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GEOSPATIAL ANALYSIS OF FLOOD DRIVERS AND FLOOD RISK IN AYAMELUM LOCAL GOVERNMENT AREA, ANAMBRA STATE, NIGERIA

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Abstract

Flooding remains one of the most recurrent environmental hazards affecting communities, infrastructure, and agricultural activities in many parts of southeastern Nigeria. Ayamelum Local Government Area of Anambra State experiences frequent flood events due to its low-lying terrain, extensive drainage networks, and floodplain characteristics. This study employed geospatial techniques to analyze the drivers of flooding and assess flood risk within the study area. Five flood-influencing factors, namely elevation, slope, flow accumulation, proximity to natural drainage channels, and watershed characteristics, were derived from a 30 m Shuttle Radar Topography Mission (SRTM) Digital Elevation Model. The factors were standardized using fuzzy membership functions to establish a common suitability scale and subsequently weighted using the Entropy Weighting Method to determine their relative contributions to flood occurrence. The weighted factors were integrated using a Weighted Linear Combination approach to generate a Flood Risk Index and delineate flood risk zones. The results showed that flow accumulation (0.313), proximity to drainage channels (0.267), and elevation (0.231) were the most influential flood drivers, while slope (0.145) and watershed characteristics (0.044) exerted relatively lower influence. Flood risk assessment revealed that 422.92 km² (72.26%) of the study area falls within the Very Low Risk category, 74.91 km² (12.80%) within the Low Risk category, 70.08 km² (11.97%) within the Moderate Risk category, and 17.40 km² (2.97%) within the High Risk category. High-risk zones were concentrated mainly within Umuerum and Anaku wards, while moderate-risk conditions extended across Omor 1, Omor 2, Omor 3, Umuerum, Igbakwu, and Anaku wards. The study demonstrates that flood susceptibility in Ayamelum Local Government Area is controlled largely by the interaction of topographic and hydrological factors. The resulting flood risk map provides a valuable decision-support tool for flood management, land-use planning, disaster preparedness, and sustainable environmental management within the study area.

Keywords: Flood Risk Assessment; Geospatial Analysis; Entropy Weighting; Fuzzy Membership; Ayamelum Local Government Area.

1. Introduction

Flooding is one of the most frequent and destructive natural hazards affecting human populations, infrastructure, agricultural lands, and ecosystems worldwide. Increasing urbanization, climate variability, land-use changes, and the intensification of extreme precipitation events have significantly increased flood occurrence and severity across many regions of the world [1][2]. According to [3], floods account for a substantial proportion of global disaster losses, affecting millions of people annually and causing extensive economic and environmental damage. The growing impacts of flooding have prompted governments, international organizations, and researchers to develop more effective approaches for flood risk assessment, management, and mitigation. This concern is reflected in the European Union Floods Directive, which emphasizes the need for systematic assessment and management of flood risks to reduce adverse consequences for human health, the environment, cultural heritage, and economic activities [4].

Flood risk is influenced by a complex interaction of climatic, hydrological, topographic, environmental, and anthropogenic factors. Variations in rainfall intensity, drainage characteristics, land use patterns, elevation, slope, soil conditions, and river channel morphology collectively determine the extent and severity of flood events [5][6] [7]. Hydrological modelling studies have demonstrated the importance of understanding rainfall-runoff relationships and watershed characteristics in predicting flood occurrence and magnitude [8][9]. Recent advances in hydrodynamic modelling have further enhanced the ability to simulate flood processes and evaluate the resilience of physical systems under extreme flood scenarios [10].

Geospatial technologies have emerged as indispensable tools for flood hazard and risk assessment due to their capability to integrate, analyze, and visualize spatial datasets from multiple sources. Geographic Information Systems (GIS), Remote Sensing, Digital Elevation Models (DEMs), and spatial modelling techniques enable the identification of flood-prone areas and the evaluation of factors contributing to flood vulnerability [11]. The integration of geospatial data with multi-criteria decision analysis (MCDA) has gained considerable attention in recent years because it facilitates the assessment of flood susceptibility using multiple environmental and socio-economic variables simultaneously. Applications of GIS-MCDA have been successfully employed for flood vulnerability assessment and zoning in various regions, including Iran, Somalia, Greece, and Cyprus [12][13][14] [15].

Flood risk assessment has evolved from simple hazard mapping approaches to more comprehensive frameworks that incorporate physical exposure, social vulnerability, and adaptive capacity. [16] demonstrated the effectiveness of flood risk mapping frameworks in evaluating spatial variations in flood risk, while [17] integrated hazard and vulnerability assessments to improve flood management planning. Recent studies have also incorporated probabilistic and stochastic approaches to account for uncertainties associated with flood occurrence and susceptibility [15][18]. Similarly, fuzzy logic techniques have been employed to address uncertainties in vulnerability assessment and decision-making processes, particularly in densely populated urban environments [19].

Human activities have increasingly contributed to flood generation and amplification through land-use modification, urban expansion, deforestation, and encroachment into natural floodplains. Urbanization alters natural hydrological processes by increasing impervious surfaces, reducing infiltration, and accelerating surface runoff, thereby increasing flood susceptibility [2]. Consequently, understanding the drivers of flooding has become a major component of flood risk management. Identification of flood drivers enables planners and policymakers to implement targeted interventions that address the root causes of flooding rather than focusing solely on post-disaster response measures.

Flood risk assessment also plays an important role in disaster preparedness and emergency management. Accurate identification of flood-prone areas supports the development of evacuation strategies and enhances community resilience. Several studies have demonstrated the usefulness of geospatial analysis in optimizing evacuation routes and minimizing hazard exposure during flood events [20][21][22]. Similar approaches have been applied in disaster route planning under other hazard conditions, emphasizing the importance of integrating risk assessment with emergency response planning [23]. Recent reviews further highlight the growing importance of incorporating flood risk information into evacuation planning and disaster management frameworks [24].

Nigeria experiences recurrent flooding resulting from intense rainfall, river overflow, poor drainage systems, land-use changes, and inadequate flood management infrastructure. The impacts of flooding have become increasingly severe in many parts of the country, particularly within low-lying floodplain environments associated with major river systems. Anambra State is among the states frequently affected by seasonal flooding due to its proximity to the River Niger and its extensive floodplain landscapes. Ayamelum Local Government Area, located within the northern part of Anambra State, is particularly vulnerable because of its low elevation, extensive river networks, agricultural land use, and seasonal inundation associated with river overflow and intense rainfall events. Flood occurrences within the area have resulted in significant losses to agricultural production, infrastructure, settlements, and livelihoods, thereby posing serious socio-economic challenges to local communities.

