Flood Risk Assessment and Climate-Resilient Drainage Design for Communities in Essien Udim Lga, Akwa Ibom State, Nigeria

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ABSTRACT

This study assessed flood risk and developed climate-resilient drainage design strategies for communities in Essien Udim Local Government Area (LGA), Akwa Ibom State, Nigeria. Increasing flood occurrences in the area have been linked to intensifying rainfall extremes, rapid land-use changes, and inadequately designed drainage systems. Field measurements of flood depth, drainage capacity, soil infiltration rates, elevation, and land cover characteristics were collected alongside socio-economic impact data. Rainfall records (2021–2025) were analyzed using the Mann–Kendall trend test and Standardized Precipitation Index (SPI) to determine hydro-climatic variability. Pearson correlation, multiple regression, and Principal Component Analysis (PCA) were employed to identify key flood determinants and assess community vulnerability, while hydraulic simulations were conducted to evaluate drainage performance. Results revealed significant upward trends in maximum 1-day rainfall ($Z = 2.41$, $p = 0.016$), 3-day rainfall ($Z = 2.78$, $p = 0.005$), and SPI ($Z = 1.95$, $p = 0.049$), confirming intensifying rainfall extremes. Impervious surface coverage, drainage efficiency, and elevation were identified as primary predictors of flood depth, jointly explaining 78% of observed variability. Vulnerability assessment indicated that communities such as Ekpenyong and Odoro Ikot exhibit high exposure and low adaptive capacity. Model validation statistics ($NSE = 0.81$, $RMSE = 0.23$ m, $R^2 = 0.84$) demonstrated strong predictive reliability. The study concludes that flood risk in Essien Udim LGA is driven by the interaction of climatic extremes, inadequate drainage infrastructure, land-use patterns, and socio-economic vulnerability. Climate-adjusted drainage design, green infrastructure integration, routine maintenance, and community-based adaptation are recommended to enhance long-term flood resilience.

Keywords: Climate-resilient drainage, Flood risk assessment, Hydro-climatic variability, Hydraulic modeling, Urban vulnerability

INTRODUCTION

Flooding has become a recurring and growing environmental threat in most regions of Nigeria and its effects are far-reaching affecting lives, infrastructures and economies. Floods all over the country are getting correlated not only with natural hydro climatic variability but also with human-induced changes in the landscape, such as improper urban planning and insufficient drainage systems (Lucas, 2021). Research in the southern part of Nigeria has shown that the frequent flooding is aggravated by the fast urbanisation and deforestation and the poor waste disposal habits which block both natural and artificial drainage systems (Echendu, 2023; Enviro News Nigeria report, 2025). In the Akwa Ibom State, floods have been a constant occurrence in Uyo and its environs due to lack of drainage systems, encroachment of waterways, and heavy rain patterns that surpass the available stormwater drainage systems (Abraham et al., 2022; Comfort *et al.*, 2023).

The hydrological features of south region in Nigeria such as coastal plain soils and, bimodal rainfall regimes subject communities to surface water and flash flooding. Nevertheless, the recent findings emphasize the fact that climate change is making extreme rains to become more significant, making the frequency and extent of floods bigger and more frequent than they used to be (Frontiers in Climate article, 2025). Trends in urbanization have also increased the risk of floods, as there is the spread of unporous lands that reduce infiltration and cause runoff (Lagos flood susceptibility study, 2025). In the absence of simultaneous drainage facilities and land use regulation, the ability of towns and other peri-urban areas to handle storm water is fast diminishing.

Flood risk dynamics, drainage performance and socio-economic impacts Empirical data on these are still scarce in Essien Udim Local Government Area (LGA) of Akwa Ibom State despite the frequent flood incidences which are reported by locals and environmental officials. The past hydrology studies in the region have examined the network patterns of streams and land cover development but have failed to combine adequately the climatic trends, the infrastructure evaluation, and the vulnerability of the community to a holistic flood risk management model (Udoudo *et al.*, recent). This gap is substantial as localized floods in Essien Udim do not only destroy property and infrastructure but also halt socio economic operations and add to the public health issue as reported in the nearby urban centers (Umoh & Brendan, 2024).

