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GIS-Based Flood Susceptibility Mapping Using Weighted Overlay and Analytical Hierarchy Process in Awka North, Anambra State, Nigeria

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Abstract

Flood susceptibility assessment provides an important spatial basis for land-use planning, drainage management and flood-risk reduction, particularly in areas experiencing increasing development and seasonal rainfall. This study developed a Geographic Information System (GIS)-based flood susceptibility map for **Awka North Local Government Area, Anambra State, Nigeria**, using elevation, slope, Topographic Wetness Index (TWI) and distance to drainage derived from a 30-m Shuttle Radar Topography Mission (SRTM) digital elevation model. The spatial datasets were harmonized in the Minna/Nigeria Mid Belt projected coordinate reference system (EPSG: 26392), standardized into Four susceptibility classes and integrated using a weighted linear combination. The adopted weights were 30% for elevation, 25% for slope, 25% for TWI and 20% for distance to drainage. An Analytical Hierarchy Process (AHP) sensitivity assessment was additionally conducted to examine the influence and consistency of an alternative weighting structure. The resulting flood susceptibility index ranged from 0.75 to 4.50, with a mean value of 2.7725. Of the **351.6831 km²** of valid classified area, **226.7766 km² (64.48%)** was classified as High susceptibility, **62.4915 km² (17.77%)** as Very High, and **57.4371 km² (16.33%)** as Moderate. The High and Very High classes together accounted for **289.2681 km² (82.25%)** of the valid area. The AHP assessment produced weights of 33.81% for elevation, 20.48% for slope, 28.81% for TWI and 16.90% for distance to drainage, with a consistency ratio of **0.0225**, indicating acceptable consistency. A 2022 historical flood inventory generated using Google Earth Engine identified **110 flood polygons covering approximately 1.3546 km²**. The resulting map represents a relative flood-susceptibility screening product rather than a direct prediction of flood depth, frequency or discharge. The study provides a spatial baseline for drainage assessment, development planning, flood preparedness and future validation using higher-resolution data, field observations and additional hydrological variables.

Keywords: Flood Susceptibility, Geographic Information System, Weighted Overlay, Analytical Hierarchy Process, Topographic Wetness Index, SRTM, Drainage Distance, Awka North, Anambra State

1. Introduction

Flooding is often first experienced not as a statistic, but as water entering a home, cutting off a road, damaging farmland or interrupting the ordinary rhythm of community life. Across many developing environments, these impacts emerge from the interaction of rainfall, terrain, drainage capacity, soil conditions, land cover and human modification of natural flow pathways. In southeastern Nigeria, seasonal intense rainfall, expanding settlements and inadequate stormwater infrastructure can increase the likelihood of localized flooding, especially where water accumulates faster than it can be conveyed away.

Awka North Local Government Area presents a landscape in which these processes can interact. Settlements, cultivated land, roads, developing residential areas and undeveloped surfaces occupy terrain with contrasting elevation and slope conditions. Natural drainage pathways coexist with areas where development may alter runoff routes or reduce the space available for water movement. Identifying where these characteristics combine to create greater relative susceptibility is therefore important for land-use planning, drainage improvement and disaster risk reduction.

Geographic information systems (GIS) offer a practical way to bring these interacting conditions into a single spatial decision-support framework. Terrain-derived variables such as elevation, slope, flow accumulation, Topographic Wetness Index (TWI) and distance to drainage can be standardized and combined to reveal the relative spatial pattern of flood susceptibility.

Weighted overlay is transparent and computationally efficient, while the Analytical Hierarchy Process (AHP) provides a structured means of deriving and checking the consistency of factor weights.

Against this background, the present study develops a reproducible four-factor flood susceptibility model for Awka North. The analysis combines elevation, slope, TWI and distance to drainage derived from a 30 m digital elevation model, supplements the primary model with an AHP-based sensitivity assessment, and prepares a historical flood inventory for independent reference. The objective is not to claim that every high-susceptibility location will flood, but to provide a defensible spatial baseline that can guide further investigation, planning and future validation.

