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Flood Vulnerability Assessment using GIS in Osun Watershed, Irewole Local Government Area, Ikire, Osun State, Nigeria

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Abstract: Floods pose significant risks to human life and property, particularly in areas where risk analysis and assessment are insufficient or inadequately implemented. This study addresses flood vulnerability in the Osun watershed, with a specific focus on the Ikire region, by employing a multi-criteria analysis method within the Geographic Information System (GIS). Key factors such as slope, elevation, land use/land cover, drainage density, rainfall, and soil types were evaluated to assess their impact on flood risk. Historical riverbank data, past flood discharge records, and topographic information were utilized to create detailed maps that identify flood-prone areas under varying discharge conditions. The study employed pairwise comparison techniques to conduct a weighted-overlay analysis, resulting in a comprehensive flood vulnerability map categorizing zones into very high (5%), high (13%), moderate (20%), low (44%), and very low (18%) flood risks. Notably, Agricultural fields are situated in flood-prone areas, posing significant risks to social and economic growth due to the potential for substantial property damage and loss of life. The findings suggest that the region's flood vulnerability is more closely linked to factors such as unplanned settlements, inadequate drainage systems, and poor sanitation practices than to excessive rainfall alone. The study concludes that implementing sustainable sanitation practices and effective urban planning measures can significantly reduce flood vulnerability. Overall, this research provides essential insights and valuable tools for informed decision-making in flood risk mitigation and sustainable development efforts in the region.

Keywords: GIS, Multi-Criteria Analysis, Weighted Overlay, Pairwise Comparison, Flood-Prone, Sustainable Development, Flood Vulnerability Map

Nomenclature

Abbreviation	Expansion
LGA	Local Government Area
MCDA	Multi-Criteria Decision Analysis
GIS	Geographic Information Systems
FR	Frequency Ratio
ANP	Analytic Network Process
DEM	Digital Elevation Model
IDW	Inverse Distance Weight
AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio

1. Introduction

With dire repercussions for infrastructure, businesses, and communities, urban flooding has become a major global danger to cities [26] [20] [27]. This expanding issue is best represented by the Osun Watershed, more especially by the Irewole LGA in Ikire, Osun State, Nigeria. Unpredictable rainfall patterns, growing urbanization, and poor infrastructure have all contributed to the region's alarming surge in urban floods [26]. By changing precipitation patterns and increasing the frequency of strong storms, climate change makes these problems worse [28]. The growth of impermeable surfaces brought about by rapid urbanization has decreased natural infiltration and increased surface runoff, all of which are factors in flash floods [27]. Moreover, inadequate waste management and drainage systems exacerbate the problem and have a major negative influence on flooding [26]. These floods have a wide range of negative effects, such as fatalities, resident relocation, property damage, and financial losses. Particularly in danger are disadvantaged communities and other vulnerable people [11]. Effective flood risk management is

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hampered by the underdevelopment of localized flood susceptibility mapping and risk assessments in Ire wole LGA, notwithstanding these obstacles.

This study not only aims to address these gaps by developing a comprehensive flood susceptibility map for Ire wole LGA using MCDA and GIS but also seeks to provide insights that could inform broader urban flood management strategies in similar contexts across Nigeria and beyond. By identifying high-risk areas and offering targeted recommendations, this research can serve as a model for local governments, urban planners, and disaster management agencies working to mitigate the growing threat of urban flooding.

The objectives of this research are

1. To gather and analyze relevant data on flood-contributing factors, including rainfall patterns, topography, land use changes, and drainage systems in Ire wole LGA, Ikire, Osun State, Nigeria.
2. To apply advanced GIS and MCDA techniques to develop a detailed and accurate flood susceptibility map for Ire wole LGA.
3. To classify the area into distinct flood risk zones (e.g., very high, high, moderate, low, very low susceptibility) based on the flood susceptibility map and to assess and prioritize local administrative units (wards) within Ire wole LGA in terms of their flood susceptibility and risk. V. To provide recommendations and actionable insights to local governments, urban planners, and stakeholders for the formulation of effective flood disaster prevention policies and resource allocation in Ire wole LGA.

