees)	15	0 - 3.127219166 3.127219167 - 5.60293434 5.602934341 - 8.860454305 8.860454306 - 14.59368944 14.59368945 - 33.22670364	5 4 3 2 1
Soil classes	13	Red Ferralsols on Loose Sandy Sediments	2

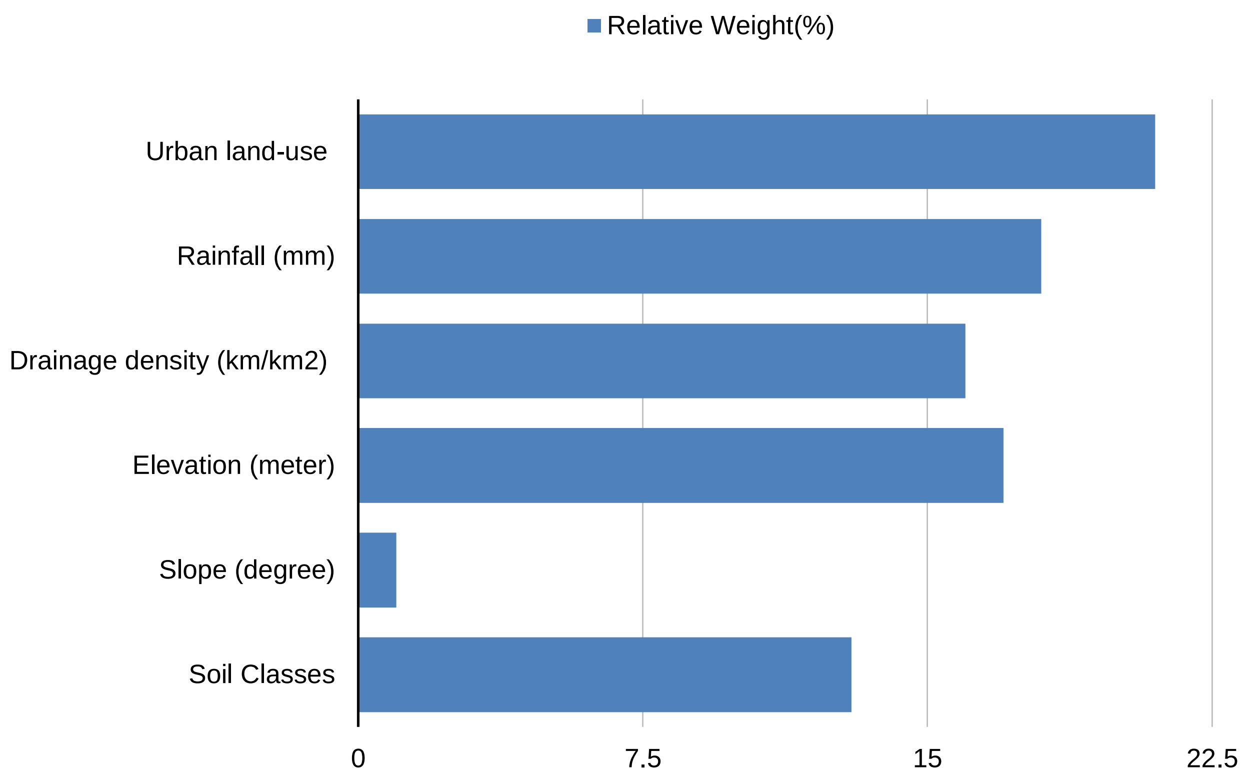


Fig. 4.8: Bar chart weighted ranking for the case study.

4.2 Discussion

4.2.1 Discussion of the Results (Variables and Analysis for Flood Vulnerability Mapping)

The morphometric and topographic features, as well as the analysis of variables, are presented in this section as factors in the construction of AHP-GIS decision-making for checking dam suitability. The selection of parameters significantly impacts the variables used for the multi-parametric AHP. This section discusses the factors utilized in the suitability analysis and their classification into suitability classes and importance levels.

