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Research Article

# Flood Risk Zone Identification Using Land Use/Land Cover Change Detection and AHP Analysis

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## Abstract

Flooding is a prevalent disaster in both developed and developing nations, exerting a lasting influence on several regions in Lagos State. In this study, the geographical information system (GIS) technique and the analytical hierarchy process (AHP) of the multi-criteria evaluation (MCE) technique were used to create a floodplain map of Lagos State. Rainfall, land use land cover (LULC), slope, digital elevation model, flow direction, drainage density, normalized difference water index (Ndwi), and soil texture map were the eight parameters identified. The data about the factors were obtained from an online source and processed using the spatial analytic tools in ArcGIS 10.6.1. To calculate the relevant ranking weight, the elements were compared pairwise. The output consistency ratio (CR) was 2.7%, which is below the permitted limit of 10%. The weight percentage obtained was then utilized in the weighted overlay operation to identify the flood risk zone. Based on an analysis of the produced land use and land cover in 2020, 2022, and 2024, changes in water bodies were found to be proportional to changes in built-up areas, with a kappa coefficient of the dataset being 82.8%. From the results, up to 25% of Lagos State is covered by water bodies, 58% of the state's total land is in the high flood zone, and less than 1% is in the very high and low flood areas. Overlaying locations subsequently validated the result declared flood-threatened by the National Emergency Management Agency (NEMA), giving an agreement ratio of approximately 85% and found to fall within the high flood zones.

## Keywords

Flood Risk, Geographical Information System (GIS), Analytical Hierarchy Process (AHP), Land Use, Land Cover

## 1. Introduction

Flooding often occurs when the volume of a river's channel is exceeded by discharge, forcing the river to overflow onto the nearby lands [1]. Flooding has become one of the major natural disasters affecting the world, including developed nations. Each year, hundreds of people are killed, and this natural disaster damages billions of dollars' worth of property and infrastructure [1]. In recent years, the effects of flood disasters on society and sustainable development have been increasingly apparent [2]. Flooding has been directly attributed to natural sources such as heavy rainfall (see Figure 3), although it occurs in a variety of ways that are not directly related to current weather events, such as inadequate drainage systems,

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blocked drainage channels due to improper waste disposal practices, urban sprawl, climate change, and haphazard development, etc. These factors accelerate the force of flowing water, the deposition of dirt and debris when floodwater eventually subsides, causing several property damages [3].

Nigeria has experienced a variety of all classes of flood events in recent years, with Lagos state being one of the most affected. Flooding in Nigeria has been classified as coastal, pluvial, or riverine. Lagos state, being a coastal state with low elevation, is susceptible to flooding [4]. As a result of this, there is a high level of vulnerability and poor capacity for coping within the rapidly expanding state; many lives and properties are vulnerable to the effects of the rapid occurrence of extreme events brought on by climate change [4]. Locations such as Ikoyi, Victoria Island, Ipaja-Ayobo, Ajegunle, Agege, Iyana Paja, Ikorodu, Agiliti, Mile 12, and others within Lagos state have continually been reported to have faced this hazard. See Figures 1 and 2 for the flood level after rainfall [5]. Therefore, collaboration amongst the various agencies becomes very important for flood management.

Geographic Information Systems (GIS) have been globally employed by agencies and individuals in the analysis of natural hazards by many studies, but when combined with the Analytic Hierarchy Process (AHP) of the Multi-Criteria Decision Analysis (MCDA) method, GIS helps analyze hazards such as flood vulnerability using a large volume of geospatial data, ranking a group of co-factors, overlaying based on calculated weight and provides decision-makers with sufficient information from these for flood management [6]. GIS has become a platform where various geographic data, both raster and vector, can be converted, georeferenced, and numerically analyzed to integrate and compare with each other for result-oriented purposes [8, 9]. Despite these applications and work done, the limitations continue to be visible in Lagos' yearly flood hazard, as shown in Figure 2.

The incorporation of land use and Land cover change effects to produce floodplain maps has yet to be effectively addressed in studies focusing on Lagos State. This aspect is critical given the research area's rapid urbanization and spike in population. More research has investigated specific locations inside the state without a comprehensive state viewpoint, understanding the interconnectedness of the area's topography within the state, and the impacts of flood spreading into areas that were not under consideration. These inadequacies are resolved by considering the entire state, resulting in a dependable map on which policymakers and planners may rely.

Source: Phone camera

***Figure 1.*** *Flood occurrence at the Federal Palace area, Victoria Island, in 2021.*

Managing an area's land-use and land-cover is a major concern in flood hazard mapping since it is one factor that not only shows the land's current use, pattern, and type of use, but also the importance of that use in relation to soil stability and infiltration [10, 11]. Alongside a notable decline in flora, water bodies, and bare soil in Lagos state, the built-up area increased from 496 km$^2$ to approximately 1256 km$^2$ between 1990 and 2020 [11]. Increased flood risk is a result of both the conversion of wetlands into developed regions and unplanned development in flood hazard zones [12]. Without a doubt, comprehending how land use and Land cover are crucial for directing sustainable urban design and enhancing resilience throughout the state, given that it can affect how long it takes for water to build and regularly raise the water's peak flow or overflow [14, 15].