1.1 Aim and Objectives

The aim of this study is to develop a GIS-based flood susceptibility map for Awka North Local Government Area, Anambra State, Nigeria.

1. Prepare and standardize the study-area boundary and digital elevation model;
2. Derive elevation, slope, flow accumulation, Topographic Wetness Index and distance-to-drainage layers;
3. Reclassify the conditioning factors into a common five-class susceptibility scale;
4. Combine the factors using a weighted-overlay model;
5. Derive AHP weights and assess their consistency;
6. Produce a five-class flood susceptibility map and quantify the area occupied by each class; and Prepare a historical flood inventory as an independent reference dataset for future validation.

2. Study Area, Materials and Methods

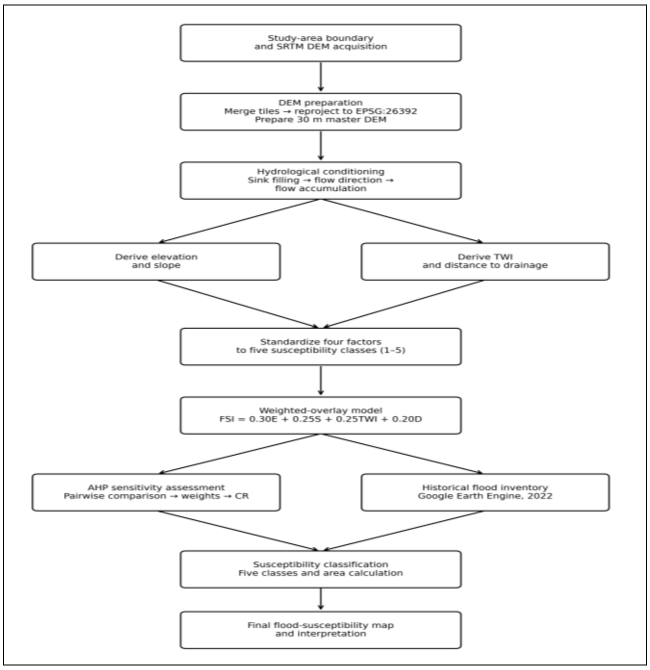

Fig 1: Methodological workflow for the GIS-based flood-susceptibility assessment in Awka North

2.1 Study area

The study was conducted in Awka North Local Government Area of Anambra State, southeastern Nigeria. The area forms part of the wider Awka region and contains settlements, roads, agricultural land and undeveloped surfaces. Its terrain varies from relatively low-lying and gently sloping locations, where runoff may accumulate or remain longer, to elevated and steeper locations, where water may be conveyed more rapidly downslope. Seasonal rainfall, settlement expansion and modifications to natural drainage create a setting in which localized flooding may occur and where spatial screening can support preventive planning.

All spatial processing was conducted in the Minna/Nigeria Mid Belt projected coordinate reference system, EPSG: 26392. The use of a projected coordinate system ensured that distances, areas and raster-cell calculations were expressed in meters and square meters.

2.2 Data sources and software

The primary elevation data were obtained from the SRTM 1 Arc-Second Global digital elevation model. Two adjacent tiles, SRTM_N06E006.tif and SRTM_N06E007.tif, were merged to cover the study region. The Awka North administrative boundary was used to define the analysis extent and clip the raster products. The GIS workflow was implemented using QGIS 3.38.1 (QGIS.org, 2024) [3], GRASS GIS, GDAL, Google Earth Engine and ArcGIS Pro.

2.3 DEM Preparation and Hydrological Conditioning

The SRTM tiles were merged into a continuous elevation raster, reprojected to EPSG:26392 and prepared as a 30-m master DEM. The master DEM recorded elevations from approximately 0.00 m to 122.87 m, with a mean elevation of approximately 31.73 m. **Sink filling and flow-direction processing were performed to improve hydrological continuity and support the derivation of flow accumulation and drainage-related surfaces** [2, 4]. The filled DEM was subsequently used to derive flow accumulation and drainage-related surfaces.

