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Research article

DIMENSIONS OF RAINFALL ANOMALIES AND PLUVIAL DISASTER RISKS IN IMO MORPHO-CLIMATIC ZONES: AWARENESS AND ADAPTATION

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ABSTRACT

This study examined the spatial and temporal dimensions of annual rainfall anomalies, community awareness, and adaptation to pluvial disaster risks across the northern, eastern, and western morpho-climatic zones of Imo State, Nigeria. Annual rainfall data for 1923–2023 were obtained from the Climatic Research Unit time-series dataset using $0.5^\circ \times 0.5^\circ$ cells for extraction. Primary data were collected from 442 respondents through structured questionnaires, and interviews, and analysed using descriptive statistics and linear trend models. The most severe negative anomaly occurred in eastern Imo in 1983 (−618.71 mm), whereas the highest positive anomaly occurred in northern Imo in 1954 (487.20 mm). Awareness of rainfall-related hazards was generally high, but perceived adaptation capacity was constrained by finance, government support, weather-monitoring capacity, and assets. Trend estimates indicated declining anomaly series across the three zones, although the western-zone trend was not statistically significant at the 5% level. The study concludes that high awareness has not translated into commensurate adaptive capacity. It recommends coordinated early warning, risk-sensitive land-use planning, drainage and erosion control, environmental education, and targeted household support. The study contributes zone-specific evidence for climate-risk governance in south-eastern Nigeria.

KEYWORDS

climate adaptation; extreme rainfall; flood risk; gully erosion; Imo State; morpho-climatic zones; rainfall anomalies

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1. INTRODUCTION

Rainfall and temperature are dominant climatic controls on human activity and environmental processes within the humid tropical rainforest belt. In the Anthropocene, climatic variability interacts with intensive human modification of landscapes. Malhi et al. (2014) observed that human influence on planetary functioning is pervasive, while its consequences vary across ecological and social settings. In Imo State, rainfall anomalies affect water availability, agriculture, settlements, infrastructure, and geomorphic stability; nevertheless, awareness of these risks and the capacity to respond remain uneven across communities.

The intensification of human–environment interactions has strengthened the proposition that the planet has entered the Anthropocene (Crutzen, 2002; Steffen et al., 2011). Humans now operate as major geological and geomorphological agents through land conversion, urbanisation, excavation, drainage alteration, and occupation of hazard-prone terrain (Zalasiewicz et al., 2008, 2010). Rainfall extremes become disasters when they intersect with exposed populations, fragile infrastructure, erodible materials, and limited institutional capacity.

2. LITERATURE REVIEW

Climate change is altering precipitation regimes and the frequency and intensity of extremes. Intense rainfall increases the probability of landslides, debris flows, flooding, and related geomorphic failures (Segoni et al.,

2016; Araújo et al., 2022). Rainfall thresholds are important in landslide-warning systems (Bandeira & Coutinho, 2015), while long-term records reveal substantial spatial and temporal variability in precipitation (Mazzoglio et al., 2022; Cheru et al., 2025). Risk is further conditioned by lithology, land use, soil, hydrology, fault proximity, topography, and settlement patterns (Marengo et al., 2021; Li et al., 2025; Liu et al., 2025).

Evidence from Brazil illustrates how climatic hazards become disasters through the concentration of people, property, and infrastructure. The south and south-east have recorded extensive exposure to flash flooding and landslides, including recurring fatalities around São Paulo (Nobre et al., 2011; Ávila et al., 2016; De Almeida et al., 2016; Debortoli et al., 2017; Di Giulio et al., 2018; Alvala et al., 2019; Young et al., 2019; Marengo et al., 2020; Travassos et al., 2020). These studies show that hazard magnitude alone does not determine loss; governance, vulnerability, infrastructure, and preparedness mediate outcomes.

Positive rainfall anomalies can accelerate surface-water accumulation, generate flash or river flooding, and increase runoff capable of initiating gullies, enlarging channels, and driving headward erosion. Settlement expansion into flood-prone land and ageing drainage systems may increase losses independently of changes in the climatic hazard itself (Sirisena et al., 2026). Integrated hydraulic and spatial modelling can differentiate hazard classes and reveal variations in flood and debris-flow risk (Aronica et al., 2012). Scenario-based approaches similarly show that medium- and high-risk zones expand as rainfall intensity or return period increases (Li et al., 2020; Wang & Hou, 2023).