2. Literature Review

Flood susceptibility in Nigeria is a significant concern influenced by geographical attributes, climate dynamics, and land use practices. Flood susceptibility mapping is crucial for assessing and managing flood risk, especially given the socio-economic activities and infrastructure vulnerable to inundation [11]. Nigeria experiences two main types of floods: river and flash floods, with areas along the Niger River and other major water bodies being particularly prone to inundation. Floods pose significant threats to both urban and rural areas, causing direct harm to infrastructure, agriculture, and human life [5] [1]. The topography, closeness to water bodies, and soil composition of the Osun watershed, in particular within the Ire wole LGA, increase the region's susceptibility to flooding. This danger is further increased by climate change, erratic rainfall patterns, and increasing urbanization [6] [7]. Creating successful flood risk reduction methods in this region requires mapping flood susceptibility [2]. GIS plays an indispensable role in flood susceptibility mapping, enabling the integration and analysis of spatial data such as topography, hydrology, rainfall, and land use. GIS-based methodologies facilitate the creation of detailed flood hazard maps, which are crucial for decision-makers and urban planners in managing flood risk [12] [16]. MCDA is another critical tool in flood susceptibility mapping. It allows for the systematic evaluation of multiple factors contributing to flood risk, such as topographic gradients, rainfall intensities, and land cover. By assigning dynamic weights to these factors, MCDA provides a comprehensive assessment of flood susceptibility in the Osun watershed and Ire wole LGA [20] [23].

2.1 Review Table

Table 1. *Related works and their limitations*

Related Work	Methodology	Advantages	Disadvantages
Islam et al., 2020 [12]	Machine Learning Models	Simple, easy to implement	May not capture complex flood dynamics
Sarkar & Mondal 2019 [21]	FR Model	Provides straightforward probabilistic outcomes	Requires historical data, assumes past conditions
Shaf apour Tehrany et al. 2014 [22]	Ensemble Weights-of-Evidence and Support Vector Machine Models	Integrates multiple factors, robust in complex scenarios	Requires large datasets, complex interpretation
Flood susceptibility mapping using an improved analytic network process with statistical models [23]	Analytic Network Process (ANP)	Visualizes spatial relationships, flexible in analysis	Subjective weight assignment, data-dependent
Scenario-Based Real-Time Flood Prediction with Logistic Regression [29]	Hydrodynamic Modeling	Detailed, accurate representation of flood scenarios	Requires detailed data, computationally expensive

2.2 Research Gap

The methodologies for flood susceptibility modeling exhibit a range of strengths and weaknesses, reflecting the diverse approaches used to assess flood risk. Each method brings unique advantages to the table, contributing to a more nuanced understanding of flood dynamics.

Machine learning models [12] offer simplicity and are relatively easy to implement, but they may fall short in capturing the intricate complexities of flood events, potentially leading to less precise results. In contrast, the FR model [21] relies on historical data to estimate flood risk, which, while straightforward, assumes past conditions predict future events, a limitation in dynamic environments. Ensemble approaches that combine weights-of-evidence with support vector machines [22] integrate multiple factors for a comprehensive assessment, yet they require extensive datasets and can be complex to interpret. The ANP [23] provides a flexible framework for analyzing spatial relationships and assigning weights, but it can be subjective and dependent on the data quality. On the other hand, hydrodynamic modeling (Lee & Kim, 2021) offers a detailed and accurate representation of flood scenarios, which is crucial for real-time predictions but demands high levels of data detail and computational resources (Lee & Kim, 2021).

Previous studies on flood susceptibility mapping provide valuable frameworks and data, but the unique characteristics of Irewole LGA necessitate a tailored approach. This research aims to build upon existing methodologies while adapting them to the region's specific needs, ultimately producing precise and actionable flood susceptibility maps [8] [17].

Overall, these methodologies collectively underscore the importance of balancing complexity, data requirements, and computational demands. While each approach offers valuable insights into flood susceptibility, its limitations highlight the need for careful selection based on specific study contexts and available resources. Integrating various methods or choosing the most appropriate one based on the specific characteristics of the study area can enhance the effectiveness of flood risk assessments. A thorough assessment of flood vulnerability can be achieved by utilizing the strengths of several elements, which is made possible by the weighted overlay method based on GIS. In contrast to certain models that exclusively depend on statistical or machine learning methods, this strategy incorporates expert opinion via AHP, improving interpretability and accuracy [13] [17]. Still, there are certain disadvantages to the approach. Subjectivity is introduced depending on expert opinion, and the model's efficacy is dependent on the correctness and caliber of the input data. Furthermore, even though the weighted overlay method is adaptable, in highly changeable contexts it might not fully reflect the intricacies of flood dynamics [8][16].

To develop accurate and responsive flood susceptibility maps for Irewole LGA, it is essential to understand the region's unique geographical and environmental attributes (Olanrewaju, 2023; [7]). The region's meandering rivers, expansive low-lying terrains, and seasonal rainfall patterns contribute to its heightened flood vulnerability. The development of dynamic flood susceptibility maps that respond to these nuances is crucial for effective disaster preparedness and risk mitigation [21] [22].