Despite the recurring nature of flooding within Ayamelum Local Government Area, there remains a limited understanding of the relative influence of the various environmental and anthropogenic factors that drive flood occurrence and shape flood risk patterns. Existing studies have primarily focused on flood hazard mapping and vulnerability assessment in other regions using GIS, hydrological modelling, and MCDA approaches [12][13][14]. Few studies have comprehensively examined the spatial relationships between flood drivers and flood risk within the context of Ayamelum Local Government Area. Such information is necessary for developing effective flood mitigation strategies, enhancing disaster preparedness, and supporting sustainable land-use planning.

This study therefore undertakes a geospatial analysis of flood drivers and flood risk in Ayamelum Local Government Area, Anambra State, Nigeria. The study integrates geospatial datasets and spatial analytical techniques to identify the key factors influencing flooding, evaluate their spatial distribution, and assess flood risk patterns across the study area. The findings are expected to contribute to flood risk reduction efforts, environmental management, land-use planning, and disaster preparedness initiatives within Ayamelum Local Government Area and similar flood-prone environments.

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2. Materials and Methods

2.1. Study Area

Ayamelum Local Government Area is located in the northern part of Anambra State, southeastern Nigeria. It lies within the lower Niger floodplain and is characterized by extensive low-lying terrain and a dense network of rivers, streams, and seasonal drainage channels. The LGA is bounded by riverine and agricultural landscapes that make it one of the most flood-prone areas in Anambra State.

The area is predominantly rural, with settlements such as Anaku, Omor, Umuerum, Umumbo, Omasi, Igbakwu, and Ifite-Ogwari serving as major communities. Agriculture constitutes the principal economic activity, with rice cultivation, fishing, and other floodplain-based livelihoods being widespread. The reliance on agriculture makes the local economy highly sensitive to flood events and seasonal hydrological variations.

Topographically, Ayamelum is characterized by gently undulating to nearly flat terrain with elevations generally ranging from about 14 m to 157 m above mean sea level. The low-gradient landscape reduces runoff velocity and promotes water accumulation during periods of heavy rainfall and river overflow. The climate is humid tropical, with a distinct wet season and dry season, and annual rainfall is sufficiently high to generate substantial surface runoff during peak rainfall periods.

The combination of low elevation, extensive floodplains, proximity to major drainage systems, and intensive land use creates conditions that favor recurrent flooding. These characteristics make Ayamelum Local Government Area an appropriate setting for investigating the spatial drivers of flooding and assessing flood risk using geospatial techniques.

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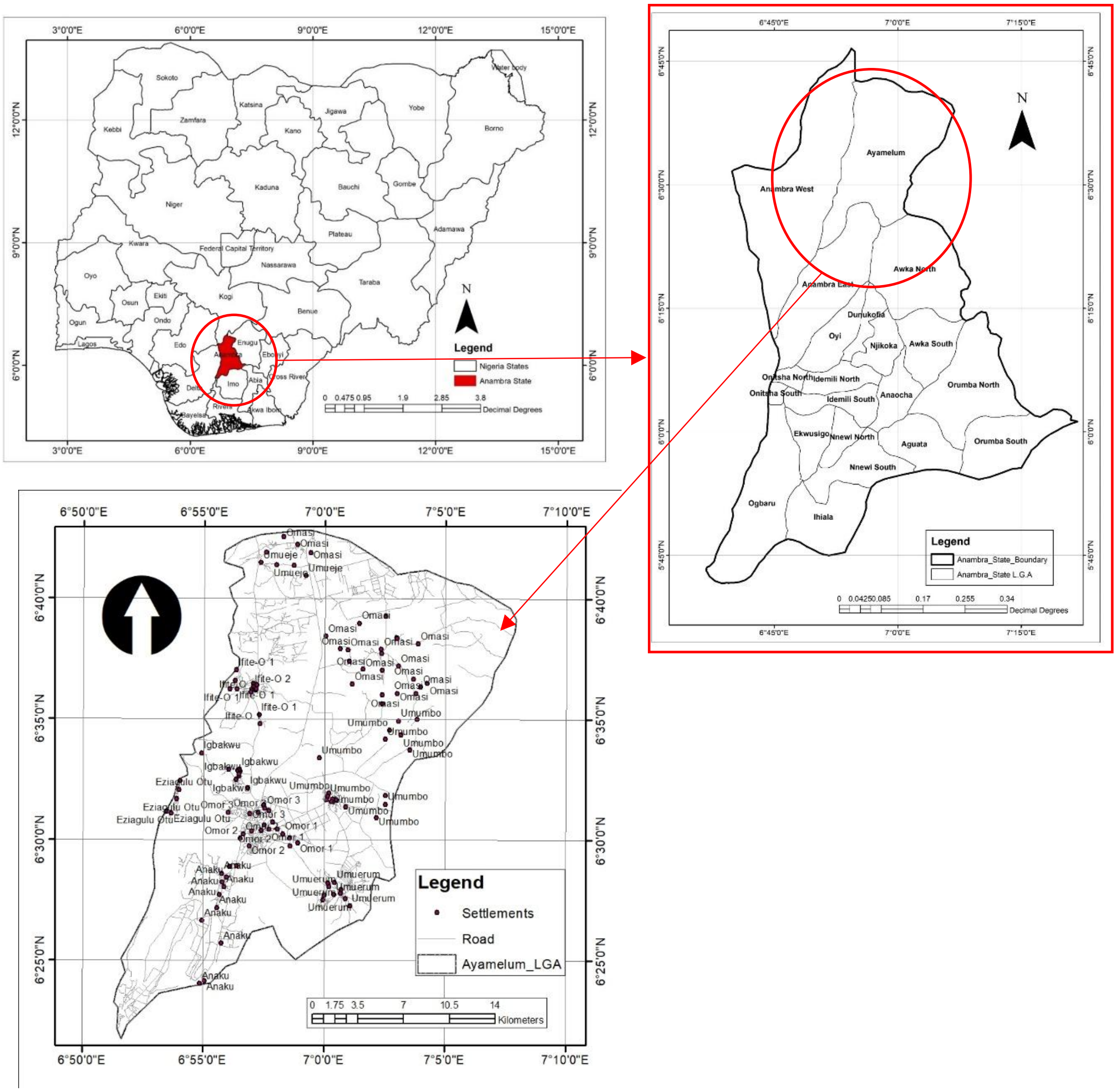

Figure 1: Map of the Study Area

2.2. Methodology

This study utilized secondary geospatial datasets to identify flood drivers and assess flood risk in Ayamelum Local Government Area, Anambra State. The required datasets included a Digital Elevation Model (DEM), administrative boundary data, drainage network data, and derived hydrological parameters. The DEM was used to generate elevation, slope, flow accumulation, watershed, and proximity-to-drainage layers required for flood risk analysis.

2.2.1. Data Acquisition

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model with a spatial resolution of 30 m was acquired and clipped to the boundary of Ayamelum Local Government Area. The DEM was projected to the Universal Transverse Mercator (UTM) coordinate system to ensure spatial consistency during analysis. The DEM was subjected to hydrological preprocessing procedures, including sink filling, flow direction generation, flow accumulation computation, watershed delineation, and drainage extraction. These operations were performed using the Hydrology tools available in ArcGIS Pro.