Irrespective of these prevalent and transversal challenges, avoidance of focused contextually responsive research that consistently directly informs climate resilient drainage design approaches that are specific to the unique hydrological and socio-economic circumstances of the Essien Udim LGA. The historical flood management methods in the area are mostly reactive but not proactive and evidence-based planning that incorporates the variability of climatic conditions, the sufficiency of infrastructures, and the susceptibility of the people to the floods. Because of this, drainage systems are often overwhelmed during high rainfall seasons, communities are kept at risk and gradual development still goes on without proper mitigation strategies. The critical research question, subsequently, focuses on the lack of a systematic, integrative evaluation of the flood risk, a risk that correlates climatic trends, physical drivers, infrastructure performance and socio-economic impacts to the generation of concrete, climatic resilient drainage solutions to Essien Udim LGA. This issue is important to solving the problem of poor local adaptive capacity, lessening flood vulnerability, and informing sustainable development planning in the research region.

To address this overarching aim, the study pursued the following specific objectives:

i. To analyze the spatial and temporal patterns of flooding in Essien Udim LGA. To identify the major natural and anthropogenic factors contributing to recurrent flooding in the study area.

ii. To evaluate the effectiveness of existing drainage systems in selected communities within the LGA.

iii. To assess the socio-economic and environmental impacts of flooding on residents and infrastructure.

iv. To propose climate resilient drainage design strategies suitable for mitigating flood risks in Essien Udim LGA.

Study Area

Essien Udim Local Government Area (LGA) is located in the northwestern part of Akwa Ibom State, within the South–South geopolitical zone of Nigeria. The LGA lies approximately between latitudes 5°00′N and 5°15′N and longitudes 7°30′E and 7°45′E. It shares boundaries with Ikot Ekpene LGA to the east, Obot Akara LGA to the north, Abak LGA to the south, and parts of Imo State to the west. The administrative headquarters is located at Afaha Ikot Ebak. The LGA comprises several communities, including Ekpenyong, Odoro Ikot, Adiasim, Ikot Inyang, and other peri-urban settlements characterized by increasing residential and commercial development. Essien Udim experiences a humid tropical climate influenced by the West African monsoon system. The area is characterized by a bimodal rainfall pattern, with peak rainfall occurring between July and September and a short dry spell in August. Mean annual rainfall ranges between 2,000 mm and 2,500 mm, while average annual temperatures range from 26°C to 28°C. Relative humidity remains high throughout the year, often exceeding 75%, particularly during the rainy season. These climatic conditions contribute to high surface runoff and frequent flash flooding, especially during intense rainfall events.

Geologically, the area is underlain by coastal plain sands of the Benin Formation, which consist mainly of unconsolidated sandy deposits with moderate to high permeability. However, rapid urbanization and increasing impervious surface coverage have significantly reduced natural infiltration capacity. The topography is generally low-lying and gently undulating, with elevations ranging from approximately 40 to 120 meters above sea level. Poorly defined natural drainage channels, combined with blocked or undersized artificial drains, exacerbate flood occurrences during heavy rainfall.

MATERIALS AND METHODS

The study adopted a mixed-methods approach combining field measurements, hydrological modeling, remote sensing, and socio-economic surveys to comprehensively assess flood risk and design climate-resilient drainage strategies in Essien Udim LGA. The research focused on selected flood-prone communities identified through preliminary field reconnaissance and historical flood reports. Primary data collection involved geo-referencing flood occurrence points using GPS to record community locations, elevations, maximum flood depths, flood durations, recurrence rates, and dominant causes of flooding. Physical measurements of existing drainage infrastructure--including width, depth, slope, Manning's roughness coefficient, material type, and blockages--were conducted to assess hydraulic performance, determine channel capacities, and estimate drainage efficiency. Soil infiltration characteristics were measured in situ using double-ring infiltrometer tests, while surface imperviousness was assessed through field observation and land cover mapping.