Source: www.Gettyimages.com

***Figure 2.*** *Flood in Aboru, Oke Odo, and Flood in Agege motorway, Mushin area, Lagos state.*

Hence, this research addresses these gaps by employing GIS–AHP-Based Flood Risk Mapping and Land Use Change Analysis for Lagos State, Nigeria. Incorporating literature-based flood causative factors tailored to Lagos' unique ecosystem, sprawl, and drainage system, this study produced a unique floodplain map, which is a progress from previous literature to enhance sustainable development.

Focused on improving urban planning, disaster preparedness, and sustainable flood management, the development of a GIS-AHP framework for flood hazard assessment in Lagos State was done, combining recent land-use and land-cover change data with various spatial flood-conditioning factors. The study produces an updated and clearly defined flood risk map that reflects the current realities of Lagos's rapidly urbanizing environment. The resulting model improves the accuracy of flood prediction, supports data-driven policy making, and provides a practical tool for urban planners, environmental managers, and disaster risk reduction agencies. Ultimately, this research strengthens climate resilience and encourages sustainable flood management in one of Nigeria's most vulnerable coastal cities.

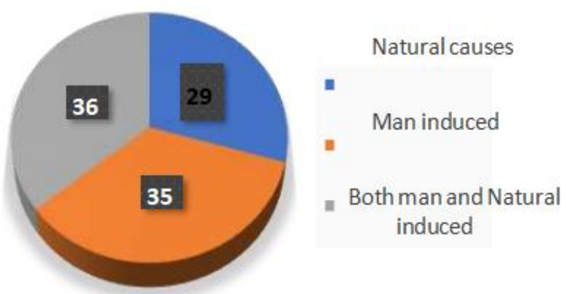


***Figure 3.*** *Flood causes in Lagos state [15].*

## 2. Study Area

The city of Lagos is located in the southwest of Nigeria (see Figure 4), West Africa, and is a low-lying coastal region with a high population. With a land area of about 1100 km2, the city is located between 3.1 and 3.4 E longitude and 6.5 and 6.8 N latitude, approximately 425 square miles. Its southern border is the Atlantic Ocean. The conurbation serves as a major hub for Nigerian transportation, tourism, and business. It is made up of the Lagos Lagoon, which empties into the Atlantic, as well as several inland waterways. With a population of more than 20 million, the Lagos metropolitan area is the largest metropolis in Nigeria (despite having the smallest land area) and the second largest city in Africa [2]. In the metropolis of Lagos, the population growth rate is expected to be 3.2%. [16]. Given this, the United Nations estimates that Nigeria will have a population of between 505 million and 1.03 billion by the year 2100, placing it among the eight nations that will collectively be responsible for half of the world's population growth between 2005 and 2050 [17]. The high population density in the Lagos area is a significant issue since it offers little space for a range of human activities. Overcrowding, slum encirclements, pollution, illegal buildings, and other social and environmental disorders are common ways that this issue shows up [18]. These components have the potential to increase risk exposure, particularly the dangers related to yearly flooding events, either separately or in combination.

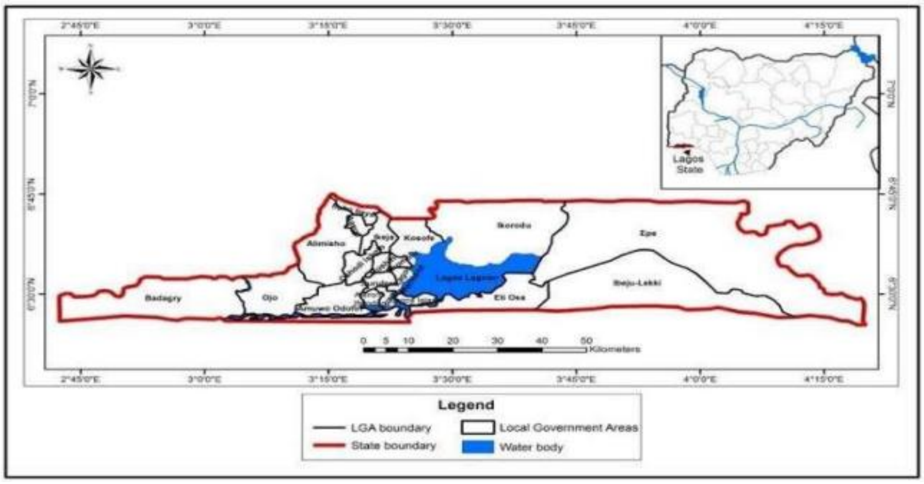


*Figure 4. Map of Lagos state showing water bodies, local government areas, and boundaries [19].*

## 3. Materials and Methods

AHP multi-criteria evaluation method for analyzing problems with several factors involved was adopted in this study [20]. The Pair-wise Comparison Method with a GIS-weighted overlay tool was used to develop the floodplain map, as shown in Figure 5.