2.4 Conditioning factors

2.4.1 Elevation

Elevation was derived from the master DEM. Lower elevations were assigned higher susceptibility scores because low-lying areas may receive and retain runoff from surrounding terrain.

2.4.2 Slope

Slope was calculated in degrees. Gentle and nearly flat terrain was assigned higher susceptibility scores because runoff movement may be slower and surface-water accumulation may be more likely. The slope surface ranged from 0° to approximately 63.61°.

2.4.3 Flow accumulation and Topographic Wetness Index

Flow accumulation was derived from the corrected flow-accumulation workflow using the filled DEM. The Topographic Wetness Index (TWI) was calculated using the relationship between upslope contributing area and local slope, providing an indication of the tendency of terrain to accumulate water [1].

TWI was calculated using the relationship:

$$TWI = \ln[(\text{Flow accumulation} \times \text{cell size}) / \tan(\text{slope in radians})]$$

A minimum slope threshold was applied where necessary to avoid division by zero. Higher TWI values were interpreted as indicating greater potential for topographic convergence and moisture accumulation.

2.4.4 Drainage network and distance to drainage

A provisional stream network was extracted from the corrected flow-accumulation raster using a threshold of 100 cells. At a 30-m cell size, this represents an upstream contributing area of approximately 0.09 km². Distance to drainage was then calculated, and locations closer to drainage channels were assigned higher susceptibility scores because they may be more exposed to concentrated flow, channel overflow or saturated conditions.

Drainage density was considered during the workflow but was not included in the final model because the available drainage-density output was not sufficiently reliable for defensible interpretation. Omitting the factor avoided introducing an uncertain layer into the susceptibility index.

2.5 Reclassification and standardization

Each conditioning factor was standardized to an ordinal scale from 1 to 5. A score of 1 represents relatively low susceptibility and a score of 5 represents relatively high susceptibility. The four standardized rasters were aligned to the same extent, cell size, projection and snap raster before overlay processing.

Factor	Relative susceptibility interpretation	Standardization
Elevation	Lower elevation = higher susceptibility	Five ordinal classes, 1–5
Slope	Gentler slope = higher susceptibility	Five ordinal classes, 1–5
TWI	Higher wetness/convergence = higher susceptibility	Five ordinal classes, 1–5
Distance to drainage	Closer to drainage = higher susceptibility	Five ordinal classes, 1–5

2.6 Weighted-overlay model

The flood susceptibility index (FSI) was calculated using a weighted linear combination of the four standardized factors:

$$\mathbf{FSI = 0.30E + 0.25S + 0.25TWI + 0.20D}$$

Where E is reclassified elevation, S is reclassified slope, TWI is reclassified Topographic Wetness Index, and D is reclassified distance to drainage. The weights sum to 1.00 and reflect the assumed relative influence of the factors on surface-water accumulation and flood susceptibility.

Factor	Weight	Percentage
Elevation	0.30	30%
Slope	0.25	25%
TWI	0.25	25%
Distance to drainage	0.20	20%
Total	1.00	100%

2.7 AHP sensitivity assessment

An Analytical Hierarchy Process assessment was conducted to examine an alternative weighting structure. Pairwise comparisons were assigned using Saaty's preference scale, with reciprocal values used for the lower-triangular portion of the matrix. The resulting priority weights were calculated by normalizing the comparison matrix. Consistency was assessed using λmax, the consistency index (CI), the random index (RI) and the consistency ratio (CR). A CR below 0.10 was considered acceptable.

Factor	Elevation	Slope	TWI	Distance
Elevation	1	2	1	2
Slope	0.5	1	1	1
TWI	1	1	1	2
Distance to drainage	0.5	1	0.5	1

Factor	AHP weight	Percentage
Elevation	0.338095	33.81%
Slope	0.204762	20.48%
TWI	0.288095	28.81%
Distance to drainage	0.169048	16.90%
Total	1.000000	100%

The AHP calculations produced λmax = 4.060688, CI = 0.020229, RI = 0.90 and CR = 0.022477 (2.25%). The CR is below 0.10, indicating that the pairwise judgments were acceptably consistent. The AHP results were used as a sensitivity assessment of the relative importance of the factors and not as a replacement for the primary weighted-overlay result.