3. Methodology

3.1 The Study Area

The study area is centered in the Osun watershed within Irewole LGA, situated in the southern part of Osun State, Nigeria. The town of Ikire serves as the LGA headquarters, positioned at approximately 7°21′40″N latitude and 4°11′00″E longitude. Covering an area of approximately 271 square kilometers, the watershed is characterized by its geographic features and hydrological dynamics. The population within this watershed was recorded at 143,599 residents during the 2006 census. The postal code for Irewole LGA is 221. Irewole LGA holds historical and cultural significance within Osun State, contributing to the state's socio-economic landscape. Flooding is a seasonal challenge in Irewole LGA, as in many regions of Nigeria. It occurs due to factors such as heavy rainfall, overflowing rivers, and inadequate drainage systems. These flooding incidents can have adverse effects on communities, including property damage, displacement of residents, and disruptions to daily life.

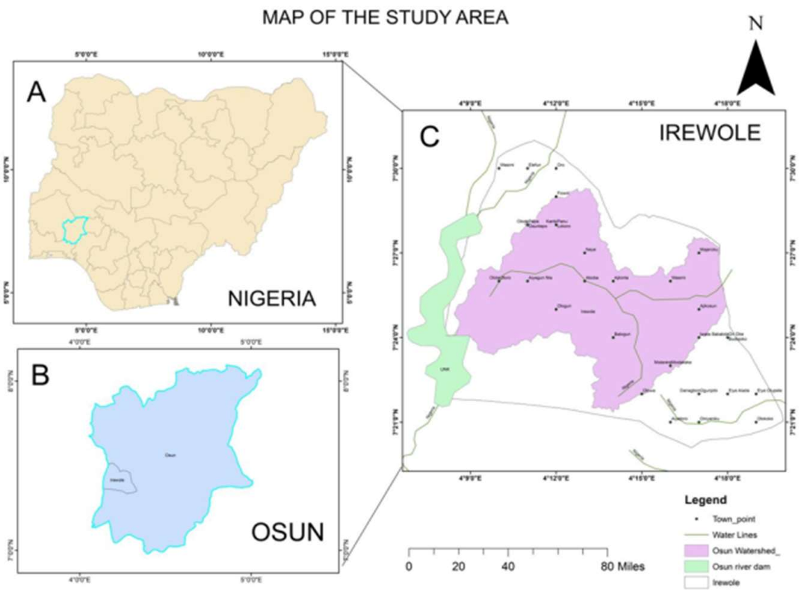

Fig 1. *Study Area Map*

3.2 Methods and Materials

This study utilized comprehensive secondary data, including streamflow records, precipitation data, and various geospatial datasets, to assess flood vulnerability. Key flood-related factors—drainage density, DEM, land use/land cover, soil type, rainfall, and slope—were analyzed using ArcGIS.

A high-resolution (30m by 30m) SRTM DEM and rainfall data covering 2011-2022 were used to create a flood plains map. The DEM was processed to generate elevation raster layers, which were categorized into five classes based on the Equal Interval classification system. Rainfall data were interpolated using the IDW method and similarly re-categorized. Slope characteristics were derived from the DEM, converted to 3D shapefiles, and classified into five ranks reflecting flood susceptibility.

Soil types in the study area were classified according to the FAO soil classification for Nigerian soil, and their flood risk was evaluated. Drainage density was calculated using GIS line density modules to quantify the density of river systems, offering insights into the distribution of drainage networks. Land use/land cover analysis was performed using Landsat 8 satellite images and supervised classification within ArcGIS, with the results categorized into five classes.

All these factors were integrated through a weighted overlay process in ArcGIS, generating a comprehensive flood vulnerability map. The MCDA methodology, specifically the AHP, was employed to assign relative importance to each factor. The CI and CR were calculated to ensure the reliability of these weightings, confirming a robust assessment of flood-prone areas.

The CI, a measure of departure from consistency, is estimated using the procedure:

$$CI = \frac{\lambda - n}{n - 1} \tag{1}$$

Where n is the number of factors (6) and λ is the average value of the consistency vector estimated in Table 7.

Λ = (5.88 + 5.90+ 5.83+ 5.60+ 5.75+ 8.00) / 6 = 6.16

Based on the above equation, CI = 6.16- 6/6 - 1 = 0.03

To measure the heftiness of the professional sight, the Consistency Ratio (CR) was computed with Eq. (2), and the effect was presented in Table 7.

$$CR = \frac{CI}{RI} \tag{2}$$

Where RI is the random inconsistency index, standardized using Saaty (1980), and its value depends on the number n of aspects being associated for (n = 6), (RI = 1.24).

$$CR = \frac{CI}{RI} = \frac{0.03}{1.24} = 0.02$$

The result, 0.024 < 0.1, indicates a practical degree of consistency in pair-wise comparisons. Consequently, weights were allocated as follows: 0.42 for slope, 0.20 for elevation, 0.18 for rainfall, 0.09 for land use/cover, 0.08 for drainage density, and 0.03 for soil types.