2.2.2. Identification of Flood Risk Factors

Five flood-driving factors were considered based on their influence on flood generation and propagation:

1. Elevation
2. Slope
3. Flow Accumulation
4. Proximity to Natural Drainage
5. Watershed Characteristics

Elevation was extracted directly from the SRTM DEM. Areas with lower elevations were considered more susceptible to flooding because they act as natural zones for runoff accumulation and water stagnation.

Slope was derived from the DEM using the Spatial Analyst Slope function. Slope was calculated using equation 1:

$$S = \tan^{-1}\left(\sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2}\right) \qquad \ldots(1)$$

where:
(S) = slope angle,
$\left(\frac{dz}{dx}\right)$ = rate of elevation change in the x-direction,
$\left(\frac{dz}{dy}\right)$ = rate of elevation change in the y-direction.

Lower slope values were considered more favourable for flood occurrence because of reduced runoff velocity.

Flow accumulation was also generated from the flow direction raster using the D8 hydrological algorithm. Flow accumulation estimates the number of upstream cells contributing runoff to a given location. Higher flow accumulation values indicate greater runoff concentration and consequently higher flood susceptibility.

Natural drainage channels were extracted from the flow accumulation raster using an appropriate threshold value. Euclidean Distance analysis was subsequently applied to calculate the distance of every location from the nearest drainage channel. Areas located closer to drainage channels were considered more vulnerable to flooding due to channel overflow and floodplain inundation. Watershed boundaries were then delineated using the flow direction raster and pour points generated from the drainage network. Watershed size was used as an indicator of the runoff-contributing area, with larger watersheds assumed to generate greater runoff volumes during storm events.

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2.2.3. Fuzzy Membership Standardization

The selected flood risk factors were measured in different units and scales. Consequently, fuzzy membership functions were applied to standardize all factors into a common scale ranging from 0 to 1. For factors exhibiting an inverse relationship with flood risk (Elevation, Slope, and Distance to Drainage), the Fuzzy Small membership function was applied using equation 2:

$$\mu(x) = \frac{1}{1 + \left(\frac{x}{f_2}\right)^{f_1}} \qquad \ldots(2)$$

where:
$(\mu(x))$ = membership value,
(x) = factor value,
$(f_1) and (f_2)$ = fuzzy spread parameters.

For factors exhibiting a direct relationship with flood risk (Flow Accumulation and Watershed Size), the Fuzzy Large membership function was applied using equation 3:

$$\mu(x) = \frac{1}{1 + \left(\frac{x}{f_2}\right)^{-f_1}} \qquad \ldots(3)$$

The resulting fuzzy membership values range between 0 and 1, where values closer to 1 indicate greater flood susceptibility.

2.2.4. Entropy Weighting of Flood Risk Factors

The Entropy Weighting Method (EWM) was used to objectively determine the relative importance of each flood risk factor. Entropy weighting evaluates the amount of information contributed by each criterion based on its spatial variability.

Step 1: Normalization

The normalized value of each criterion was calculated as equation 4:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \qquad \ldots(4)$$

where:
(P_{ij}) = normalized value,
(X_{ij}) = value of criterion (j) at location (i),
(m) = total number of observations.

Step 2: Entropy Calculation

The entropy value for each criterion was computed using equation 5 and 6:

$$E_j = -k \sum_{i=1}^{m} P_{ij} \ln(P_{ij}) \qquad \ldots(5)$$

where:

$$k = \frac{1}{\ln(m)} \qquad \ldots(6)$$

and:
(E_j) = entropy value of criterion (j).

Step 3: Diversification Coefficient
The degree of diversification was calculated as equation 7:

$$D_j = 1 - E_j \qquad \ldots(7)$$

where:
(D_j) = diversification coefficient.

Step 4: Weight Determination
The final weight of each criterion was determined using equation 8:

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \qquad \ldots(8)$$

where:
(W_j) = weight assigned to criterion (j),
(n) = number of criteria.
Factors with higher variability received larger weights and contributed more significantly to the flood risk model.

2.2.5. Flood Risk Modelling

The Flood Risk Index (FRI) was generated by integrating the fuzzy-standardized factor layers with their corresponding entropy-derived weights using the Weighted Linear Combination (WLC) approach.
The Flood Risk Index was computed as equation 9:

$$FRI = \sum_{i=1}^{n} (W_i \times F_i) \qquad \ldots(9)$$

where:
(FRI) = Flood Risk Index,
(W_i) = entropy weight of factor (i),
(F_i) = fuzzy membership value of factor (i),
(n) = number of flood risk factors.
The resulting flood risk surface was classified into four categories using the Natural Breaks (Jenks) classification method:

1. Very Low Risk
2. Low Risk
3. Moderate Risk
4. High Risk

2.2.6. Flood Risk Zonation and Ward-Based Assessment

The generated flood risk map was overlaid with the ward boundaries of Ayamelum Local Government Area. Spatial intersection analysis was performed to determine the distribution of flood risk categories across the wards. Area statistics and percentage coverage were subsequently computed for each flood risk class to quantify the spatial extent of flood vulnerability within the study area.

3. Results

3.1. Spatial Distribution of Flood Drivers in Ayamelum Local Government Area

The spatial distribution of the flood drivers in Ayamelum Local Government Area was examined using elevation, slope, flow accumulation, proximity to natural drainage channels, and watershed characteristics. Analysis of these drivers was undertaken to understand their spatial variability and their potential contribution to flood generation and propagation across the study area. The resulting spatial distributions are presented collectively in Figure 2.