2.8 Susceptibility classification and area calculation

The continuous weighted-overlay index was classified into five categories using the following intervals: 0.75–1.50 Very Low; 1.50–2.25 Low; 2.25–3.00 Moderate; 3.00–3.75 High; and 3.75–4.51 Very High. Class areas were calculated by multiplying the number of valid raster cells by the 900 m² cell area. NoData cells and the Float32 NoData sentinel were excluded from the area calculations.

2.9 Historical flood inventory

A historical flood inventory was prepared using a Google Earth Engine workflow. Pre-flood and flood-period imagery were compared within the Awka North boundary to delineate areas exhibiting flood-related surface-water change. The resulting flood polygons were exported for use as an independent reference dataset. The inventory represents observed or remotely detected flood-related areas for the selected 2022 period; it was not used as an additional susceptibility factor.

3. Results

3.1 Terrain and hydrological factor results

The processed master DEM represented the elevation variation across Awka North at 30-m spatial resolution. Elevation ranged from approximately 0.00 m to 122.87 m, while slope ranged from 0° to approximately 63.61°. The corrected flow-accumulation surface supported the derivation of TWI and the provisional drainage network. The distance-to-drainage surface recorded distances of approximately 1.38 km at its maximum extent. All four conditioning factors were successfully standardized to the five-point susceptibility scale.

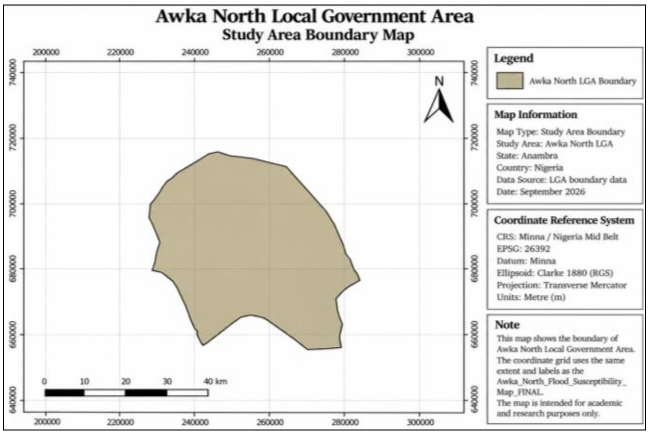

Fig 2: Location and boundary map of Awka North Local Government Area, Anambra State, Nigeria

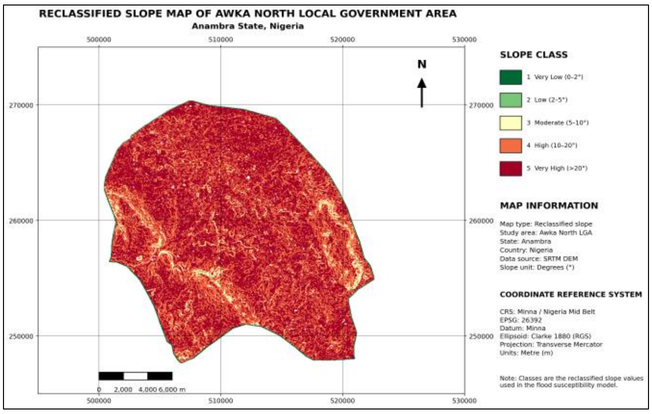

Fig 3: Reclassified slope map of Awka North Local Government Area

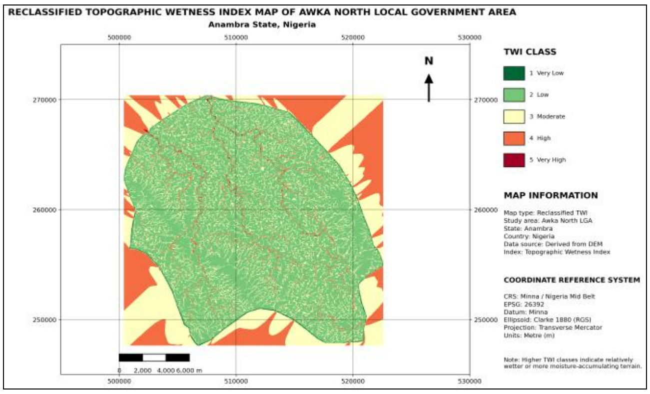

Fig 4: Reclassified Topographic Wetness Index map of Awka North Local Government Area