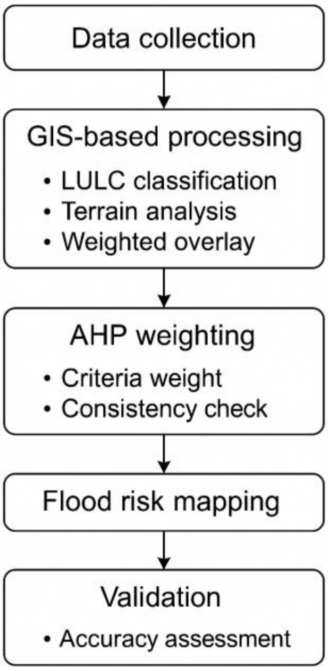


*Figure 5. Designed methodology flow chart.*

### 3.1. Determination of the Causative Flood Factors

To identify relevant factors causing floods within the study area (Lagos state), literatures were reviewed to identify the factors that best capture the hydrological, physical, and environmental nature of the study area. Eight criteria were identified in all, categorized into acquired and derived, for the analysis [12, 22, 25].

*Criteria acquired:* Land use/Land cover (LULC), Elevation, Rainfall, Soil

*Criteria derived:* Slope, Normalized difference water index (NDWI), Drainage Density, Flow direction.

LULC changes have remained indispensable to flood analysis due to their influence on water runoff by their impervious surfaces, increased infiltrations by vegetation, and wetland acquisitions by infrastructure [26, 27]. These changes are on the rise within the study area and make it more susceptible to flooding.

Elevation of the study area plays a significant role in flood risk analysis, since a whole state cannot be of the same elevation; the low areas are more susceptible to flooding [27, 28]. The study area being a coastal state, coastal cities within the state are also the lowest elevation area, having more water accumulation, especially during high rainfall.

Rainfall directly influences the rate of water volume, increasing surface runoff and accumulation in the study area that experiences high precipitation [26, 28]. Data such as this is highly required.

Soil types have varying capabilities for water absorption. Soils with low permeability and infiltration capability contribute to higher surface runoff [26]. As a result, soil texture data were recognized as an important component to examine.

Slopes can be low slopes or gentle or steep, but low and gentle slopes tend to be more susceptible to flooding, so they have water accumulation within the zones [28]. Areas such as these must be identified and considered holistically, along with other factors.

NDWI reveals soil moisture content and surface water bodies vividly, making it easier to identify water features from other land cover types [29]. This data helps to determine susceptible areas to flooding.

Drainage density is characterized as the total length of a stream channel per unit area; high-density areas have more stream channels, which are directly tied to compacted soils and contribute to increased surface runoff, which aids flooding [26].

Flow direction reveals the pattern of water on the surface, showing where accumulation of water would be, thereby causing flooding [30].

### 3.2. Data Collection and Sources

Data was downloaded about the selected criteria, and the image resolutions obtained were based on a combination of literature values and available data [31]. The source and details of the downloaded data are listed below in Table 1.

*Table 1. Details of the data acquired and their respective source.*

| S/ N | DATA | SOURCE AND WEB ADDRESS | YEAR | RESOLUTION |
|---|---|---|---|---|
| 1. | Sentinel- 2 Land use land cover (LULC) image | ESRI https://www.arcgis.com/apps/instant/media/index.html?appid= fc92d38533d440078f17678ebc20e8e2 | 2024 | 10m-30m |
| 2. | ALOS Digital Evolution Model (DEM) | ASF (Alaska satellite facility) data search vertex https://search.asf.alaska.edu/#/?zoom=9.914&center=3.814,6.471&dataset=ALOS | 2014 | 30m |
| 3. | Soil Map | FAO MAP CATALOG https://data.apps.fao.org/map/catalog/srv/eng/catalog.search; | 2023 | 30m |
| 4. | Rainfall Data | Climatic Research Unit CRU TS 4.06 Data https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_.06/cruts.2205201912.v4.06/pre/ | 2024 | 30m |
| 5. | Landsat 8 imagery | Landsat imagery http://earthexplorer.usgs.gov/ | 2024 | 30m |
| 6. | Population Data | https://hub.worldpop.org/geodata/summary?id=74734 | 2022 & 2024 | 100m |

### 3.3. Reclassification

The process of reclassifying a raster entails changing a value, a range of values, or a list of values to new output values. Reclassification was done in this study to have five classes in total, based on all criteria. These five classes were selected to accommodate the description for the final floodplain map class of very low flood, low flood, high flood, and very high flood. This was done using the reclassification under the reclass tool; all criteria were ensured to have the same number of classifications.

### 3.4. Resampling

The Resample function modifies the type of resampling, the size of the raster pixels, or both. It is frequently preferable to resample the data to a common resolution before merging and analyzing rasters with disparate resolutions. For this study, the resolutions were fixed to 10m.

### 3.5. AHP Multicriteria Ranking and Weight Calculation

One of the most used multicriteria procedures is the analytic hierarchy process (AHP). The methods of rating options and combining them to identify the most pertinent options are combined in AHP. When performing an evaluation, the pairwise comparison values were derived through a mixed approach combining a Systematic review of four study-area–specific flood risk assessment literature [12, 22-24] and an Independent expert judgment from three professionals (hydrologist, GIS specialist, and environmental planner). This ranking or selection is done to achieve an overall aim that is divided into several criteria [32].