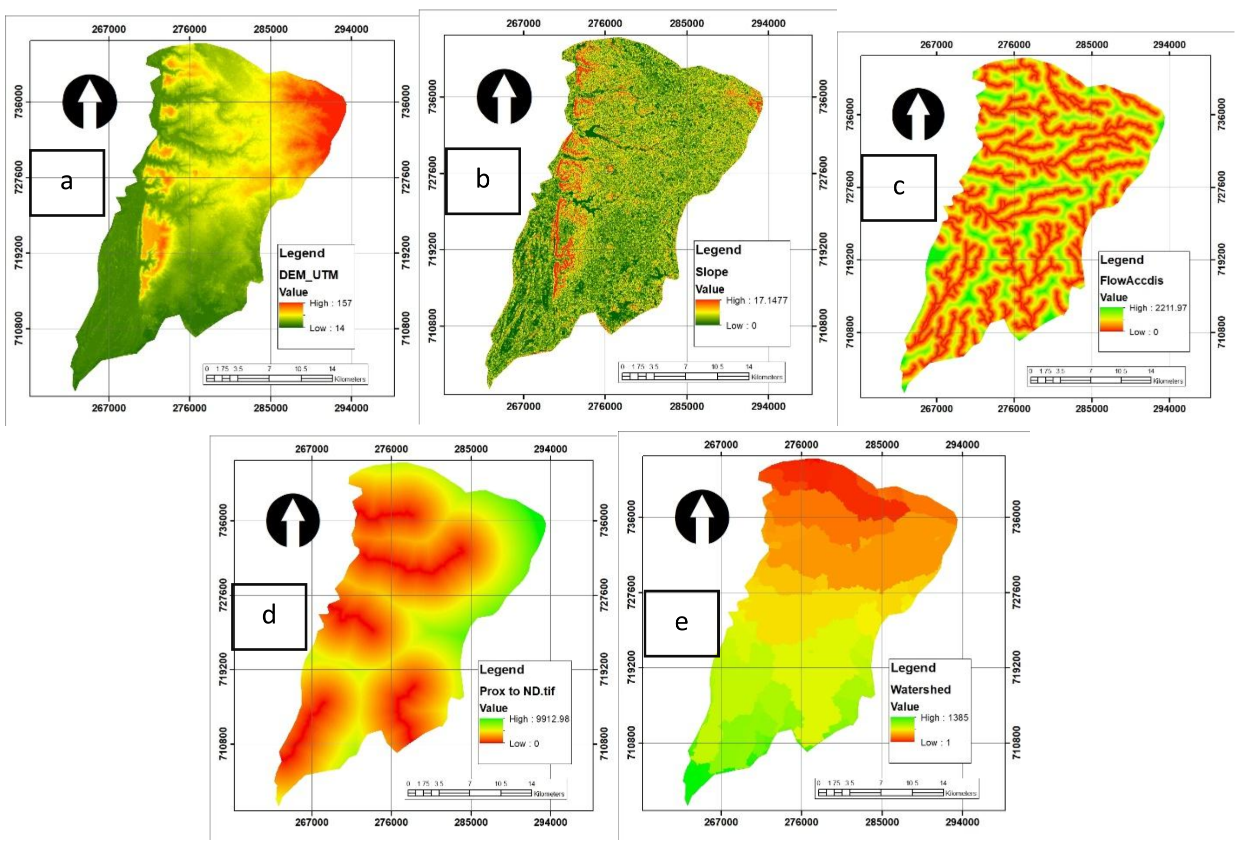

Figure 2: Spatial Distribution of (a) Elevation, (b) Slope, (c) Flow Accumulation, (d) Proximity to Drainage Channels, and (e) Watershed Characteristics in Ayamelum Local Government Area, Anambra State

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Figure 2 reveals considerable spatial variability in the distribution of the flood drivers across the study area. The elevation map (Figure 2a) indicates that terrain heights range from approximately 14 m to 157 m above mean sea level. Low-lying areas dominate much of the southern, central, and western portions of Ayamelum, while relatively higher elevations are concentrated in the northeastern region and isolated sections along the western margin. The predominance of low elevations across a substantial proportion of the study area indicates favourable conditions for surface water accumulation and prolonged inundation during periods of intense rainfall and river overflow.

The slope distribution (Figure 2b) shows that the terrain is generally characterized by gentle gradients, with slope values ranging from 0° to approximately 17.15°. Flat and gently sloping surfaces occupy most parts of the LGA, whereas steeper slopes are restricted to localized ridges and elevated areas, particularly within the western and northwestern sections. The dominance of low-gradient terrain reduces runoff velocity and promotes water retention on the land surface, thereby increasing flood susceptibility.

The flow accumulation pattern (Figure 2c) reveals the existence of extensive runoff convergence corridors distributed throughout the study area. Flow accumulation values range from 0 to approximately 2,211.97, with the highest values concentrated along major drainage pathways. These zones represent locations where runoff from large upstream areas converges and accumulates, resulting in increased flood potential. The dense drainage convergence network observed across Ayamelum demonstrates the significant role of surface hydrological processes in controlling flood occurrence.

The proximity-to-drainage (Figure 2d) further highlights the influence of river systems on flood generation. Distances from natural drainage channels range from 0 m to approximately 9,912.98 m. Areas located close to rivers and drainage networks are widely distributed throughout the northern, central, and southwestern sections of the LGA. Since flooding frequently occurs through river overflow and channel inundation, locations situated nearest to drainage channels are expected to experience higher flood susceptibility than areas located farther away.

The watershed map (Figure 2e) illustrates the spatial distribution of contributing drainage areas across the study region. Watershed values range from 1 to approximately 1,385, with larger watershed systems predominantly occurring in the northern section of Ayamelum. These larger catchments receive runoff from extensive upstream areas and therefore generate higher discharge volumes during storm events. Consequently, flood susceptibility tends to increase within areas associated with large watershed extents.

The collective assessment of the factors presented in Figure 2 demonstrates that flooding in Ayamelum Local Government Area is largely controlled by the interaction of topographic and hydrological conditions. The extensive occurrence of low elevations, gentle slopes, high flow accumulation corridors, close proximity to drainage channels, and large watershed catchments creates favourable conditions for flood generation and propagation. These spatial patterns indicate that the northern, central, and low-lying floodplain environments of the LGA possess greater susceptibility to flooding compared with the relatively elevated portions of the northeastern region. The identified factors therefore provide the fundamental basis for subsequent flood susceptibility modelling and flood risk assessment within the study area.

3.2. Reclassification and Standardization of Flood Risk Factors Using Fuzzy Membership Functions

The identified flood risk factors were subsequently reclassified and standardized using fuzzy membership functions to establish a common measurement scale for flood susceptibility analysis. Since the selected factors were measured in different units and possessed varying data ranges, direct integration would have introduced inconsistencies into the modelling process. Fuzzy membership transformation was therefore employed to convert all factors into standardized values ranging from 0 to 1, where values closer to 1 represent greater influence on flood occurrence and values closer to 0 indicate lower flood susceptibility.

The fuzzy standardization process was performed on elevation, slope, flow accumulation, proximity to natural drainage channels, and watershed characteristics. The resulting fuzzy membership maps are presented collectively in Figure 3, while the fuzzy membership functions adopted for each factor are summarized in Table 1.

Table 1: Fuzzy Membership Functions Applied to Flood Risk Factors

Factor	Relationship with Flood Risk	Fuzzy Membership Type
Elevation	Lower elevations have higher flood susceptibility	Small
Slope	Gentle slopes have higher flood susceptibility	Small
Flow Accumulation	Higher accumulation increases flood susceptibility	Large
Proximity to Drainage	Shorter distances increase flood susceptibility	Small
Watershed Size	Larger contributing watersheds increase flood susceptibility	Large

As shown in Table 1**,** factors exhibiting an inverse relationship with flood risk, such as elevation, slope, and distance from drainage channels, were standardized using the fuzzy small membership function. Conversely, flow accumulation and watershed size, which increase flood susceptibility with increasing values, were standardized using the fuzzy large membership function.