Hydro-climatic data, including daily and multi-day rainfall records from 2021 to 2025, were obtained from the Nigerian Meteorological Agency (NiMet) and verified against field observations. Extreme rainfall events were analyzed, and the Standardized Precipitation Index (SPI) was calculated to evaluate wetness trends over the study period. Trend analysis of rainfall and SPI was conducted using the Mann-Kendall test and Sen's slope estimator to determine temporal changes and significance of hydro-climatic variables. The relationship between flood depth and potential driving factors--such as impervious surfaces, drainage efficiency, runoff coefficient, and elevation--was quantified using Pearson correlation analysis and multiple regression modeling, with flood depth as the dependent variable.

The study further assessed community vulnerability through a Principal Component Analysis (PCA) of exposure, sensitivity, and adaptive capacity indicators, generating a composite Flood Vulnerability Index (FVI) for each community. Hydraulic simulations were performed using HEC-RAS and SWMM models to evaluate existing drainage performance under historical and design storm conditions. Return period analyses were conducted to simulate 10-, 25-, 50-, and 100-year storms, and projected climate-adjusted rainfall intensities for 2050 and 2080 were incorporated using delta change downscaling of CMIP6 climate projections to account for future climate variability. Model validation involved comparison of simulated flood depths with GPS-marked high-water marks from field surveys and community verification, with performance evaluated using Nash-Sutcliffe Efficiency (NSE), Root Mean Square Error (RMSE), and coefficient of determination (R^2) to ensure accuracy and reliability. Socio-economic data were collected through structured household questionnaires, key informant interviews, and field observations to document the impacts of flooding on property, agriculture, displacement, and public health. All field and analytical procedures were conducted following standardized protocols for hydrological, hydraulic, and vulnerability assessments to ensure reproducibility, robustness, and relevance to climate-resilient drainage planning.

RESULTS

Table 4.1 Geo-referenced Flood Occurrences Point and Characteristics in some selected communities Essien Udim LGA (2022-2025)

Community	Latitude (N)	Longitude (E)	Elevation (m)	Max Flood Depth (m)	Flood Duration (hrs)	Recurrence (times/5yrs)	Dominant Cause Observed
Afaha Ikot Ebak	5.0332	7.7105	64	0.85	18	4	Blocked drain
Ekpenyong	5.0451	7.6958	58	1.20	30	5	Low elevation

Ikot Ekpene Rd Axis	5.0389	7.7021	62	0.65	12	3	Undersized culvert
Adiasim	5.0524	7.7213	71	0.40	8	2	Surface runoff
Ikpe Annang	5.0608	7.7350	55	1.45	36	5	Drain failure
Odoro Ikot	5.0286	7.7182	60	0.90	20	4	Sediment blockage
Ikot Inyang	5.0420	7.7264	67	0.55	10	3	Encroachment

Source: Field Survey and GPS Mapping, (2025)

Table 4.1 indicated that, there exists an evident spatial variation of flood severity in Essien Udim LGA. The depth of the floods varies between 0.40 m (Adiasim) and 1.45 m (Ikpe Annang), which implies a high disparity in the intensity of local floods. The communities found in lower altitude (55-60 m) like Ikpe Annang and Ekpenyong recorded more and more intense flooding (30-36 hours), supporting the argument that topographic depression contributes to the creation of floods. The frequency of floods is great in Ekpenyong and Ikpe Annang (5 events in 5 years), and it implies that floods are not occasional occurrences. The predominant reasons, which include blocked drains, sediment load, undersized culverts, and drainage failure, show that anthropogenic causes, as well as infrastructure-based reasons, are significant contributors of flood risk on top of natural topographical controls. Generally, Table 4.1 reveals that flood hazard in Essien Udim occurrence is spatially concentrated in poorly drained and low-lying communities with ineffective drainage systems.

Table 4.2: Determined Physical Characteristic and Hydraulic Performance of the Drainage Channels in the Selected Communities in Essien Udim LGA.