4. Results

4.1 Flood Vulnerability Factors Analysis

The primary factors contributing to flooding, including slope, elevation, average rainfall, drainage density, land use/land cover, and soil type, were employed in the assessment of vulnerability to inundation. The raster layers were categorized based on their capacity to cause inundation within the watershed, building upon previous work [30]

4.2 Elevation Factor

The topography of the study area was characterized by varying elevation values, with lower values indicating flatter terrain and higher values representing steeper slopes. To assess vulnerability to flooding, these elevation classes were classified into five levels, as depicted in Fig 3. Regions with the lowest elevations, below 190 meters, were deemed highly susceptible to floods and classified as class 1. Areas with elevations ranging from 191 to 210 meters were categorized as class 2, indicating a high vulnerability to flooding. Moderate vulnerability was assigned to regions with elevations between 211 and 229 meters, classified as class 3. Similarly, areas with elevations ranging from 230 to 251 meters were labeled as class 4, representing low vulnerability to flooding. Finally, regions with the highest elevations, above 252.2 meters, were classified as class 5, indicating very low vulnerability to flooding. The maximum elevation recorded in the study area was 299 meters, while the minimum elevation was 150 meters.

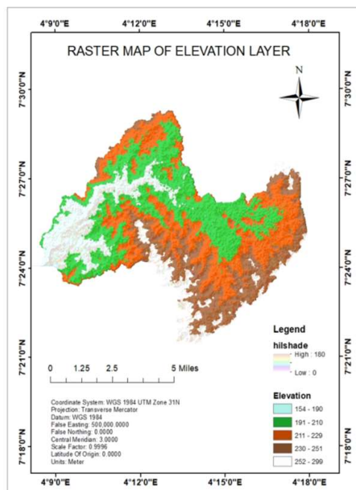

Fig 2. *Raster map of Elevation Layer*

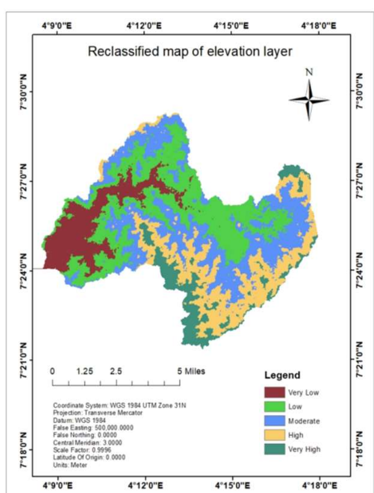

Fig 3. *Reclassified Raster map of Elevation Layer*

4.3 Drainage density factor

To evaluate flood susceptibility, we utilized the drainage density data obtained from the spatial analyst extension. Our analysis involved a classification scheme, as illustrated in Fig 4 and 5, which categorizes different regions based on their drainage density values. Areas with higher drainage density values are identified as more susceptible to flooding and are classified into higher-risk classes. For instance, regions with drainage density values exceeding 298.376 km/km2 are classified as class five, indicating a very high susceptibility to flooding. Conversely, areas with lower drainage density values are considered less susceptible to flooding and are classified into lower-risk classes, with class one representing the least susceptibility, characterized by drainage density values below 54.448 km/km2.

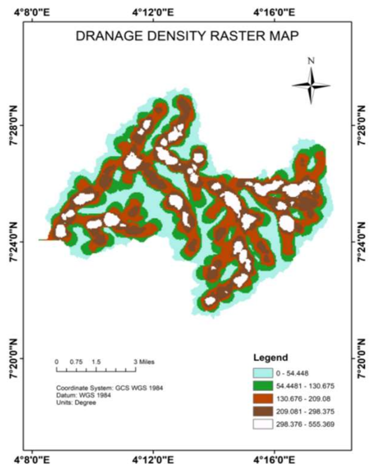

Fig 4. *Raster map of Drainage Density Layer*

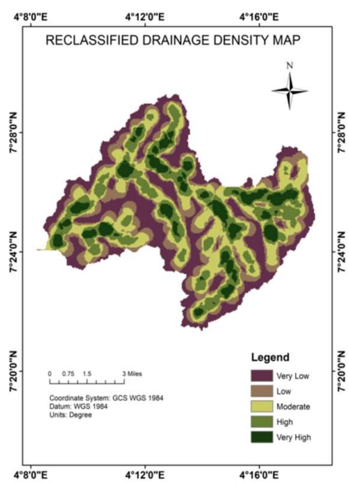

Fig 5. *Reclassified Raster map of Drainage Density Layer*

4.4 Rainfall Factor

In our classification scheme, as illustrated in Fig 7, regions experiencing higher levels of rainfall were found to be particularly susceptible to overflow events, it is associated with other factors like elevation and slope. This classification categorized areas based on their annual rainfall values into five distinct classes. Class five (>102.568 mm/year) represented regions with extreme exposure to overflow, indicating the highest susceptibility. Class four (101.79–102.567 mm/year) denoted areas with high susceptibility to flooding, while class three (101.242–101.789 mm/year) indicated moderate vulnerability. Regions with annual rainfall ranging from 100.695 to 101.241 mm/year were classified as class two, representing low susceptibility to flooding. Finally, class one (<100.694 mm/year) encompassed areas with very low rainfall and minimal susceptibility to flooding. It's noteworthy to mention that although the variation in rainfall across the study area may not be significant, areas with higher rainfall exhibited a higher tendency for overflow, thus increasing susceptibility to flooding.