Recent research combines gridded climate records, remote sensing, geographic information systems, and multi-criteria methods. Studies of the Ili River Basin provide quantitative evidence for extreme-precipitation assessment and geo-disaster risk classification (Liu et al., 2025; Li et al., 2025), while Sujatha and Sudharsan (2024) identify multi-source integration as central to susceptibility mapping. Adaptation also depends on education, experience, finance, public-health planning, and locally appropriate interventions (Ebi & Semenza, 2008; Jay et al., 2021; Sanchez, 2023; Amnuaylojaroen & Parasin, 2024). In Nigeria, Umo et al. (2021) advocate people-centred flood-risk awareness, while Umo (2025) highlights the relationship between geomorphic vulnerability and sustainable land management.

This study therefore evaluates annual rainfall anomalies and residents' awareness and adaptation across three Imo morpho-climatic zones. It asks: (1) How do extreme annual rainfall anomalies vary among the zones? (2) What are residents' levels of awareness of the associated pluvial disaster risks? and (3) Which factors shape adaptation capacity? The combination of a 101-year climate record and community evidence provides a spatially differentiated basis for climate-risk planning in south-eastern Nigeria.

3. STUDY AREA

Imo State is situated in south-eastern Nigeria between approximately 5°10'02" and 6°02'01" N and 6°07'11" and 7°29'13" E (Figure 1). It covers about 5,530 km² and contains densely settled urban, peri-urban, and rural landscapes (National Population Commission, 2009; National Bureau of Statistics, 2017). The study distinguishes northern, eastern, and western morpho-climatic zones to capture differences in terrain, geology, drainage, land use, and rainfall exposure.

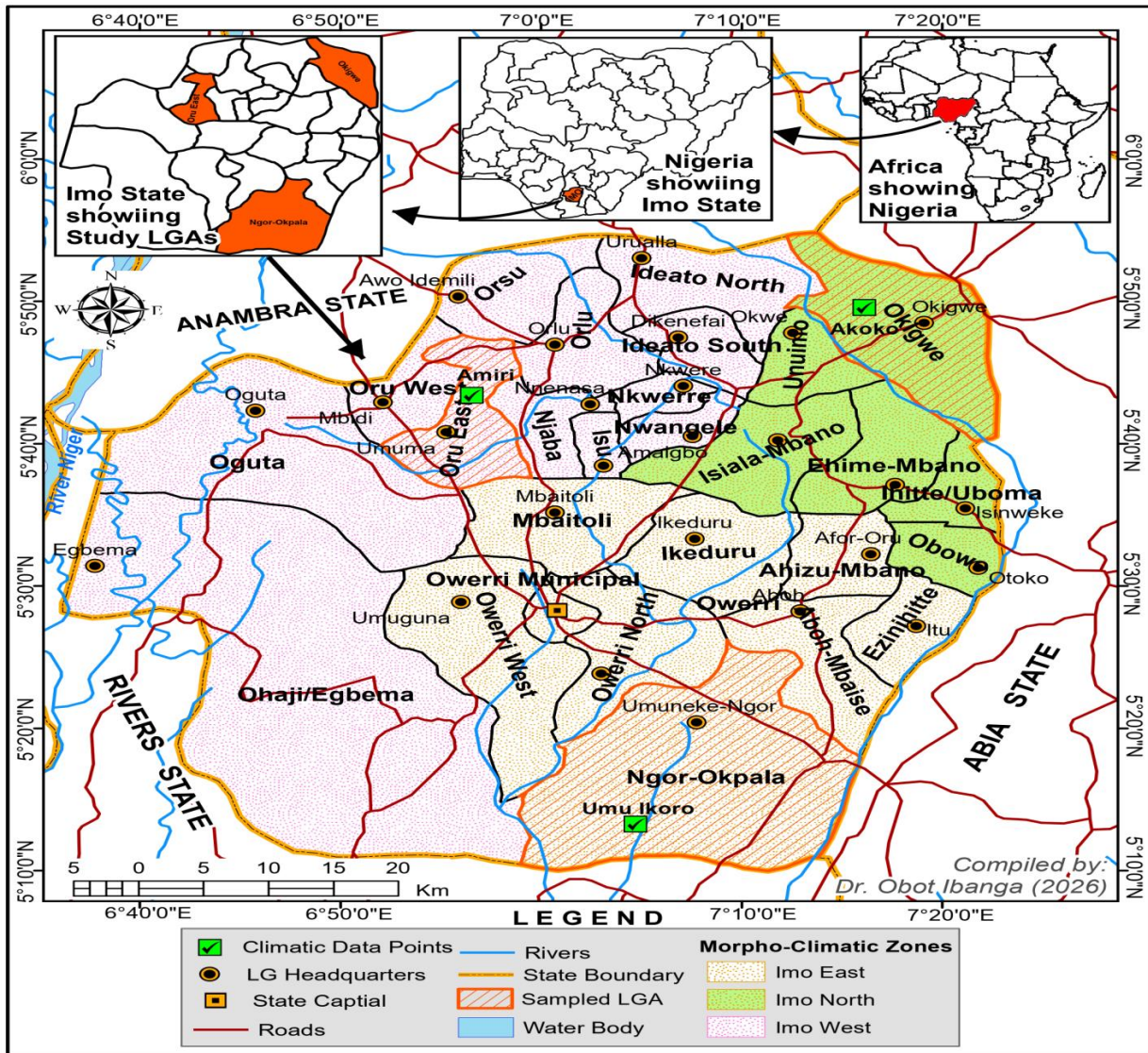


Figure 1. Imo State showing sampled local government areas, morpho-climatic zones, and rainfall-data extraction points