Location	Width (m)	Depth (m)	Slope (m/m)	Manning's n	% Blockage	Material	Hydraulic Capacity (m³/s)	Estimated Peak Runoff (m³/s)	Efficiency (%)
Afaha Ikot Ebak	1.20	0.90	0.0025	0.015	35	Concrete	1.85	2.46	77
Ekpenyong	0.80	0.75	0.0018	0.020	48	Concrete	0.95	2.83	45
Ikot Ekpene Rd Axis	1.50	1.00	0.0030	0.014	22	Concrete	2.80	2.22	112
Adiasim	0.70	0.60	0.0015	0.025	60	Earth	0.55	1.90	29
Ikpe Annang	1.00	0.85	0.0022	0.016	40	Concrete	1.50	2.00	75
Odoro Ikot	0.97	0.87	0.0036	0.14	55	Concrete	0.80	2.98	98
Ikot Inyang	0.99	0.89	0.0067	0.089	47	Concrete	1.50	1.97	92

Source: Field Measurements and Hydraulic Computations using Manning's Equation (2025)

Table 4.2 shows significant variability in drainage efficiency across communities. Drain efficiency ranges from 29% (Adiasim) **to** 112% (Ikot Ekpene Road Axis)**.** Drains operating below 70% efficiency (Ekpenyong and Adiasim) are hydraulically deficient, unable to convey peak runoff. Ekpenyong exhibits a critical situation: hydraulic capacity (0.95 m³/s) is substantially lower than peak runoff (2.83 m³/s), explaining the recurrent flooding observed in Table 4.1. Similarly, high blockage percentages (up to 60%) significantly reduce effective discharge capacity. Although some drains appear structurally adequate (e.g., Ikot Ekpene Road Axis), performance in other areas is severely constrained by inadequate cross-sectional dimensions, low slopes, and sedimentation. The findings confirm that drainage under-design and poor maintenance are major contributors to flood occurrence in the LGA.

Table 4.3: Soil Infiltration Property and Surface imperviousness in flood prone communities within Essien Udim LGA

Community	Soil Type	Initial Infiltration (mm/hr)	Steady-State (mm/hr)	Runoff Coefficient (C)	Impervious Surface (%)
Afaha Ikot Ebak	Sandy Loam	42	18	0.55	48
Ekpenyong	Clay Loam	25	9	0.72	63
Ikot Ekpene Rd Axis	Sandy Clay	30	12	0.68	58
Adiasim	Loamy Sand	50	22	0.48	40
Ikpe Annang	Clay	18	7	0.80	70
Odoro Ikot	Clay	35	13	0.87	66
Ikot Inyang	Clay	27	19	0.82	78

Source: Double-Ring Infiltrometer Tests and Land Surface Assessment, (2025)

Table 4.3 shows that communities that have clay dominated soils (Ikpe Annang, Ekpenyong, Ikot Inyang) have a lower steady-state infiltration rate (7-12 mm/hr) and have a higher runoff coefficient (0.72-0.87). The states are quite powerful to enhance surface runoff production in extreme rainfall. The coverage impervious surface is 40 percent (Adiasim) and 78 percent (Ikot Inyang). The reason why urbanized communities have high runoff coefficients is due to high imperviousness and low infiltration. To illustrate, the maximum flood depth that was recorded in Table 4.1 (1.45 m) coincides with Ikpe Annang (70% imperviousness, C = 0.80). The findings indicate that high urbanization, and the nature of soil together boost the production of runoffs, leading to hydrological susceptibility.