Step 1: Modelling the problem.

At this stage, the problem's goals were expanded to encompass all selected factors and associated consequences, and decision factors such as alternatives, criteria, and decision rules were identified. The criteria are the eight main decision elements that are arranged in a hierarchy of linked choice elements based on the study area reviewed literature [12, 23-25]. This procedure has been regarded as the most crucial part of AHP. The Saaty 1-9 fundamental scale strength of importance was used to rank the criteria selected based on the area-based literature reviews done. Numerical value (e.g., 1, 3, 5) was given when multiple studies showed similar influence levels, while intermediate values (2, 4, 6, 8) were used when the studies showed context-dependent differences, see Table 2. The 1–9 scale of factor importance used in Table 2 [20].

Strength of importance Explanation [33]

1 Equal significance

3 Medium significance

5 Strong

7 Very strong significance

9 Maximum significance

2, 4, 6, and 8 are Intermediate between two adjacent values

***Table 2.*** *Details of the basis for the pairwise comparison matrix.*

| **Criterion (Significance)** | **Numerical JUDGEMENT** |
|---|---|
| Rainfall – 5 (Strong) | Studies identified the most influential factor driving flood |
| Drainage Density – 5 (Strong) | Major influence of runoff volume and overflow possibilities. |
| LULC – 1 (Equal) | The infrastructure rate determines the effect; hence, it varies. |
| Elevation – 1 (Equal) | Presented moderately within the study area |
| Slope – 2 (Intermediate) | The effect of slope revealed a moderate influence on the runoff velocity. |
| Flow Direction – 2 (Intermediate) | It affects water flow concentration but with limited spatial variability. |
| Soil – 3 (Medium) | Water infiltration is influenced by soil permeability |
| NDWI – 3 (Medium) | Indicates surface water presence and moisture, moderately linked to flood potential. |

Step 2: Determining Priorities among the Decision Elements of the Hierarchy

In this step, ratings for each of the criteria and alternatives are gathered using a rating scale of relative relevance and a pairwise comparison technique. Using a matrix-based pairwise comparison method, as indicated in Table 3, this stage enlists the assistance of experts and literature to determine the relative relevance of one criterion or alternative over another [10]. The number of comparisons = n (n - 1)/2 =8(7)/2=28 shows the number of comparisons for the decision-making elements (i.e., criteria or alternatives) in each level. Each comparison was carried out by utilizing an online calculator and a pairwise comparison method that Saaty designed.

Step 3: Finding the Decision Elements' Overall Relative Weights

The relative importance of the alternatives for the criteria and the relative relevance of the criteria to the goal's accomplishment are determined in this step, following the creation of a pairwise comparison matrix for the criteria and the alternatives. To achieve this, the actions listed below are taken: Finding the normalized principal eigenvectors (also known as relative weights) and (i) computing the normalized values for each criterion and alternative. The normalized values for each criterion and alternative in their respective matrices are calculated by dividing the value for each cell by the total number of columns in the cell. This method results in a column total of 1 for each criterion and choice. The corresponding weights are then obtained by averaging the rows of each matrix. The resulting values demonstrate how the alternatives are weighed in relation to the criteria and how the criteria are weighed in relation to the aim. The overall relative weights of the alternatives are obtained by computing the linear combination (LC) of the result between the relative weight of each criterion and the relative weight of the alternative for that criterion [34].

Steps 4 and 5: Confirming the Consistency of Decisions and Drawing Inferences from the Data

These procedures are necessary to determine the consistency of the evaluation and compute the consistency ratio prior to deciding. If the objective under consideration was to select the best alternative, the CRs for all the matrices (i.e., for the criteria and the alternatives) are calculated first, followed by the overall relative weights of the alternatives. Determine the maximum eigenvalue, consistency index, consistency ratio, and normalized values for each criterion or alternative. If the ratio is more than 0.1, it is thought that the judgments may be too inconsistent to be relied upon. Consequently, it is acceptable to have a CR below 0.1% or 10% [35]. If the evaluation is inconclusive, the procedure is repeated until the CR is within the acceptable range. Afterward, based on the findings, decision-makers conclude. Consistency Index (CI).

$$CI = \frac{\lambda_{max} - n}{n-1}$$

$$n = 8$$

$$\lambda_{\max} \approx 8.2541126$$

Using $RI = 1.41$(for n = 8):

$$CR = \frac{0.0363018}{1.41} \approx 0.02574\ (\approx 0.0257 = 2.57\%)$$

Decision Matrix

A decision hierarchical structure involves breaking down a difficult choice problem into smaller, more manageable components of various levels or layers. Using the online calculator, the calculation beneath this was completed (https://bpmsg.com/ahp/ahp-calc.php). The resulting weights are based on the principal eigenvector of the decision matrix, as shown in Table 3 below:

***Table 3.*** *Decision matrix.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0.5 | 1 | 3 | 2 | 3 | 1 |
| 2 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 1 |
| 3 | 2 | 1 | 1 | 2 | 3 | 1 | 2 | 1 |
| 4 | 1 | 1 | 0.5 | 1 | 3 | 1 | 3 | 1 |
| 5 | 0.33 | 0.33 | 0.33 | 0.33 | 1 | 0.33 | 0.5 | 0.33 |
| 6 | 0.5 | 1 | 1 | 1 | 3 | 1 | 1 | 0.5 |
| 7 | 0.33 | 0.33 | 0.5 | 0.33 | 2 | 1 | 1 | 0.5 |
| 8 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 1 |

*Land Use/Land Cover Classification (2020, 2022, 2024)*

The LULC change maps for 2020, 2022, and 2024 were created using supervised classification in this work. These classes were then utilized to ascertain the rate of change and its impact on flood hazards. This classification technique was chosen because it incorporates defined training samples, which will improve a ground-truthed theme class in a dynamic environment.

*The Supervised Classification Procedure*

The Landsat imagery was imported into the ArcGIS 10.6.1 environment, composited & clipped to fit the area of study. The Maximum Likelihood Classifier (MLC) was selected due to its ability to handle spectral variability. Trained samples were created using about 30 polygons in reference to the Google Earth image and local knowledge to categorize all pixels into Vegetation, Bare soil, Built-up, Flooded vegetation, and Water bodies.

*Overall Accuracy and Kappa Coefficient*

Overall Accuracy (OA) $OA = \frac{\text{Total Correctly Classified}}{\text{Total Validation Samples}}$

Correctly classified = 52 + 49 + 51 + 50 + 57 = 259

$$OA = \frac{259}{300} = 0.863\ (86.3\%)$$

Kappa Coefficient (κ) $\kappa = \frac{OA-P_e}{1-P_e}$

Where $P_e$= expected agreement by chance:

$$P_e = \frac{(58)(60)+(61)(60)+(65)(60)+(57)(60)+(59)(60)}{300^2} P_e$$

$$= \frac{3600+3660+3900+3420+3540}{90000} P_e = \frac{18120}{90000}$$

$$= 0.2013\kappa = \frac{0.863-0.2013}{1-0.2013}\kappa = \frac{0.6617}{0.7987} = 0.828$$

Kappa = 0.828 (82.8%), which shows strong classification agreement.

Accuracy Assessment

The LULC classification was validated by selecting 300 independent points across the classes (60 per class) to determine reliability, compared with the Google Earth image.

A confusion matrix was constructed (see Table 4), and the classified pixel was compared with the true land-cover classes.

*Table 4. Confusion Matrix (2024 LULC).*

| Reference \ Classified | Veg | Bare soil | Built-up | Fld. Veg | Water | Row Total |
|---|---|---|---|---|---|---|
| Vegetation | 52 | 4 | 2 | 2 | 0 | 60 |
| Bare soil | 3 | 49 | 6 | 2 | 0 | 60 |
| Built-up | 1 | 5 | 51 | 2 | 1 | 60 |
| Flooded Vegetation | 2 | 3 | 4 | 50 | 1 | 60 |
| Water | 0 | 0 | 2 | 1 | 57 | 60 |
| Column Total | 58 | 61 | 65 | 57 | 59 | 300 |

## 4. Results

These are the results for the criteria based on your pairwise comparisons in Table 5 below:

*Table 5. Criteria weight calculated.*

| Category | | Priority | Rank |
|---|---|---|---|
| 1 | LULC | 15.2% | 3 |
| 2 | Elevation | 14.9% | 4 |
| 3 | RAINFALL | 17.6% | 1 |
| 4 | SLOPE | 13.9% | 5 |
| 5 | NDWI | 4.5% | 8 |
| 6 | FLOW Direction | 11.3% | 6 |
| 7 | SOIL | 7.1% | 7 |
| 8 | Drainage density | 15.4% | 2 |

Number of comparisons = 28

Principal eigenvalue = 8.265 Eigenvector solution: 4 iterations, delta = 9.1E-8

Consistency Ratio CR = 2.7%. When CR is less than 10% it's acceptable to perform the weighted overlay calculations to incorporate the weighted parameters for the flood hazard zoning [35].

The pairwise comparison matrix and the factor maps are both employed in the stage where weight and ranking are calculated. To achieve the best fit to the weight set, the pairwise comparison matrix's primary eigenvector is calculated. Absolute numbers between zero and one, known as weight values, represent priorities. The weights must add up to 1 when using a weighted linear combination, according to this. Table 6 provides an overview of the causative flood factors or variables development, displaying the numerous components, their respective weights, and how they are ranked concerning how they affect flood episodes in the research area.