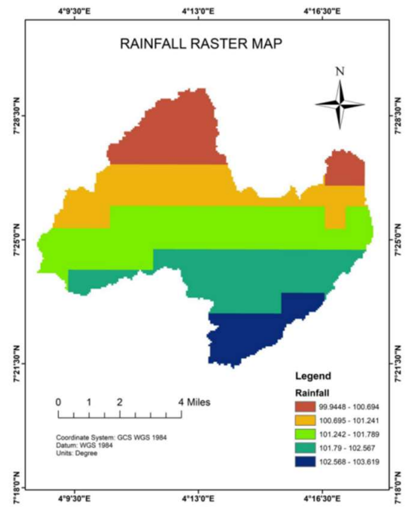

Fig 6. *Raster map of Rainfall Layer*

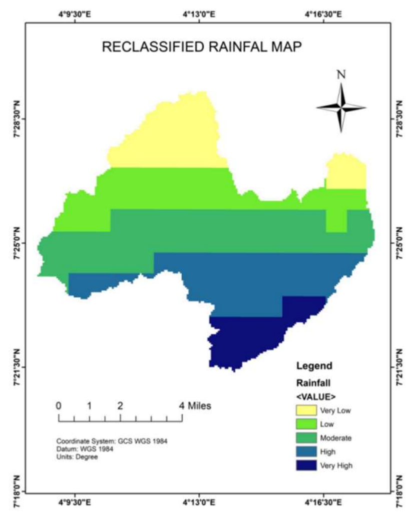

Fig 7. *Reclassified Raster map of Rainfall Layer*

4.5 Slope Factor

Slope plays a critical role in shaping surface hydrological processes and influencing the occurrence of floods. It determines whether infiltration, runoff, or subsurface flow predominates in a given area (Naef, 2003). Lower slope values indicate flatter terrain, while higher values indicate steeper terrain. To assess susceptibility to inundation, slopes were categorized into five ranks. Areas with the smallest slopes, below 20%, were classified as class five, encompassing 45% of the study area and highly affected by floods. Class four (20–40%), covering 43% of the study area, was designated as highly vulnerable to flooding. Moderate vulnerability was assigned to class three (40–60%), representing 12% of the study area. Areas with slopes ranging from 60% to 80% were classified as class two, indicating low vulnerability, while those with slopes exceeding 80% were classified as class one, signifying very low vulnerability. These classifications were established based on local data, expert knowledge, and a comprehensive understanding of slope hazards.

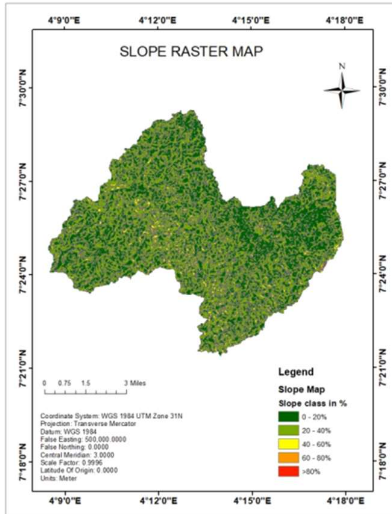

Fig 8. *Raster map of Slope Layer*

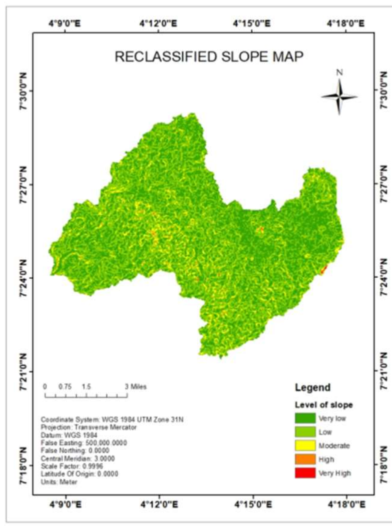

Fig 9. *Reclassified Raster map of Slope Layer*

4.6 Soi1 Factor

In this classification scheme, the categorization of soil types into different classes reflects their varying capabilities to produce flood rates. Class five signifies soils with an exceptionally high capacity to generate an extremely high flood rate, indicating a heightened susceptibility to flooding. Conversely, class one denotes soils with an extremely low capacity to produce flood rates, suggesting minimal susceptibility to flooding. As a result of these criteria, loam is classified as class two, while clay is classified as class one, as illustrated in Fig 10 and 11.