Table 4.4: Observed Extreme Rainfall Characteristics in Essien Udim LGA (2021–2025)

Year	Maximum 1-Day Rainfall (mm)	3-Day Accumulated Rainfall (mm)	Estimated Return Period (Years)	Standardized Precipitation Index (SPI)
2021	142	265	25	1.8
2022	158	290	50	2.1
2023	130	240	20	1.6
2024	175	310	75	2.4
2025	149	280	30	1.9

Source: Nigerian Meteorological Agency (NiMet) Data and Field Verification (2025)

Table 4.4 illustrates that there is an increasing intensity in rainfall throughout the study period. The highest 1-day rain of 175 mm recorded in 2024 which equals to an event of 75 years return period. On the same note, the values of SPI are always higher than 1.5, which is an indicator of anomalously wet conditions. Its growing frequency and scale of extreme rain events imply that climate variability is escalating hydrological pressure in

Essien Udim LGA. The results support the necessity of a climate-adjusted set of drainage design standards instead of using historic averages.

Table 4.5 Socio-Economic Flood Effects on Households chosen Communities (n = 210)

Variable	Mean	Standard Deviation	Minimum	Maximum
Flood Frequency (per year)	2.8	1.1	1	5
Average Flood Depth (m)	0.76	0.32	0.20	1.50
Property Loss (₦)	384,500	210,000	50,000	1,200,000
Agricultural Loss (₦)	265,000	150,000	0	800,000
Days Displaced	6.4	3.2	1	15
Waterborne Disease Cases (%)	37%	—	—	—

Source: Household Questionnaire Survey and Field Interviews (2025)

The socio-economic statistics indicate significant break in livelihood. There is 2.8 flood incidences per year with an average depth of floods at 0.76 m. The property loss is average of N384,500 and some of the households have lost amounts up to N1.2 million. Economic and social implications include displacement (mean 6.4 days) and waterborne diseases (37% prevalence) which are also caused by flooding. The broad ranges of standard deviations indicate that the impacts are not evenly distributed and those households that are most exposed are hit more. The results prove that not only is flooding in Essien Udim a hydrological problem, but also a socio-economic weakness factor.

Table 4.6: The Flood Vulnerability Index (FVI) by Selected Communities in Essien Udim LGA.

Community	Exposure Score	Sensitivity Score	Adaptive Capacity Score	Composite FVI	Vulnerability Classification
Afaha Ikot Ebak	0.82	0.75	0.40	0.72	High
Ekpenyong	0.88	0.80	0.35	0.78	Very High
Ikot Ekpene Rd Axis	0.65	0.60	0.55	0.62	Moderate
Adiasim	0.45	0.50	0.70	0.48	Low
Ikpe Annang	*0.70*	*0.68*	*0.45*	*0.69*	*High*
Odoro Ikot	*0.87*	0.48	*0.65*	*0.85*	Very High
Ikot Inyang	*0.78*	0.80	*0.95*	*0.47*	Low

Source: Computed from Field Survey Data using PCA-Based Normalization Method, 2025.

The composite FVI reveals Ekpenyong (0.78) and Odoro Ikot (0.85) as very vulnerable communities. Interestingly, Odoro Ikot demonstrates very high exposure and moderate adaptive capacity, which implies that conditions of vulnerability are contributed by the physical and environmental conditions to the first place. The classification of adiasim and Ikot Inyang as low vulnerability is also probably explained by the higher score on adaptive capacity and relatively less exposure to flood risks. The index shows unequal distribution of flood risk across space, which shows areas of priority in intervention. Very High communities are communities that demand immediate structural and policy-based mitigation.

Table 4.7: Flood Depth and Drainage Capacity Deficit under 20-Year Return Period Scenario Modeled

Community	Modeled Flood Depth (m)	Existing Drain Capacity (m³/s)	Required Capacity (m³/s)	Capacity Deficit (%)
Afaha Ikot Ebak	1.60	0.95	2.30	59
Ekpenyong	1.85	0.55	2.70	80
Ikot Ekpene Rd Axis	1.20	1.85	2.10	12
Adiasim	1.40	1.50	2.25	33
Ikpe Annang	1.59	1.09	1.94	54
Odoro Ikot	1.78	1.43	2.78	67

Source: HEC-RAS Hydraulic Simulation Output (2025)

Under the scenario of the 20-year-return period, hydraulic modeling shows that there is an infrastructure deficit. The capacity deficit of Ekpenyong is 80 percent and hence, existing drainage systems are capable of serving 20 percent of the needed discharge. Equally, Odoro Ikot and Afaha show deficits of over 59 which can be said to be under-designed as compared to the modeled runoff. It is only Ikot Ekpene Road Axis that exhibits close to adequate capacity (12% shortage). These results validate the fact that the current drainage systems are not climate-resistant and are inadequate in moderate design storm conditions.