*Table 6. Criteria Weight Ranking and Classification.*

| S/N | FLOOD CAUSATIVE CRITERION | UNIT | CLASS | CLASS RANGING | CLASS RATING | WEIGHT (%) |
|---|---|---|---|---|---|---|
| 1. | LAND USE LAND | level | Water | Very High | 5 | 15.2 |
| | COVER | | Flooded | High | 4 | |
| | | | Vegetation | Moderate | 3 | |
| | | | Built up | Low | 2 | |
| | | | Bare soil | Very low | 1 | |
| | | | Vegetation | | | |
| 2. | ELEVATION | Meter | – 5 > | Very Low | 1 | |
| | | | 5 – 20 | Low | 2 | |

| S/N | FLOOD CAUSATIVE CRITERION | UNIT | CLASS | CLASS RANGING | CLASS RATING | WEIGHT (%) |
|---|---|---|---|---|---|---|
| | | | 20 – 35 | Moderate | 3 | 14.9% |
| | | | 35 – 50 | High | 4 | |
| | | | 50 - 100 | Very High | 5 | |
| 3. | RAINFALL | mm | < - 1 | Very low | 1 | |
| | | | 1.01 – 3 | Low | 2 | |
| | | | 3.01 – 5 | Moderate | 3 | 17.6% |
| | | | 5.01 – 7 | High | 4 | |
| | | | 7.01 – 9 | Very High | 5 | |
| 4. | Drainage Density | Km2 | 0 – 271 | Very low | 1 | 15.4% |
| | | | 271 - 760 | Low | 2 | |
| | | | 760.- 1,290 | Moderate | 3 | |
| | | | 1,290 - 1,915 | High | 4 | |
| | | | 1,915 - 3,463. | Very High | 5 | |
| 5. | SLOPE | Percentage | 0 - 3.088 | Very low | 1 | |
| | | | 3.088 - 8.878 | Low | 2 | |
| | | | 8.878 - 16.984 | Moderate | 3 | 13.9% |
| | | | 16.984 - 29.723 | High | 4 | |
| | | | 29.723 - 98.433 | Very High | 5 | |
| 6. | NORMALIZED | level | -0.314 - -0.190 | Very low | 1 | |
| | DIFFERENCE WATER INDEX | | -0.190 - -0.163<br>-0.163 - -0.126 | Low<br>Moderate | 2<br>3 | 4.5% |
| | (NDWI) | | -0.126 - -0.049 | High | 4 | |
| | | | -0.049 - -0.0373 | Very High | 5 | |
| 7. | FLOW DIRECTION | Meter | 1 -2 | Very High | 5 | |
| | | | 2 – 8 | High | 4 | |
| | | | 8 – 32 | Moderate | 3 | 11.3% |
| | | | 32 – 64 | Low | 2 | |
| | | | 64 -128 | Very low | 1 | |
| 8. | SOIL TYPE | level | 1550- Sandy | Very low | 1 | |
| | | | Topsoil | Low | 2 | |
| | | | 1552- Sandy | Moderate | 3 | |
| | | | Topsoil | High | 4 | 7.1% |
| | | | 1554- Bs topsoil | Very High | 5 | |
| | | | 1656-sandy/clay | | | |
| | | | 1972 -water | | | |

## 5. Land Use Land Cover Map

The management of the Land use Land Cover dynamic pattern plays a major role in flood risk mapping, showing the rate of infrastructural encroachment on runoff paths, with connection to other factors such as soil, slope, precipitation, etc. [10]. The LULC change showed a considerable loss of wetlands and a dramatic increase in built areas, which can be seen to have its roots in the population increase of the study area, see Figures 7-9. The population increase was calculated to be 7.46% between 2020 to 2024 [36], which seems directly proportional to the infrastructural growth of the area (see Figure 6), as the natural flow pattern has been altered, and alternatives provided cannot accommodate the flow. When this growth opposes planning, flood vulnerability is one of the results.

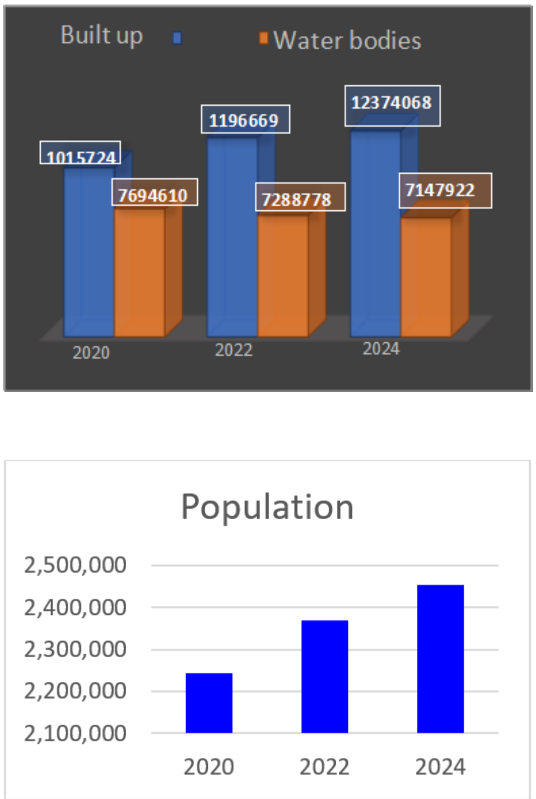


*Figure 6. Bar chart showing built-up, water body, and population in 2020, 2022, and 2024 [36].*