The fuzzy-standardized elevation layer shown in Figure 3 indicates that a substantial proportion of Ayamelum LGA possesses high membership values approaching 1.0. These areas correspond predominantly to the low-lying sections identified in the DEM analysis. The northeastern uplands and isolated elevated regions display lower membership values, indicating reduced flood susceptibility. The standardized elevation values range from approximately 0.14 to 1.00, demonstrating the strong influence of low terrain on flood generation within the study area.

The fuzzy-standardized slope layer similarly exhibits high membership values across most parts of the study area. The predominance of flat and gently sloping terrain resulted in extensive areas receiving values close to 1.0. Lower membership values are restricted to the steeper ridges and escarpments observed in the western and north-western sections. This pattern confirms that the generally low-gradient terrain of Ayamelum contributes significantly to water retention and flood development.

The fuzzy flow accumulation layer highlights the major runoff concentration corridors distributed throughout the study area. Areas associated with high accumulation values received membership values approaching 1.0, reflecting their increased flood potential. Locations characterized by limited runoff convergence were assigned lower membership values. The resulting pattern emphasizes the importance of concentrated surface runoff pathways in controlling flood occurrence.

The fuzzy proximity-to-drainage layer demonstrates a clear relationship between flood susceptibility and distance from natural drainage channels. Areas located adjacent to rivers and streams exhibit the highest membership values, while susceptibility decreases progressively with increasing distance from the drainage network. The extensive occurrence of high membership values near drainage channels confirms the dominant influence of river overflow and channel inundation on flood occurrence within Ayamelum LGA.

The fuzzy-standardized watershed layer reveals considerable spatial variation in flood susceptibility across the study area. Larger contributing watersheds, particularly within the northern section of the LGA, exhibit higher membership values because of their ability to generate substantial runoff volumes during storm events. Smaller watersheds received lower membership values, reflecting their comparatively reduced hydrological contribution to flooding.

The descriptive statistics of the fuzzy-standardized factors are presented in Table 2**.**

Table 2: Summary of Fuzzy Membership Values

Factor	Minimum Value	Maximum Value
Elevation	0.140	1.000
Slope	0.088	1.000
Flow Accumulation	0.000	1.000
Proximity to Drainage	0.223	1.000
Watershed Size	0.000	0.750

The values presented in Table 2 indicate that all factors were successfully transformed into a comparable continuous scale suitable for multi-criteria integration. Elevation and slope achieved maximum membership values of 1.0 across extensive portions of the study area, reflecting the widespread occurrence of low elevations and gentle terrain. Flow accumulation and proximity to

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drainage channels similarly attained maximum values of 1.0 within major runoff corridors and floodplain environments. Watershed size exhibited a maximum fuzzy membership value of approximately 0.75, indicating moderate spatial variability relative to the other flood-driving factors.

The standardized layers presented in Figure 3 and summarized in Tables 1 and 2 demonstrate that the flood susceptibility of Ayamelum LGA is strongly influenced by low elevations, gentle slopes, high runoff concentration, proximity to drainage channels, and large contributing watersheds. The fuzzy membership transformation successfully harmonized the diverse datasets into a common analytical framework, thereby providing a reliable basis for subsequent flood risk modelling and spatial integration of the flood-driving factors.

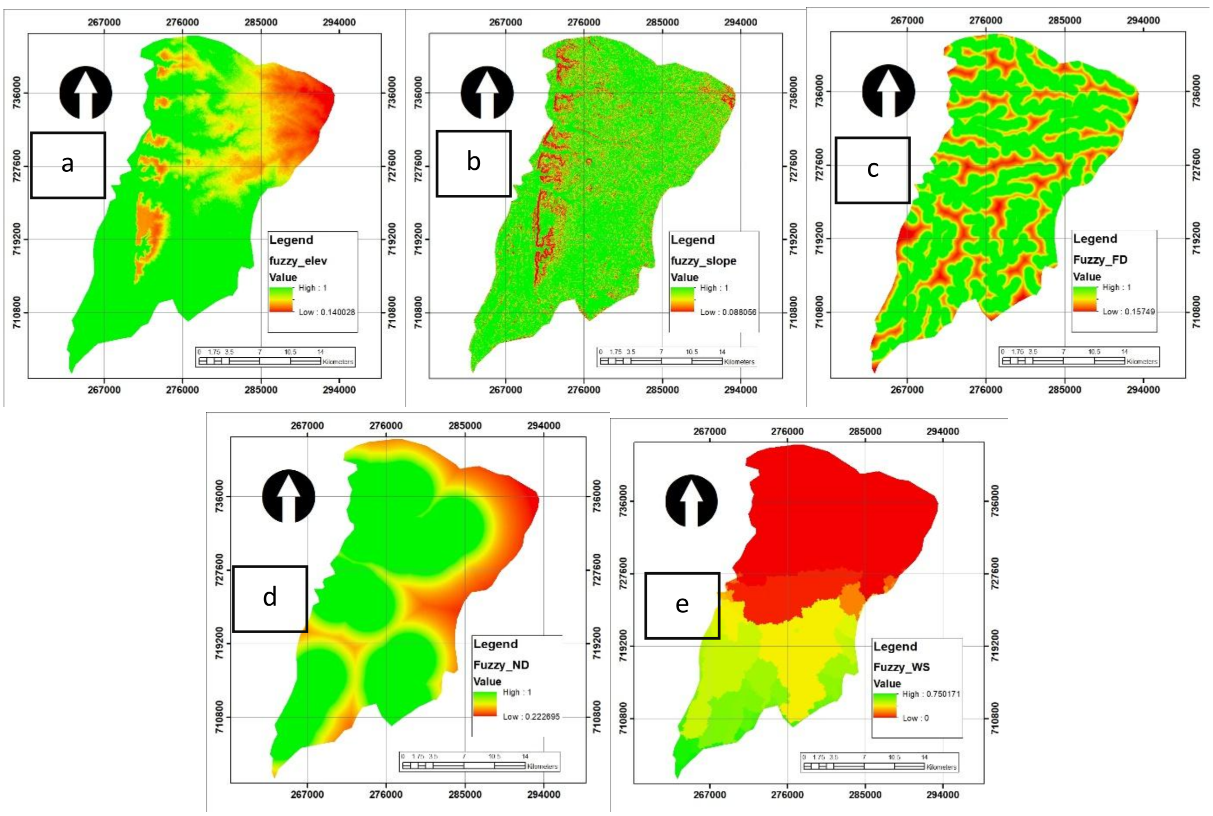

Figure 3: Reclassification and Standardization of (a) Elevation, (b) Slope, (c) Flow Accumulation, (d) Proximity to Drainage Channels, and (e) Watershed Characteristics in Ayamelum Local Government Area, Anambra State

3.3. Integration of Flood Risk Factors Using Entropy Weighting

Following the reclassification and standardization of the flood risk factors, the next stage involved the determination of their relative importance using the Entropy Weighting Method (EWM). Entropy weighting is an objective weighting technique that derives criterion weights directly from the inherent information contained within the data. Unlike subjective weighting approaches that depend on expert judgment, entropy weighting evaluates the degree of variability within each criterion and assigns higher weights to factors exhibiting greater information content and stronger discriminatory power. Consequently, factors displaying greater spatial variability contribute more significantly to the final flood risk model than factors exhibiting relatively uniform spatial distributions.