Loam soil, characterized by its balanced mixture of sand, silt, and clay particles, exhibits moderate water retention capabilities and permeability. However, its susceptibility to compaction, especially when subjected to heavy rainfall or flooding events, can impede water infiltration and exacerbate surface runoff, leading to increased flood risk. (Gashaw and Legesse, 2011). On the other hand, Clay soil, with its fine particles and high compaction tendency, has low permeability, which restricts water infiltration. Consequently, Clay soil is highly prone to surface waterlogging and runoff during precipitation events, making it particularly susceptible to flooding. (Gashaw and Legesse, 2011).

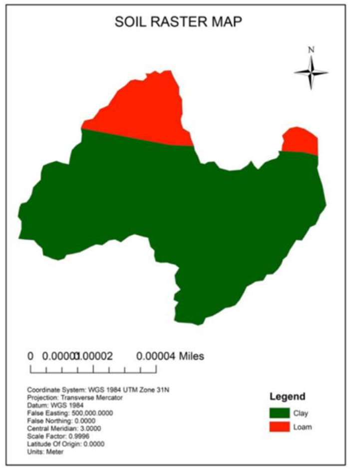

Fig10. *Raster map of Soil Layer*

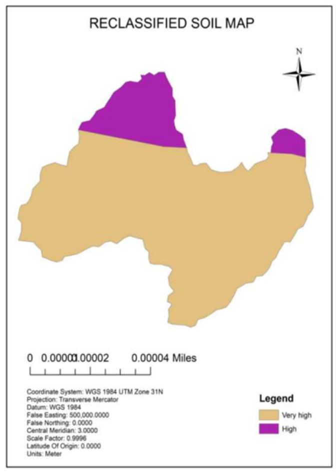

Fig 11. *Reclassified Raster map of soil Layer*

4.7 Land Use/Land Cover Factor

Following the image classification process, the resulting information was converted into a raster layer, facilitating spatial analysis and integration with other geospatial data layers. Subsequently, the land use/land cover types were re-categorized into five classes, taking into account their respective impacts on flood susceptibility.

Bare land, lacking vegetation cover and prone to high surface runoff, was designated as class five, indicating its significant contribution to flood generation. Built-up areas, characterized by impervious surfaces like roads and buildings, were classified as class four, reflecting their role in intensifying surface runoff and inundation.

Outcrop areas, consisting of rocky terrain with limited soil infiltration capacity, were categorized as class three due to their moderate influence on flood levels. Vegetation, crucial for ecological balance, was acknowledged for its potential to either exacerbate or mitigate flood risk based on density and type, and thus assigned as class two.

Lastly, forested land, with its dense canopy cover and extensive root systems, was identified as having minimal capacity to contribute to flooding and was ranked as class one. This re-categorization process provides valuable insights into the complex interactions between land use/land cover patterns and flood susceptibility within the watershed area. This classification is presented in Fig 12 and 13.

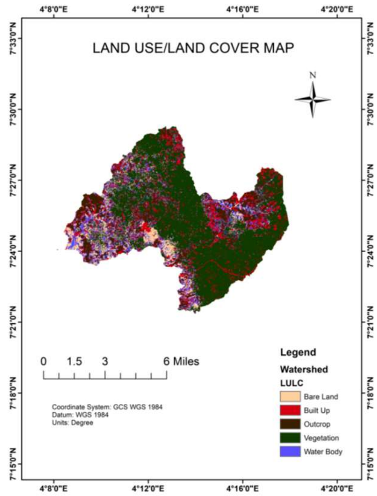

Fig 12. *Raster map of Land Use/Land Cover Layer*

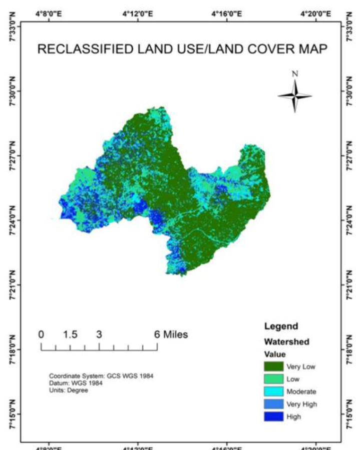

Fig 13. *Raster map of Land Use/Land Cover Layer*

Table 2. *Pairwise comparison of six criterion matrix.*

Factors	Slope	Elevation	Rainfall	Land cover/cover	Drainage density	Soil type
Slope	1	3	5	3	5	7
Elevation	$\frac{1}{3}$	1	1	3	3	5
Rainfall	$\frac{1}{3}$	$\frac{1}{3}$	1	3	3	5
Land Use/Land cover	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	1	$\frac{1}{3}$	5
Drainage density	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{5}$	1	1	3
Soil type	$\frac{1}{5}$	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{5}$	1