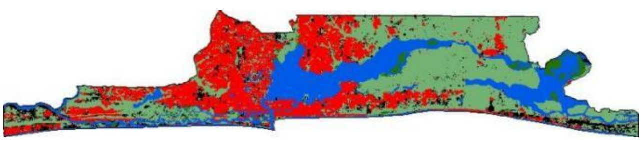

*Figure 7. 2020 land use and land cover of Lagos state.*

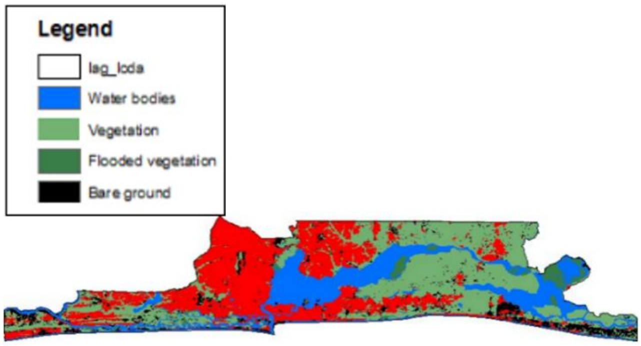


*Figure 8. 2022 Land Use Land Cover Of Lagos State.*

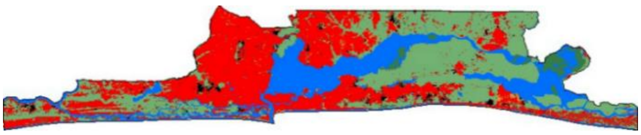

*Figure 9. 2024 land use and land cover of Lagos state.*

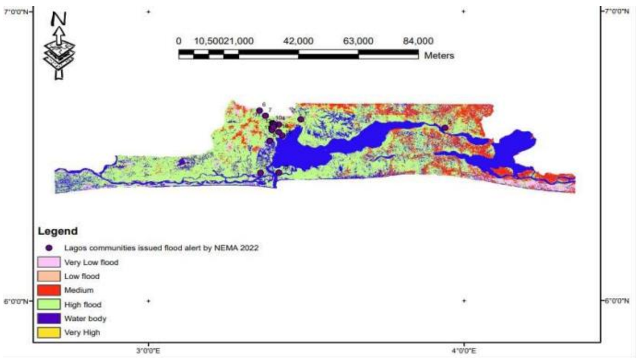


*Figure 10. Floodplain map of Lagos state. Source: ArcGIS processing result.*

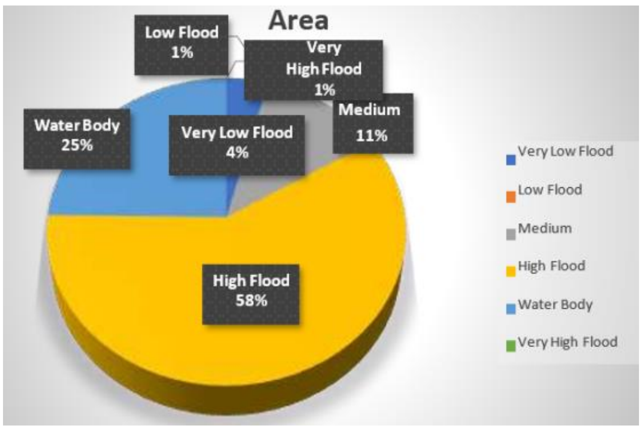


*Figure 11. Floodplain percentile pie chart of Lagos state.*

## 6. Discussion

The overlaying of recorded flood occurrences on the generated flood zone map was done to validate the results, which indicated a strong agreement ratio. In agreement with the National Emergency Management Agency (NEMA) issuing yearly flood alert due to heavy rainfall covering 19 communities in Lagos State, this study also agrees that areas such as Ketu, Alapere, Agric, Owode Onirin, Ajegunle, Alagbole, Kara, Isheri Olowora, Araromi, Otun Orisha, Agiliti, Meiran, Maidan, Odo Ogun, Owode Elede, Agboyi I, Agboyi II, Agboyi III, and Mile 12, are seen to be prone to high flood events [2]. To quantify the validation in addition to the qualitative comparison, value accuracy metrics were calculated, with 102 points selected from the flood hotspots and geolocated on the floodplain map. To calculate the percentile agreement ratio, the number of observed flood hotspots in high flood zones was added to the high flood zones as shown in Figure 10, divided by the total number of observed flood hotspots, and multiplied by 100. 87 of the 102 observed flood hotspots fell within the high flood zone, resulting in an agreement ratio of approximately 85%, indicating a strong predictability ratio.

The weight generated from the AHP calculation is strongly consistent with research in Nigerian basins such as Benue, Lower Ogun, Cross River, and Owerri. Rainfall has a major impact on flood risk, as evidenced by various studies [38-40] because of its direct influence on surface runoff. Furthermore, the LULC, elevation, slope, and drainage density are acknowledged as key factors of flood risk, with a focus on flow accumulation and sequencing. Flow direction and soil have a large influence on runoff, although NDWI has a minimal impact. As a result, the weight distribution follows standard modeling practices.