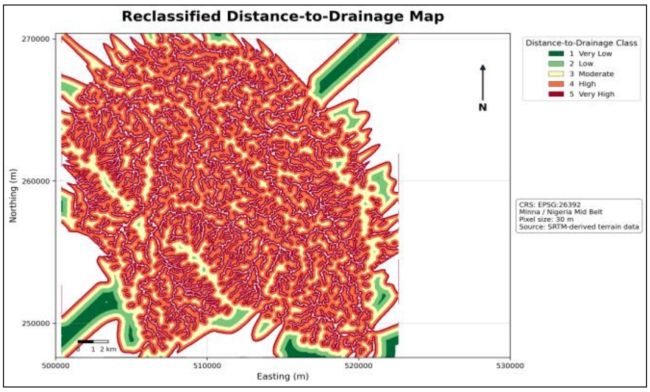

Fig 5: Reclassified distance-to-drainage map of Awka North Local Government Area

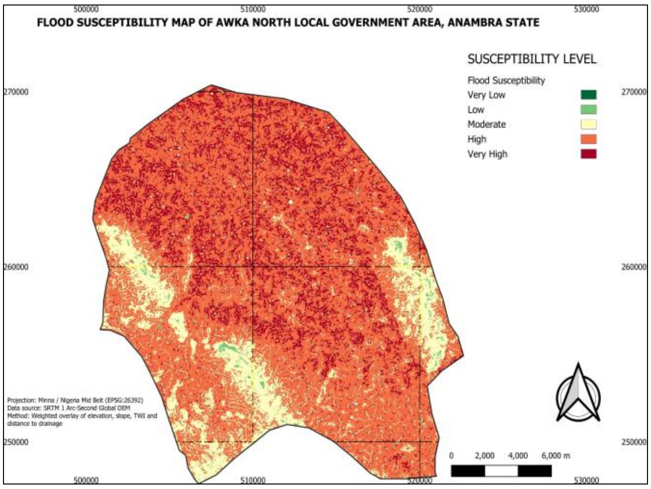

Fig 6: Final weighted-overlay flood susceptibility map of Awka North Local Government Area

3.2 Flood susceptibility index

The four-factor weighted-overlay model produced a continuous susceptibility index ranging from 0.75 to 4.50, with a mean of 2.7725. The resulting surface presents a clear relative pattern: locations where low elevation, gentle slope, high TWI and proximity to drainage occur together receive higher susceptibility scores, while areas characterized by greater elevation, steeper terrain, lower wetness values and greater separation from drainage receive lower scores. The map therefore translates the interaction of terrain and drainage conditions into a spatial picture of where flood-related processes may be more likely to concentrate.

3.3 Area distribution of susceptibility classes

Class	Code	Area (km²)	Area (m²)	Percentage
Very Low	1	0.1728	172,800	0.05%
Low	2	4.8051	4,805,100	1.37%
Moderate	3	57.4371	57,437,100	16.33%
High	4	226.7766	226,776,600	64.48%
Very High	5	62.4915	62,491,500	17.77%
Total	—	351.6831	351,683,100	100.00%

The High susceptibility class dominated the final map, covering 226.7766 km² (64.48%). Very High susceptibility covered 62.4915 km² (17.77%), while Moderate susceptibility covered 57.4371 km² (16.33%). The Very Low and Low classes together accounted for only 4.9779 km², or 1.42% of the valid classified area. In total, the High and Very High categories covered 289.2681 km², equivalent to 82.25% of the valid classified area. This distribution suggests that, under the adopted weighting structure, much of Awka North exhibits terrain and drainage conditions that warrant attention during development planning and flood-mitigation assessment.