Table 3. *Pair-wise comparison decimal matrixes*

Factors	Slope	Elevation	Rainfall	Land cover/cover	Drainage density	Soil type
Slope	1	3	5	3	5	7
Elevation	0.33	1	1	3	3	5
Rainfall	0.33	0.33	1	3	3	5
Land cover/cover	0.33	0.33	0.33	1	0.33	5
Drainage density	0.2	0.33	0.2	1	1	5
Soil type	2.39	5.13	7.73	11.33	12.53	26

Table 4. *Normalized pairwise matrix calculated*

Factors	Slope	Elevation	Rainfall	Land cover/cover	Drainage density	Soil type
Slope	0.42	0.58	0.65	0.29	0.42	0.29
Elevation	0.14	0.19	0.13	0.29	0.25	0.21
Rainfall	0.14	0.06	0.13	0.29	0.25	0.21
Land Use/Land cover	0.14	0.06	0.04	0.09	0.03	0.18
Drainage density	0.08	0.06	0.03	0.09	0.08	0.13
Soil type	0.08	0.03	0.03	0.03	0.02	0.04

Table 5. *Determined relative criterion weights.*

	Slope	Elevation	Rainfall	Land cover/cover	Drainage density	Soil type	Criteria Weight
Slope	0.40	0.57	0.6	0.29	0.40	0.29	0.42
Elevation	0.14	0.19	0.13	0.29	0.25	0.21	0.20
Rainfall	0.14	0.06	0.13	0.29	0.25	0.21	0.18
Land Use/Land cover	0.14	0.06	0.04	0.09	0.03	0.18	0.09
Drainage density	0.08	0.06	0.03	0.09	0.08	0.13	0.08
Soil type	0.08	0.03	0.03	0.03	0.02	0.04	0.03

Table 6. *The Eigen Vector weights of each flood factor obtained after the pairwise Comparison*

Flood Factor	Normalized Weighted	Influence (Percentage)
Slope	0.42	42
Elevation	0.20	20
Rainfall	0.18	18
Land Use/Land cover	0.09	9
Drainage density	0.08	8
Soil type	0.03	3

Table 7. *Determined consistency ratios (CR)*

	Slope	Elevation	Rainfall	Land cover/cover	Drainage density	Soil type	Weighted sum value	Criteria Weight	Weighted sum value/ Criteria Weight
Slope	0.42	0.60	0.09	0.27	0.04	0.21	2.45	0.42	5.88
Elevation	0.14	0.20	0.18	0.27	0.24	0.15	0.18	0.20	5.90
Rainfall	0.14	0.07	0.18	0.27	0.24	0.15	1.05	0.18	5.83
Land Use/Land over	0.14	0.07	0.03	0.09	0.03	0.15	0.51	0.09	5.60
Drainage density	0.09	0.07	0.04	0.09	0.08	0.09	0.46	0.08	5.75
Soil type	0.09	0.03	0.04	0.03	0.02	0.03	0.24	0.03	8.00

Table 8. *Random Inconsistency Indices.*

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

4.8 AHP Spatial Flood Prediction

The flood-generating factors, which were rasterized and classified, underwent weighting using Saaty's AHP. A pair-wise comparison was organized for each map, employing a 9-point significance scale, as suggested by Saaty (1980). AHP is a multi-criteria decision-making technique that systematically measures and integrates the effects of different factors, considering both qualitative and quantitative information. It involves a rigorous evaluation of the relative importance of a set of criteria through pairwise comparisons.

Weighting techniques were applied to prioritize the significance of each factor concerning others in the weighted overlay process. A higher weight indicated greater importance of a factor relative to others in the weighted overlay. The computed consistency ratio, which was less than 0.1 (0.073), was considered acceptable.

The pairwise assessment resulted in assigning high weights to slope and elevation, followed by average precipitation, land use/land cover, drainage density, and soil group. Calculated Eigen Vector values, representing coefficients for each flood factor, were used in a weighted overlay in ArcGIS to generate the final flood hazards map for the Osun River. The weights derived from the AHP process were incorporated into the equation developed by Saaty (1980):

$$Flood\ hazards\ =\ 0.42\ x\ \left(Slope\right)\ +\ 0.20\ x\ \left(Elevation\right)\ +\ 0.18\ x\ \left(Rainfall\right)\ +\ 0.09\ x\ \left(Land\ use / cover\right)\ +\ 0.08\ x\ \left(Drainage\ density\right)\ +\ 0.03\ x\ \left(Soil\ type\right)$$

This equation represents the combined impact of various flood factors in the Osun River watershed, producing a comprehensive flood hazards map.

4.9 Flood Susceptibility Map

The comprehensive development of a flood susceptibility map for the Osun watershed involved the adept application of GIS and multi-criteria decision-making techniques, specifically AHP. This approach, aligned with established methodologies by [31], [14], [32], [14], and [33], aimed to address the escalating flood vulnerability exacerbated by climate change-induced increases in river discharges [15].