The entropy weighting procedure was applied to the fuzzy-standardized layers of elevation, slope, flow accumulation, proximity to natural drainage channels, and watershed characteristics. The entropy values, diversification coefficients, and normalized weights obtained from the analysis are presented in Table 3.

Table 3: Entropy Weighting Results for Flood Risk Factors

Factor	Entropy Value (Ej)	Diversification Coefficient (Dj)	Weight (Wj)
Elevation	0.842	0.158	0.231
Slope	0.901	0.099	0.145
Flow Accumulation	0.786	0.214	0.313
Proximity to Drainage	0.817	0.183	0.267
Watershed Size	0.921	0.079	0.044

The entropy weighting results presented in Table 3 indicate considerable variation in the relative influence of the flood risk factors. Flow accumulation received the highest weight of 0.313, indicating that it contributes the greatest amount of information to the flood risk assessment. This result reflects the strong influence of runoff concentration processes on flood generation within Ayamelum LGA. Areas characterized by high flow accumulation receive runoff from extensive upstream catchments and therefore exhibit elevated flood susceptibility.

Proximity to drainage channels received the second-highest weight of 0.267. This finding demonstrates the significant role of river systems and natural drainage networks in controlling flood occurrence. Locations situated close to drainage channels are exposed to channel overflow and floodplain inundation, making drainage proximity one of the dominant determinants of flood risk within the study area.

Elevation attained a weight of 0.231, ranking as the third most influential factor. The substantial contribution of elevation reflects the dominance of low-lying terrain across large portions of Ayamelum LGA. Lower elevations facilitate water accumulation and reduce drainage efficiency, thereby increasing flood susceptibility. The relatively high weight assigned to elevation confirms its importance as a controlling factor in flood development.

Slope received a weight of 0.145, indicating a moderate influence on flood occurrence. Although gentle slopes dominate the study area and contribute to water retention, their spatial variability is lower than that observed for flow accumulation, drainage proximity, and elevation. Consequently, slope contributes less information to the flood risk model.

Watershed size recorded the lowest weight of 0.044. This result indicates that although watershed characteristics influence runoff generation and discharge volume, their spatial variability within the study area is comparatively limited relative to the other factors. As a result, watershed size contributes less to the differentiation of flood susceptibility zones.

To facilitate interpretation of the weighting results, the factors were ranked according to their relative importance, as presented in Table 4.

Table 4: Ranking of Flood Risk Factors Based on Entropy Weights

Rank	Factor	Weight
1	Flow Accumulation	0.313
2	Proximity to Drainage	0.267
3	Elevation	0.231
4	Slope	0.145
5	Watershed Size	0.044

The ranking shown in Table 4 reveals that hydrological factors exert greater influence on flood occurrence than topographic factors within Ayamelum Local Government Area. Flow accumulation and proximity to drainage channels together account for approximately 58.0% of the total weight, emphasizing the dominant role of runoff concentration and drainage connectivity in flood generation. Elevation contributes approximately 23.1% of the overall influence, while slope and watershed size collectively account for approximately 18.9%.

The weighted flood risk model was subsequently developed through the integration of the standardized factor layers using the entropy-derived weights. The weighted linear combination procedure was used to apply the weights presented in Table 3; the flood risk model can be expressed as:

$$FRI = (0.231 \times Elevation) + (0.145 \times Slope) + (0.313 \times Flow\ ccumulation) + (0.267 \times Proximity\ to\ Drainage) + (0.044 \times Watershed)$$

The entropy weighting analysis presented in Tables 3 and 4 demonstrates that flood occurrence in Ayamelum LGA is predominantly controlled by hydrological processes, particularly runoff accumulation and drainage network influence. The integration of these objectively derived weights with the fuzzy-standardized factors provides a scientifically robust basis for generating the final flood risk map and delineating flood risk zones within the study area.

3.4 Flood Risk Assessment in Ayamelum Local Government Area

The final stage of the analysis involved the integration of the standardized flood risk factors using the entropy-derived weights to generate the Flood Risk Index (FRI) for Ayamelum Local Government Area. The resulting flood risk map was classified into four categories, namely Very

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Low Risk, Low Risk, Moderate Risk, and High Risk, to facilitate interpretation of the spatial variation in flood susceptibility across the study area. The area coverage and percentage distribution of each flood risk class are presented in Table 5.

Table 5: Flood Risk Distribution in Ayamelum Local Government Area

Flood Risk Class	Area (km²)	Percentage (%)
Very Low Risk	422.92	72.26
Low Risk	74.91	12.80
Moderate Risk	70.08	11.97
High Risk	17.40	2.97
Total	585.31	100.00