The yearly most prominent hazard in Lagos has remained flooding, which has already claimed over 600 lives and affected more than 2.5 million people [2]. Hence, the culminating factors must be carefully considered, as done in this study. The topography of Lagos has shown a considerable level of exposure to flooding, considering its spatial pattern, which shows the state's water body covers 25% of the total area, having 58% falling under a high flood risk zone, revealing the coastal influence of the state (see Figure 11). The low flood zones have covered a small portion of 4% seen to be a higher elevation area of the state with more vegetation showing lower runoff and unimpeded flow. In the medium flooding zone, 11% are characterized by areas with clogged/poor drains, suffering from heavy rainfall [40]. This agrees with what studies in Port Harcourt, Ibadan, and Accra have reported: faulty drainage systems make flood risks worse even in regions that aren't very likely to flood [40]. 1% of the state in the very high flood-risk zone is urban, and these areas are very vulnerable due to human activities, wetland encroachment, and rapid land conversion.

Comparatively, due to coastal proximity, wetland reclamation, and urban sprawl, Lagos is one of the high participants in the high flood risk susceptibility among many Nigerian cities. This pattern aligns with global coastal megacities—such as Jakarta, Ho Chi Minh City, and Manila, where sea-level rise and severe rainfall culminate in widespread flood susceptibility within the areas. [40]. Hence, the Lagos flooding finds its root in human-induced causes and hydrological natural factors.

The significant impact of urbanization-associated factors such as LULC and drainage density highlights the need for stricter land-use control, enforcement of development rules, and maintenance of natural flood buffers such as wetlands and mangroves. The inclusion of flood-risk maps into building permit approvals, infrastructure design, and urban development planning is crucial for minimizing future losses and emphasizing the importance of climate adaptation action.

Finally, the high vulnerability of densely populated areas needs enhanced drainage channels, regular clearing, and commitment to environmentally friendly solutions such as retention ponds, green corridors, and permeable surfaces. Dependable early notification systems, community-based readiness, and relocation plans for inhabitants in the most vulnerable zones are equally vital for strengthening urban resilience. The need for a GIS-based risk assessment with inclusive climate projections and sustainable urban projections is crucial for a fast-growing urban city like Lagos.

## 7. Limitation

Regardless of the GIS-AHP approach's strengths, limitations exist in the temporal mismatch of datasets, as well as the limited resolution used in cases such as rainfall, LULC, DEM, and drainage networks, which may affect the accuracy level of the weighted overlay result and the depicted spatial flood risk map. Furthermore, the validation dataset derived from a secondary source with minimal ground truthing may have an impact on the accuracy achieved.

## 8. Conclusions

This study demonstrates the prolonged and extensive flood hazards of Lagos State, coinciding with national warnings from the Ministry of Humanitarian Affairs and Crisis Management regarding the rising consequences of yearly rainfall on lives and property. The quantitative evaluation shows that water bodies constitute nearly 25% of the state's land area, and populations encompassing these zones remain notably vulnerable to potential risk, especially under forecast sea-level rise. The overlay percentile ratio further demonstrates that 58% of Lagos falls inside the high flood-risk spectrum, establishing an unambiguous rationale for the recurring flood crises regularly reported in locations such as Agege, Ifako-Ijaiye, Ikeja, Lekki, Mushin, Oshodi, Ikorodu, and some areas in Epe. Meanwhile, only 1% and 4% of the state are completely safe areas, respectively, the low and very low flood-risk zones. Analysis of LULC has shown a decrease in water bodies, resulting in infrastructural replacement, exposing such structures to the resulting effect of accumulated flow from encroachment on hydrological channels.

An effective framework for mapping many aspects of flood vulnerability in urbanizing coastal areas is provided by the combination of GIS and AHP. The validation, which is supported by flood occurrence overlays, shows 85% agreement ratios, proves the model's appropriateness for flood-risk assessment and planning actions. However, there is a need for a higher resolution dataset, evolving techniques, and inclusion of enhanced climate adaptation data for adaptable urban development in Lagos State.

## 9. Recommendations

Based on the findings of this study, the following are recommended.

To reduce loss of life and property due to the inability to find alternative shelter, the government should provide affordable housing schemes for citizens in high flood risk areas, based on a 58% percentile ratio.

Unexecuted planning equates to the absence of a plan; plans should be obligatory for the benefit of citizens.

Compliance with regulations is necessary due to the rate of urban sprawl and the infiltration of hydrological channels, where individual household mitigation measures may pose external threats to other properties or waterways, must be limited and supplemented by government-sponsored initiatives that can factor in all conditions.

## Abbreviations

| | |
|---|---|
| *MCE* | *multi-criteria evaluation* |
| *GIS* | Geographical Information System |
| *AHP* | Analytical Hierarchy Process |
| *NDWI* | Normalized Difference Water Index |
| *LULC* | Land Use Land Cover |
| *CR* | Consistency ratio |
| *NEMA* | National Emergency Management Agency |
| *DEM* | Digital Elevation Model |
| *MLC* | Maximum Likelihood Classifier |
| *CI* | Consistency Index |

## Conflicts of Interest

Authors declare no conflict of interest.

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