Within the Osun watershed, a meticulous evaluation of flood-generating factors transpired in a GIS environment. Notably, the study discerned that intensified agricultural activities, contributing to land use/land cover changes, played a significant role in elevating flood vulnerability, particularly in the downstream segments of the river basins.

To provide a nuanced understanding, the study delved into the identification of flooded areas within the Osun watershed, considering return periods of 5, 10, 25, 50, and 100 years. Employing GIS and multi-criteria Analytic Hierarchy Process methods, the overflow threat valuation map was crafted, incorporating crucial factors such as slope, elevation, rainfall, drainage density, land use/land cover, and soil types. The resultant vulnerability map categorized regions into five distinct flood vulnerability levels: very low, low, moderate, high, and very high.

Specifically, the findings revealed that 5%, 13%, 20%, 44%, and 18% of the area corresponded to very low, low, moderate, high, and very high flood susceptibility, respectively. This observed pattern aligns cohesively with similar flood vulnerability studies, drawing parallels to the insightful research conducted in Dire Dawa Town by Alemayehu (2007).

Visual representations embedded in the vulnerability map distinctly highlighted areas of high to extremely high flood vulnerability, predominantly concentrated in the downstream segments of the river. The lowland flat areas of the Osun watershed, as depicted in Fig 14, were particularly susceptible to such heightened flood threats. Notably, 40% of the region faced the highest flood threat, while the middle and downstream portions exhibited varying degrees of low to incredibly low flood vulnerability prospects. This comprehensive analysis contributes valuable insights for informed decision-making, emphasizing the need for targeted interventions and adaptive strategies to mitigate the escalating risks within the Osun watershed.

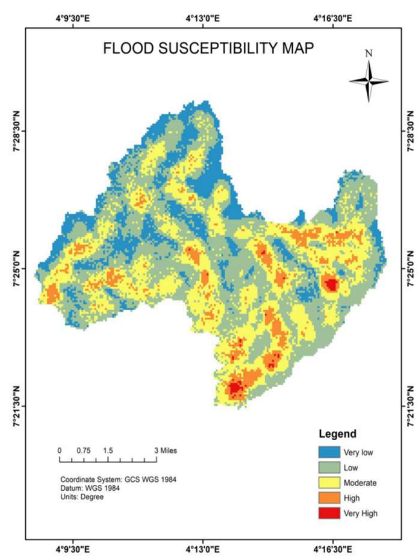

Fig 14. *Flood Susceptibility Map of Osun watershed*

5. Conclusion

This study successfully delineated flood-prone regions within the Osun watershed using advanced multi-criteria analysis within a GIS framework. By systematically analyzing key factors such as elevation, slope, rainfall, drainage density, land use/land cover, and soil type, we developed a detailed flood vulnerability map. The pairwise technique used in the weighted overlay analysis proved effective in highlighting areas of varying flood susceptibility.

Findings revealed that approximately 62% of the study area is at moderate to very high risk of flooding, with the lowland regions near the Osun River, particularly at Asejire and Ajilo villages, showing the highest vulnerability. This spatial pattern aligns well with observed flood events, indicating that the model effectively captures real-world flood dynamics. Notably, the study provides actionable insights by quantifying the extent of vulnerable areas, thus offering a valuable tool for flood risk management. The research's main contribution lies in its methodological framework, which integrates multiple environmental factors to accurately assess flood risk. This approach not only enhances the understanding of flood-prone areas but also supports the development of targeted mitigation strategies.

Future studies should focus on incorporating real-time data and climate change projections to enhance the predictive capabilities of flood vulnerability models. There is also potential for integrating socio-economic factors into the analysis to better understand and mitigate the human impacts of floods. Testing the proposed method against other advanced techniques, such as hydrodynamic modeling, could provide further validation and highlight areas for improvement. Additionally, the application of real-time flood monitoring systems, supported by satellite imagery and machine learning, could improve the accuracy and timeliness of flood prediction.

Finally, implementing and testing the recommended mitigation measures in real-world scenarios would offer valuable feedback for refining flood management policies and practices.

Recommendations

Osun watershed can be protected against flooding by implementing the following crucial strategies: To protect areas susceptible to flooding, local government and state authorities should work closely together. Evaluations of the flood risks should be incorporated into development plans. Reducing the magnitude of floods requires the implementation of soil conservation measures and flood protection structures, particularly in the upstream and downstream areas. In places that are vulnerable to flooding, adopting suitable land use planning will reduce negative effects and risks. Reducing flood risks also requires improving drainage conditions, especially in areas with high to extremely high flood vulnerability. Osun Watershed's proactive and coordinated approach to flood protection is the goal of these initiatives.

Compliance with Ethical Standards

Conflicts of Interest: Authors declared that they have no conflict of interest.

Human Participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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