3.4 Historical flood inventory results

The 2022 historical flood inventory contained 110 flood polygons. The estimated flood-related area was 1.3546 km², representing approximately 0.35% of the 389.6408 km² study-area extent used in the Google Earth Engine inventory calculation. This inventory provides an independent reference layer for future validation and should not be interpreted as the total flood extent for all years or all flood events.

Historical inventory indicator	Result
Reference period	2022
Flood polygons	110
Study-area extent	389.6408 km²
Mapped flood-related area	1.3546 km²
Flood-related percentage	0.35%

3.5 AHP sensitivity results

The AHP results assigned the greatest weight to elevation (33.81%), followed by TWI (28.81%), slope (20.48%) and distance to drainage (16.90%). Compared with the original weighted-overlay weights, AHP increased the relative importance of elevation and TWI, while reducing the relative importance of slope and distance to drainage.

Factor	Original weight	AHP weight	Difference
Elevation	30.00%	33.81%	+3.81 percentage points
Slope	25.00%	20.48%	−4.52 percentage points
TWI	25.00%	28.81%	+3.81 percentage points
Distance to drainage	20.00%	16.90%	−3.10 percentage points

4. Discussion

The dominance of the High susceptibility class is the central spatial message of the study. Under the adopted weighting structure, a large proportion of Awka North receives a combined signal associated with low relief, gentle terrain, topographic convergence, moisture accumulation and proximity to drainage pathways. This does not mean that the entire area will experience flooding at the same time or to the same depth. Rather, it indicates that the underlying landscape contains widespread conditions that may support runoff concentration, temporary water storage or reduced drainage efficiency when rainfall and local drainage capacity interact unfavorably.

The weighting structure reflects the physical logic of the selected variables. Elevation and slope influence the direction, speed and concentration of surface runoff; low-lying and gently sloping areas may receive water from surrounding terrain and may drain less efficiently. TWI contributes information about the tendency of terrain to accumulate moisture through the combined effects of contributing area and slope. Distance to drainage captures the potential influence of concentrated flow, channel overflow and saturated conditions near drainage pathways. Together, the four factors provide a transparent representation of several important processes that shape relative flood susceptibility.

The AHP sensitivity assessment supports this interpretation while showing how the final pattern may respond to a different weighting structure. Elevation remained the most influential factor, while TWI became the second most influential factor. The consistency ratio of 2.25% indicates that the pairwise judgments were internally coherent. Nevertheless, AHP weights are still dependent on the judgment structure used to construct the comparison matrix. They should therefore be understood as a structured sensitivity assessment rather than as objectively measured causal coefficients.

The historical flood inventory adds an important independent layer to the study. The 2022 Google Earth Engine workflow identified 110 flood polygons covering approximately 1.3546 km². This demonstrates that flood-related surface-water areas can be delineated within the study area, but the inventory represents a selected period rather than a complete record of all flood events. Because it was not used to train or statistically validate the susceptibility model, the study does not claim accuracy, AUC, precision, recall or F1-score.

The limited extent of the Very Low and Low classes should also be interpreted carefully. A low model score does not mean that flooding is impossible. Localized flooding may still occur where blocked culverts, undersized drainage infrastructure, intense rainfall, waste accumulation, land-cover change, road embankments or other unrepresented factors create local hydraulic problems. The map is consequently most useful as a screening instrument that identifies where closer examination is warranted.

The results are influenced by the resolution and quality of the input data. The 30-m SRTM DEM provides consistent regional elevation information, but it may not capture small channels, culverts, walls, road-drainage structures and other micro-topographic features that strongly influence urban flooding. In addition, the provisional 100-cell stream-extraction threshold affects the drainage network and, consequently, the distance-to-drainage surface. Alternative thresholds may produce different susceptibility patterns. These issues do not remove the value of the model; instead, they define the scale and confidence with which it should be applied.