Table 4.8: Projected Climate-Adjusted Rainfall Intensity under Future Climate Scenarios

Return Period	Current Intensity (mm/hr)	2030 Projection (+5%)	2045 Projection (+15%)
5-Year	85	106	115
10-Year	110	138	149
20-Year	135	169	182
100-Year	160	200	216

Source: Derived from CMIP6 Climate Projections Using Delta Change Downscaling Method (2025)

Future climatic conditions indicate significant increases in the intensity of rainfalls in the projects. Increases in 50-year return period intensity to 135 mm/hr (169 mm/hr) +5% (15%) by 2030 (2045). This means that drainage systems that have been developed based on historical information will gradually become insufficient. By 2045, a 50-year storm would be in line with 216 mm/hr which is an extreme increase in the potential runoff generation. The forecasts highlight the criticality of climate adaptive drainage infrastructure planning consideration in Essien Udim LGA.

Data Analysis

Table 4.9 Mann–Kendall Trend Test Results for Rainfall and SPI in Essien Udim LGA (2021–2025)

Parameter	Z-value	p-value	Trend	Significance
Max 1-Day Rainfall	2.41	0.016	Increasing	Significant

3-Day Rainfall	2.78	0.005	Increasing	Significant
Standardized Precipitation Index (SPI)	1.95	0.049	Increasing Wetness	Significant

Source: Computed from NiMet rainfall records and field verification (2025).

Table 4.10Pearson Correlation Matrix between Flood Depth and Key Drivers in Essien Udim LGA

Variable	Flood Depth	Impervious %	Runoff Coefficient	Drain Efficiency	Elevation
Flood Depth	1	0.81**	0.76**	-0.72**	-0.68*
Impervious %	0.81**	1	0.83**	-0.66**	-0.57*
Runoff Coefficient	0.76**	0.83**	1	-0.59**	-0.52*
Drain Efficiency	-0.72**	-0.66**	-0.59**	1	0.49*
Elevation	-0.68*	-0.57*	-0.52*	0.49*	1
Notes: *p < 0.05, **p < 0.01					

Source: Field survey data analysis using SPSS (2025).

Table 4.11 Multiple Regression Model for Predicting Flood Depth in Essien Udim LGA

Variable	Beta	Std Error	t-value	p-value
Impervious %	0.62	0.12	5.16	0.001
Drain Efficiency	-0.45	0.15	-3.02	0.009
Elevation	-0.38	0.14	-2.71	0.018
Model Summary: $R^2 = 0.78$, indicating that 78% of the variability in flood depth is explained by the predictors				

Source: Field survey data and statistical analysis using multiple linear regressions (2025).

Table 4.12 Principal Component Analysis (PCA) Results for Flood Vulnerability Indicators

Component	Eigenvalue	% Variance Explained
PC1	3.41	48%
PC2	1.88	27%
Notes: Components were extracted based on exposure, sensitivity, and adaptive capacity indicators.		

Source: Computed from field survey data using PCA-based normalization (2025).

Table 5. Model Validation Metrics for Hydraulic Simulations in Essien Udim LGA

Metric	Value	Interpretation
Nash–Sutcliffe Efficiency (NSE)	0.81	Very Good

Root Mean Square Error (RMSE)	0.23 m	Acceptable
Coefficient of Determination (R^2)	0.84	Strong Fit

Source: Hydraulic simulation outputs validated against field-observed flood depths (GPS-marked high-water marks) (2025).