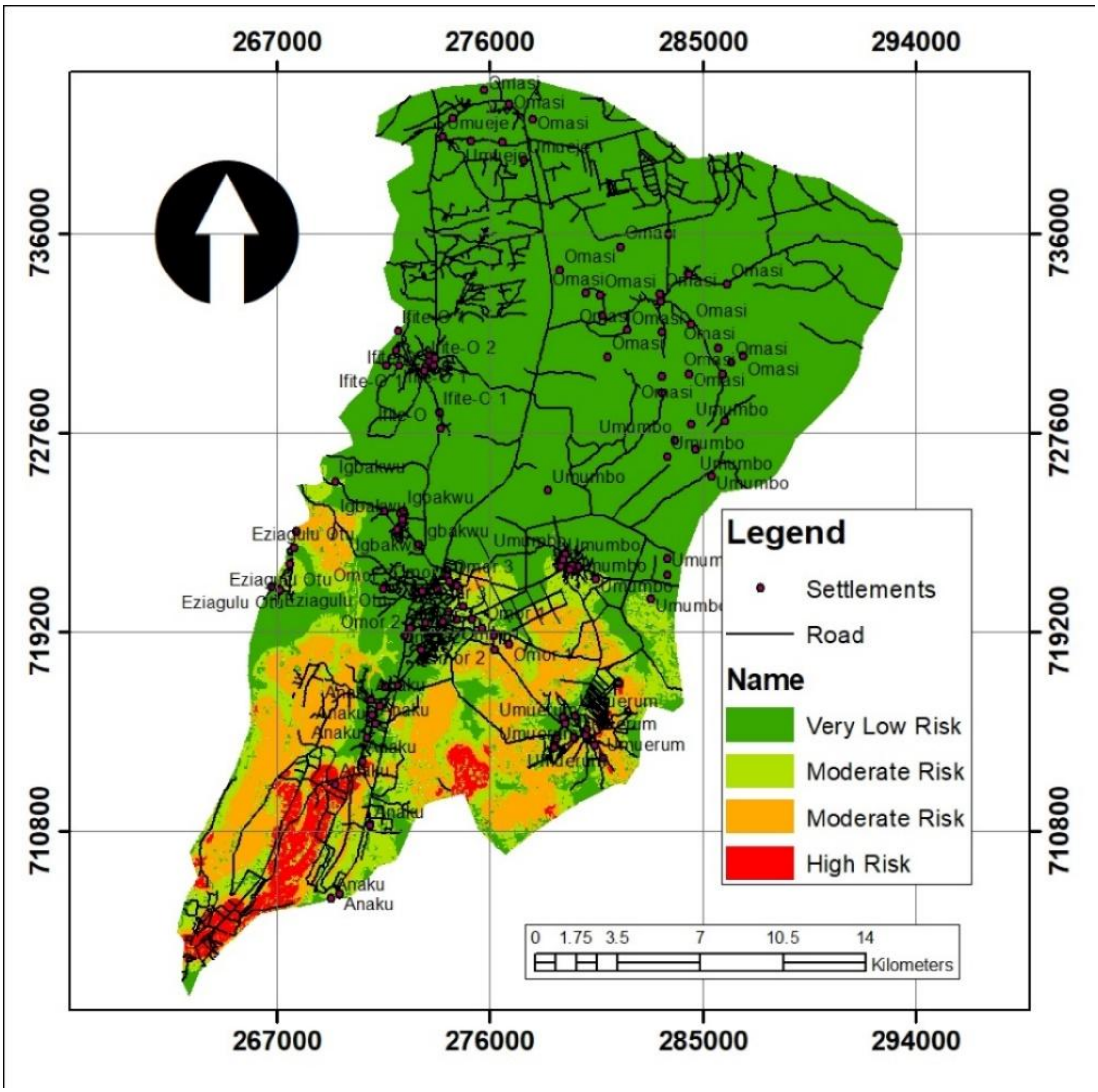

Figure 4: Spatial Distribution of Flood Risk Zones in Ayamelum LGA

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The results presented in Table 3 indicate that the largest proportion of Ayamelum LGA falls within the Very Low Risk category, covering 422.92 km² and accounting for 72.26% of the total land area. This extensive coverage indicates that a significant portion of the study area possesses relatively favourable topographic and hydrological conditions that reduce flood susceptibility. These areas are generally associated with locations exhibiting lower runoff concentration, greater distance from drainage channels, smaller contributing watersheds, or relatively elevated terrain.

The Low Risk category occupies 74.91 km², representing 12.80% of the total area. These zones serve as transitional environments between very low and moderate flood susceptibility conditions. Although flooding may occur within these areas during extreme rainfall events, the likelihood and intensity of flood occurrence remain comparatively lower than in the more vulnerable zones.

The Moderate Risk class covers 70.08 km², equivalent to 11.97% of the study area. These locations are characterized by the combined influence of multiple flood-driving factors, including low elevations, moderate flow accumulation, proximity to drainage channels, and larger watershed contributions. Areas within this category are more susceptible to seasonal flooding and may experience periodic inundation during years of above-average rainfall or river overflow.

The High Risk category occupies the smallest area, covering 17.40 km² or 2.97% of the total land area. Despite its limited spatial extent, this category represents the most vulnerable flood-prone environments within Ayamelum LGA. These areas are typically associated with drainage corridors, runoff convergence zones, low-lying floodplains, and locations receiving substantial upstream runoff contributions. The concentration of multiple flood-promoting factors within these zones significantly increases the probability and severity of flood occurrence.

The spatial distribution of the flood risk categories across the wards of Ayamelum LGA is presented in Table 6.

Table 6: Distribution of Flood Risk Classes by Ward

Flood Risk Class	Affected Wards
Very Low Risk	Omor 1, Omor 2, Omor 3, Ifite-Ogwari 1, Ifite-Ogwari 2, Umuerum, Umumbo, Omasi, Umuje, Igbakwu, Anaku
Low Risk	Omor 1, Omor 2, Omor 3, Umuerum, Umumbo, Igbakwu, Anaku
Moderate Risk	Omor 1, Omor 2, Omor 3, Umuerum, Igbakwu, Anaku
High Risk	Umuerum, Anaku

The ward-level distribution shown in Table 6 reveals important spatial variations in flood susceptibility. The Very Low Risk category is widely distributed and occurs across all major wards within the Local Government Area, indicating that relatively safe environments dominate much of the landscape. This broad distribution is consistent with the overall finding that more than 72% of the study area falls within the very low flood risk class.

The Low Risk category is concentrated within Omor 1, Omor 2, Omor 3, Umuerum, Umumbo, Igbakwu, and Anaku wards. These areas exhibit intermediate flood susceptibility and may experience localized flooding under adverse hydrological conditions.

Moderate Risk zones are observed within Omor 1, Omor 2, Omor 3, Umuerum, Igbakwu, and Anaku wards. The occurrence of moderate risk conditions within these wards indicates that they contain environments where topographic and hydrological factors combine to increase flood potential. These locations may require closer monitoring and targeted flood management interventions.

The High Risk category is restricted to only two wards, namely Umuerum and Anaku. The occurrence of high-risk zones within these wards indicates the presence of highly vulnerable floodplain environments characterized by low elevations, significant runoff concentration, close proximity to drainage channels, and substantial watershed contributions. Although the high-risk areas occupy less than 3% of the total land area, their concentration within Umuerum and Anaku makes these wards the most vulnerable to flood disasters within Ayamelum LGA.

The flood risk assessment demonstrates that flood susceptibility within Ayamelum Local Government Area is spatially heterogeneous and strongly influenced by the interaction of topographic and hydrological factors. While a large proportion of the LGA falls within the Very Low Risk category, notable pockets of Moderate and High Risk occur in specific wards, particularly Umuerum and Anaku. These findings provide valuable information for flood risk management, land-use planning, infrastructure development, and disaster preparedness initiatives. Priority attention should therefore be directed towards the identified high-risk wards, where flood mitigation measures and early warning systems would yield the greatest benefits in reducing potential flood impacts.

3.5 Discussion of Results

The findings of this study demonstrate that flood occurrence in Ayamelum Local Government Area is primarily controlled by the interaction of topographic and hydrological factors. The spatial distribution analysis revealed that low elevations, gentle slopes, high flow accumulation zones, proximity to natural drainage channels, and large contributing watersheds collectively influence flood susceptibility across the study area. The predominance of low-lying terrain, particularly within the central and northern sections of the LGA, indicates that substantial portions of Ayamelum possess environmental conditions that favour water accumulation and prolonged inundation. This finding is consistent with established hydrological principles, which indicate that low elevations and flat terrain reduce drainage efficiency and increase the likelihood of flood development.

The significance of the elevation factor is evident from the widespread occurrence of lowland environments across the study area. Areas situated at lower elevations generally function as natural collection points for surface runoff and floodwaters originating from higher surrounding terrain. This implies that communities located within these low-lying environments are more exposed to seasonal flooding, especially during periods of intense rainfall and river overflow. The implication for land-use planning is that future settlement expansion and infrastructure development should be carefully regulated within these lowland zones to minimize exposure to flood hazards.