In multi-criteria decision analysis, selecting criteria with a spatial reference is crucial for checking dam placement. The criteria used in this study were chosen based on their importance in determining suitable locations for checking dams in the study area. Elevation, slope, soil types, yearly rainfall distribution, drainage density, and land-use/land-cover information are all considered, with their respective weights derived from AHP analysis.

i. Slope and Elevation

Elevation and slope are essential factors in determining a terrain's suitability for check dam construction. The slope influences the direction and volume of surface runoff that a check dam can effectively manage. The slope has a significant impact on the water retention capacity and structural stability of check dams. It regulates the effectiveness of the structure and potential storage capacity.

According to the analysis, areas with lower slopes (0-3.12 degrees) are given the highest ranking (5) for check dam suitability, while steeper slopes (14.59-33.22 degrees) receive the lowest ranking (1). This is because gentle slopes are more suitable for check dam construction, offering better stability and water retention capacity. Similarly, for elevation, areas between 30-52 meters receive the highest ranking (5), while areas between 103-122 meters receive the lowest ranking (1), as lower elevations are generally more suitable for check dam construction. Figures 4.1 & 4.2 depict the findings of the case study's original and reclassified elevation and slope layers for check dam suitability assessment. According to Figure 4.2, significant portions of the study area have gentle to moderate slopes, making them potentially suitable for check dam construction.

ii. Type of Soil

Soil characteristics are crucial for checking dam stability and effectiveness. The soil's texture, permeability, and structural strength significantly influence check dam performance. In the study area, Red Ferralsols on Loose Sandy Sediments are present, which received a ranking of 2, indicating moderate suitability for check dam construction.

The soil's infiltration capacity and structural stability are key factors in determining suitable locations for check dams. Soils with moderate infiltration rates and good structural stability are preferred for check dam construction to ensure both water retention and structural integrity. Figure 4.3 shows the spatial distribution of soil types and their suitability rankings for check dam construction in the research region.

iii. Distribution of Rainfall

Rainfall distribution is a critical factor in check dam planning, with a relative weight of 18% in the analysis. The study area experiences rainfall ranging from 1,267mm to 2,407mm annually. Areas with higher rainfall (2,179-2,407mm) receive the highest ranking (5) for check dam suitability, as these areas have greater potential for water harvesting. Conversely, areas with lower rainfall (1,267-1,495mm) receive the lowest ranking (1). Figure 4.4 displays the results of the raster rainfall layer, IDW interpolated data layer, and classified rainfall data about check dam suitability.

iv. Density of Drainage

Drainage density, with a relative weight of 16%, is crucial for check dam placement. Areas with lower drainage density (3.67-24.98 km/km^2) receive a ranking of 1, while areas with higher density (55.24-82.42 km/km^2) receive a ranking of 5. Higher drainage density areas are more suitable for check dam construction as they indicate better potential for water harvesting and storage. Figure 4.5 shows the two major rivers in the research area derived from the flow accumulation: The Ikpoba and Ogba Rivers. Figure 4.6 illustrates the classified drainage density distribution, where areas with varying drainage density levels are ranked according to their suitability for check dam construction.

v. Land Use and Land Cover Criteria

Land use and land cover, carrying the highest relative weight of 21%, significantly influence check dam suitability. The analysis classified land use into five categories:

- Forest areas (ranking 5)
- Wetland (ranking 4)
- Urban/Built-up areas (ranking 3)
- Vegetation (ranking 2)

Forest areas receive the highest ranking due to their soil stability and reduced erosion risk, making them more suitable for check dam construction. Urban areas receive a moderate ranking due to accessibility considerations, while vegetation areas receive lower rankings due to potential land-use conflicts. Figure 4.7 depicts the findings of the land-use/land-cover data analysis, showing the spatial distribution of different land-use classes and their corresponding suitability rankings for check dam construction.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In-depth data on field conditions, hydrologic statistics, and structural components are required for comprehensive check dam suitability analysis. Probability-based analysis and findings accurately reflect the potential success and effectiveness of check dam placement in particular locations across Ugbowo and its environs. Optimizing check dam locations through proper site selection is crucial for their long-term sustainability and effectiveness.