The weighted-overlay approach remains valuable because it is transparent, reproducible and practical in settings where detailed flood observations are limited. Its greatest contribution is not the prediction of an exact flood depth or discharge, but the organization of available spatial evidence into a map that can support field inspection, drainage assessment, development control and emergency preparedness. It should therefore be used as a first-level screening product, alongside field evidence and, where required, hydraulic analysis for site-specific decisions.

5. Conclusion

This study began with a practical question: where within Awka North do terrain and drainage conditions combine to create greater relative susceptibility to flooding? By integrating elevation, slope, Topographic Wetness Index and distance to drainage from a 30 m SRTM digital elevation model, the study produced a reproducible GIS-based susceptibility map. The factors were harmonized in a common projected coordinate system, standardized to a five-point scale and combined using a weighted-overlay model.

The final susceptibility index ranged from 0.75 to 4.50, with a mean of 2.7725. Within the valid classified area of 351.6831 km², the High susceptibility class occupied 226.7766 km² (64.48%), the Very High susceptibility class occupied 62.4915 km² (17.77%), and Moderate susceptibility occupied 57.4371 km² (16.33%). Together, the High and Very High classes covered 289.2681 km², representing 82.25% of the valid classified area. The result points to a broad spatial priority for drainage assessment, development review and flood-preparedness planning.

The AHP sensitivity assessment produced weights of 33.81% for elevation, 20.48% for slope, 28.81% for TWI and 16.90% for distance to drainage. Its consistency ratio of 0.0225 indicated acceptable consistency in the pairwise judgments. In addition, the 2022 historical flood inventory contained 110 polygons and mapped approximately 1.3546 km² of flood-related area, or 0.35% of the inventory study-area extent. This inventory is retained as an independent reference dataset for future validation rather than being presented as a completed statistical accuracy assessment.

The study's principal contribution is therefore a practical spatial baseline for Awka North. It identifies areas that deserve greater planning attention while making clear that susceptibility is not the same as flood occurrence, depth or damage. The map can support drainage planning, land-use management, development control, emergency preparedness and the prioritization of field surveys. Future research should strengthen the evidence base through higher-resolution elevation data, surveyed drainage networks, rainfall and land-use variables, multi-year flood inventories and hydraulic modelling. Such additions would allow the present screening framework to develop into a more rigorously validated flood-risk assessment.

6. Recommendations

High- and Very-High-susceptibility zones should receive priority during drainage planning, road design, development review and flood-mitigation interventions.

Development approval in susceptible areas should be supported by site-specific drainage and stormwater assessments.

Natural drainage channels should be protected from obstruction, indiscriminate dumping and unplanned construction.

The susceptibility map should be integrated into local emergency-response planning, community awareness and flood-preparedness programmes.

Field verification should be conducted in representative areas of each susceptibility class, especially locations classified as High and Very High.

Higher-resolution DEMs, surveyed drainage networks, rainfall observations and multi-year flood inventories should be collected for model validation.

Future studies should compare weighted overlay and AHP outputs with machine-learning models using independent training and testing samples and standard performance metrics.

7. Limitations

The study has several limitations that should be considered when interpreting the results. First, the 30-m DEM may not capture fine-scale drainage features and built-environment controls such as small channels, culverts, road embankments and localized depressions. Second, the stream-extraction threshold used to derive the provisional drainage network may influence the resulting distance-to-drainage surface. Third, the adopted weighted-overlay factors and their weights involve expert judgment and therefore contain an element of subjectivity. The AHP sensitivity assessment provides an additional structured examination of this weighting uncertainty.

Fourth, the historical flood inventory represents a selected period in 2022 and therefore does not constitute a complete multi-year record of flood occurrence. It was used as an independent reference dataset rather than for formal predictive validation. Consequently, the study does not report statistical accuracy measures such as AUC, precision, recall or F1-score. Finally, although AHP was used to examine the sensitivity of factor weighting, a full pixel-level agreement and statistical comparison between the weighted-overlay and AHP classified rasters was not undertaken. **These limitations do not invalidate the susceptibility assessment as a screening product; rather, they define the spatial, temporal and methodological scope within which the results should be interpreted and applied.**

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