The slope analysis further revealed that much of Ayamelum is characterized by gentle gradients. Low-gradient terrain slows runoff movement, promotes surface ponding, and increases infiltration saturation during prolonged rainfall events. The dominance of such terrain conditions indicates that floodwaters are likely to remain on the land surface for extended periods before draining away. This condition may have substantial implications for agricultural productivity, transportation infrastructure, and settlement sustainability, particularly during the peak rainy season. The finding reinforces the importance of incorporating terrain characteristics into flood mitigation and drainage planning strategies.

Flow accumulation emerged as one of the most influential flood drivers within the study area. The entropy weighting analysis assigned the highest weight to flow accumulation, indicating that runoff concentration exerts the greatest influence on flood generation. This result highlights the hydrological importance of drainage convergence zones where runoff from extensive upstream areas becomes concentrated. The implication is that flood management interventions should prioritize these runoff concentration corridors because they represent the locations most likely to experience severe flooding during storm events. Effective management of these areas could significantly reduce downstream flood impacts.

The analysis also established the importance of proximity to natural drainage channels in determining flood susceptibility. Areas located near rivers and drainage networks exhibited higher flood potential because of their exposure to channel overflow and floodplain inundation. This finding reflects the fluvial nature of flooding within Ayamelum and demonstrates that river systems remain a major source of flood hazards within the LGA. The practical implication is that development activities should be guided by appropriate setback regulations and floodplain management policies to reduce vulnerability within these high-risk environments.

Watershed characteristics also contributed to flood generation, although their influence was comparatively lower than that of flow accumulation, drainage proximity, and elevation. Larger watershed systems were associated with increased flood susceptibility because they receive runoff from extensive upstream catchments. The significance of this finding lies in the recognition that flooding within Ayamelum is not solely a local phenomenon but is also influenced by hydrological processes occurring across broader catchment systems. This indicates that flood management efforts should adopt a watershed-based approach that considers upstream and downstream hydrological interactions.

The entropy weighting results provide additional insight into the relative importance of the flood drivers. The dominance of flow accumulation and proximity to drainage channels indicates that hydrological processes exert a stronger influence on flood occurrence than terrain characteristics alone. This finding indicates that flood management strategies focusing exclusively on topographic conditions may be insufficient. Instead, greater emphasis should be placed on drainage management, runoff control, watershed conservation, and river channel maintenance. The objective nature of the entropy weighting approach further strengthens the reliability of the findings by minimizing subjectivity in factor weighting.

The flood risk assessment revealed that 72.26% of the study area falls within the Very Low Risk category, while only 2.97% is classified as High Risk. At first glance, this distribution indicates that Ayamelum is generally characterized by low flood susceptibility. However, the spatial concentration of moderate and high-risk zones within specific locations is more important from a disaster management perspective than the overall area percentages. Flood disasters are often driven by localized high-risk environments rather than regional averages. Consequently, even though high-risk areas occupy a relatively small proportion of the total land area, their presence represents a substantial threat to affected communities.

The ward-level analysis provides further insight into the spatial dimensions of flood vulnerability. High-risk zones were identified exclusively within Umuerum and Anaku wards, indicating that these communities experience the most severe combination of flood-promoting conditions. The concentration of high-risk environments within these wards indicates that they are likely to experience more frequent and intense flooding than other parts of the LGA. This finding has important implications for disaster preparedness, emergency response planning, and resource allocation. Prioritizing flood mitigation measures within these wards would likely produce the greatest reduction in flood-related losses.

Moderate flood risk conditions were identified within Omor 1, Omor 2, Omor 3, Umuerum, Igbakwu, and Anaku wards. These areas represent transitional environments where flood hazards remain significant but are less severe than those observed in the high-risk zones. The occurrence of moderate-risk conditions across multiple wards indicates that flood vulnerability is not confined to isolated locations but extends across several communities within the LGA. This highlights the need for broader flood awareness programmes, improved drainage infrastructure, and community-based adaptation measures.

The overall pattern of flood risk observed in this study demonstrates that flood susceptibility in Ayamelum Local Government Area is spatially heterogeneous. Flood occurrence is concentrated within locations where low elevations, gentle slopes, drainage proximity, high runoff concentration, and large watershed influences coincide. The findings therefore emphasize the importance of integrating multiple environmental and hydrological variables when assessing flood risk. The resulting flood risk map provides a valuable decision-support tool for government agencies, emergency management authorities, planners, and community stakeholders. Its application can support sustainable land-use planning, infrastructure development, flood early warning systems, and disaster risk reduction initiatives aimed at enhancing resilience within flood-prone communities of Ayamelum Local Government Area.

4. Conclusion

This study examined the spatial distribution of flood drivers and assessed flood risk in Ayamelum Local Government Area, Anambra State, using geospatial techniques and entropy-based multi-criteria analysis. The findings revealed that flood occurrence within the study area is influenced primarily by the combined effects of elevation, slope, flow accumulation, proximity to natural drainage channels, and watershed characteristics. The spatial analysis demonstrated that low-lying terrain, gentle slopes, runoff convergence zones, areas close to drainage networks, and locations within larger watershed systems exhibit greater susceptibility to flooding.

The fuzzy membership standardization successfully transformed the various flood-driving factors into a common analytical framework, while the entropy weighting method objectively quantified their relative contributions to flood risk. The weighting results showed that flow accumulation and proximity to drainage channels exert the greatest influence on flood occurrence, highlighting the dominant role of hydrological processes in controlling flood dynamics within the study area. Elevation and slope also contributed significantly to flood susceptibility, whereas watershed characteristics exerted a comparatively lower influence.

The flood risk assessment revealed that 422.92 km² (72.26%) of Ayamelum LGA falls within the Very Low Risk category, 74.91 km² (12.80%) within the Low Risk category, 70.08 km² (11.97%) within the Moderate Risk category, and 17.40 km² (2.97%) within the High Risk category. Although the high-risk zones occupy a relatively small proportion of the total land area, they represent the most vulnerable environments and are concentrated primarily within Umuerum and Anaku wards. Moderate-risk conditions were observed in Omor 1, Omor 2, Omor 3, Umuerum, Igbakwu, and Anaku wards, indicating the presence of widespread flood susceptibility across several communities.

The study demonstrates that flood risk in Ayamelum Local Government Area is spatially heterogeneous and strongly influenced by the interaction of topographic and hydrological conditions. The generated flood risk map provides a reliable geospatial decision-support tool for identifying vulnerable locations and prioritizing flood management interventions. The findings provide valuable information for sustainable land-use planning, infrastructure development, disaster preparedness, and flood risk reduction programmes aimed at enhancing community resilience and minimizing the adverse impacts of future flood events within the Local Government Area.

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