This study's findings can be summarized as follows:

A GIS and remote sensing-based suitability map was created incorporating specific criteria such as land cover (21%), rainfall (18%), drainage density (16%), elevation (17%), slope (15%), and soil type (13%) to analyze potential check dam locations in Ugbowo and environs.

The analysis revealed that:

- 11.46% of the study area shows High Suitability for check dam construction
- 87.32% of the study area demonstrates Moderate Suitability
- 1.22% of the study area has Low Suitability

High suitability areas are primarily located in the southeastern sections of Ugbowo, characterized by appropriate slope gradients and favourable soil conditions. The vast majority of the study area falls within moderate suitability zones, which are predominantly found in the central and western portions, where conditions are generally acceptable but may require additional engineering considerations. Low suitability areas comprise a very small portion of the study area, mainly concentrated in the northern sections of Ugbowo, where terrain and soil conditions are less favourable for check dam construction.

The three main factors influencing check dam suitability in the study area are land use/cover patterns, rainfall distribution patterns, and drainage density of 0.123m/m². Soil stability and topographic conditions are additional factors that influence the feasibility of check dam construction.

5.2 Recommendation

Below is a revised recommendation section tailored for inclusion in a research paper on flood mitigation and check dam suitability analysis:

1. **Structural Elevation and Flood-Proofing**

    - **Elevate Critical Components:** It is recommended that buildings in flood-prone areas have their lowest floor—along with all associated equipment—raised above the Base Flood Elevation (BFE). This elevation is crucial for reducing flood risk.
    - **Maintain Adequate Freeboard:** A minimum freeboard of one foot above the drainage level should be maintained. This buffer is essential to prevent overtopping during peak flood events.
    - **Apply Flood-Proofing Measures:** To further safeguard structures, apply waterproof coatings, install impermeable membranes, or incorporate additional layers of masonry or concrete on exterior walls to reduce water infiltration.

2. **Runoff and Drainage Enhancements**

    - **Regrade and Optimize Drainage:** Regrading affected areas is recommended to ensure efficient runoff drainage. Strategic landscaping and grading can direct surface water away from vulnerable structures and towards designated drainage channels.

- **Regular Maintenance of Drainage Systems:** Establish a routine maintenance program to regularly clear drains of debris and sediment. Proper channelling of these drains toward the river is essential for effective floodwater management.

3. **Check Dam Suitability and Integration**

- **Site Assessment and Design:** Conduct further site-specific analyses to determine optimal locations for check dam installations. Check dams should be designed with appropriate freeboard and spillway capacities to accommodate peak flows, thereby reducing water velocity and capturing sediment.

- **Integrate with Overall Flood Management:** Incorporate check dams as a complementary component of the broader flood mitigation strategy. Their integration can help manage watershed runoff and reduce downstream flood impacts.

4. **Relocation and Reconstruction Strategies**

- **Consider Relocation in High-Risk Zones:** In areas with very high flood risk, it is advisable to relocate buildings to higher ground outside the designated flood zones. When relocation within the same property is feasible, moving structures to elevated positions should be pursued.

- **Rebuild in Safer Locations:** For structures that cannot be effectively elevated or relocated, demolition and reconstruction on alternative sites outside the floodplain should be considered to ensure long-term safety and sustainability.

5. Additional Flood Mitigation Measures

- **Install Backflow Prevention Devices:** Equip sewer lines and drains with backflow prevention devices to mitigate the risk of reverse water flow during flood events.
- **Protect Vulnerable Openings:** All openings below the flood level should be fitted with appropriate shields to prevent water intrusion and further reduce flood damage risks.

Implementing these recommendations is expected to enhance the resilience of individual structures and improve overall watershed management. Future research should focus on refining these strategies through site-specific hydrological modelling and cost-benefit analyses to further optimize flood risk management practices.

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