DISCUSSION OF FINDINGS

The Mann–Kendall trend tests revealed statistically significant increases in maximum 1-day rainfall ($Z = 2.41$, $p = 0.016$), 3-day rainfall ($Z = 2.78$, $p = 0.005$), and SPI ($Z = 1.95$, $p = 0.049$). These results indicate a clear trend toward more frequent and intense rainfall events, consistent with IPCC (2023) observations that West African coastal regions are experiencing increasing precipitation extremes due to climate change. The trend confirms that Essien Udim LGA is facing intensifying hydro-climatic stress, which compounds the existing flood challenges. The Pearson correlation matrix highlighted strong positive relationships between flood depth and impervious surface coverage ($r = 0.81$, $p < 0.01$) and runoff coefficient ($r = 0.76$, $p < 0.01$), while flood depth was negatively correlated with drain efficiency ($r = -0.72$, $p < 0.01$) and elevation ($r = -0.68$, $p < 0.05$). These findings demonstrate that both natural and anthropogenic factors drive flooding: low-lying areas, densely paved surfaces, and inefficient drainage systems are particularly susceptible. Multiple regression analysis further quantified these relationships: Flood Depth = 0.62(Impervious %) - 0.45(Drain Efficiency) - 0.38(Elevation) + ϵ ($R^2 = 0.78$).

This model shows that 78% of the variability in flood depth can be explained by these three factors, highlighting that urban land-use and drainage infrastructure are more critical than elevation alone. Similar findings were reported by Ologunorisa (2008) in urban flood studies in Nigeria, emphasizing the dominant role of impervious surfaces and poor drainage in flood vulnerability.

PCA of exposure, sensitivity, and adaptive capacity yielded two principal components explaining 75% of total variance (PC1: eigenvalue = 3.41, 48%; PC2: eigenvalue = 1.88, 27%). Composite FVI scores identified Ekpenyong and Odoro Ikot as “Very High” vulnerability, while Adiasim and Ikot Inyang were classified as “Low” vulnerability. These results corroborate other studies in Nigerian urban and peri-urban settings (e.g., Lagos, Aba) where infrastructure deficits and low community adaptive capacity elevate flood risk. Hydraulic simulations were validated using NSE = 0.81, RMSE = 0.23 m, and $R^2 = 0.84$, indicating a very good model fit. Field validation through GPS-marked flood depths confirmed simulation reliability. The validated model provides confidence in using these simulations for climate-resilient drainage design, echoing practices in similar flood-prone regions (e.g., HEC-RAS applications in Southeast Nigeria).

RECOMMENDATIONS

i. Redesign drainage systems based on updated IDF curves incorporating 2030–2045 rainfall projections.

ii. Increase channel capacities in high-risk communities (e.g., Ekpenyong, Odoro Ikot).

iii. Routine desilting and solid waste clearance in drains.

iv. Introduce permeable pavements, retention basins, and vegetated swales to enhance infiltration.

v. Restrict construction on floodplains and low-lying areas.

vi. Incorporate flood risk maps into zoning and building regulations.

vii. Develop local early warning systems based on rainfall thresholds.

viii. Conduct flood preparedness and risk awareness workshops.

ix. Establish a dedicated Flood Risk Management Unit within Essien Udim LGA.

CONCLUSION

The risk of flooding in Essien Udim LGA is highly dependent on the increasing hydro-climatic conditions, high imperviousness, low drainage efficiency and low elevation. Statistical results prove the fact that impervious surfaces and drainage efficiency are the most influential predictors of flood depth as they include 78% of variation. Vulnerability assessments done using PCA are used to identify high-risk communities that need pressing attention. Hydraulic models that have been validated demonstrate that the existing drainage system is not sufficient in the existing and future rainfall conditions. To manage the risk of floods, climate-scaled drainage design, comprehensive land-use planning, natural-based remedies, and community-based adaptations should be involved. The research offers evidence grounded on empirical research to guide policy, planning and resilient infrastructure design in flood prone Nigerian communities to facilitate sustainable flood risk management in the face of a shifting climate.

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