Source: Authors' compilation (2026).

The state has an Af climate under the Köppen classification and lies within the humid tropical rainforest belt. Natural vegetation has been extensively modified by agriculture, settlement growth, infrastructure development, and resource extraction. High seasonal rainfall combined with land-cover change increases the sensitivity of soils, slopes, drainage channels, and built-up areas to both excessive and deficient rainfall.

Geological conditions vary across the zones. Northern Imo includes False-Bedded Sandstone and the Upper Coal Measures. The northern and western zones share parts of the Imo Shale and related formations, whereas Coastal Plain Sands are extensive in eastern Imo and also occur in the west. These differences influence infiltration, runoff, erodibility, slope response, and rainfall-related hazards.

4. METHODOLOGY

4.1 RESEARCH DESIGN

The study adopted a mixed-method descriptive survey design. Long-term rainfall analysis was combined with questionnaire responses, interviews, and focus group discussions to examine annual anomalies and the social dimensions of awareness and adaptation.

4.2 DATA SOURCES, POPULATION, AND SAMPLING

Primary data were collected through a structured questionnaire, semi-structured interviews, and focus group discussions. Secondary rainfall data were obtained from the Climatic Research Unit archive. Imo State was stratified into northern, eastern, and western morpho-climatic zones, and one geographically representative rainfall extraction point was selected within each zone (Figure 1 and Table 1).

A target sample of 450 respondents was allocated equally across the three zones. Respondents were purposively selected on the basis of residence and knowledge of how rainfall extremes affect household well-being and livelihoods, with no more than two participants selected from one household. Of the 450 questionnaires administered, 442 were complete and suitable for analysis, a response rate of 98.2%. Coordinates were recorded with a Global Positioning System receiver. The questionnaire was reviewed for clarity and content coverage before field administration, and interview and focus-group evidence was used to cross-check survey interpretation. Participation was voluntary, respondents were informed of the study purpose, and responses were treated confidentially.

Table 1. Locations of rainfall-data extraction points

Morpho-climatic Zone	LGA	Settlement	Latitudes	Longitudes
Northern Imo	Okigwe	Akoko	5.829920	7.300805
Eastern Imo	Ngor-Okpala	Umu Ikoro	5.242725	7.097892
Western Imo	Oru East	Amiri	5.723392	6.959385

Source: Authors' fieldwork (2025).

4.3 MORPHO-CLIMATIC ZONING AND RAINFALL-DATA EXTRACTION

Monthly rainfall data for 1923–2023 were extracted for three selected grid cells from CRU TS version 4.08, a $0.5^\circ \times 0.5^\circ$ gridded dataset covering 1901–2023 (University of East Anglia Climatic Research Unit et al., 2024). Monthly totals were aggregated into annual totals. For each zone, the annual anomaly was calculated as annual rainfall minus the 1923–2023 long-term mean; positive values represent wetter-than-average years and negative values drier-than-average years.

4.4 DATA ANALYSIS

Frequencies, percentages, means, tables, and graphs summarised awareness, adaptation drivers, and past adaptation success. Ordinary least-squares models of the form $A_t = \alpha + \beta t + \varepsilon_t$ were fitted separately for each zone. The northern series declined by approximately 1.63 mm per year ($R^2 = .076$, $p = .005$), the western series by 1.08 mm per year ($R^2 = .031$, $p = .079$), and the eastern series by 1.53 mm per year ($R^2 = .055$, $p = .018$). Thus, the northern and eastern trends were statistically significant at $\alpha = .05$, whereas the western trend was not. The small R^2 values indicate that year alone explains only a limited share of interannual variability.

5. RESULTS AND DISCUSSION

5.1 SPATIAL AND TEMPORAL DIMENSIONS OF RAINFALL

ANOMALIES

The dimensions of annual rainfall anomalies were elucidated using linear trend models the results are chronologically presented in Figures 3, 4, and 5. The results indicate elements of space – time deviances and homogeneities based on the morpho-climatic zones. Contextually, the results for the Northern Imo morpho-climatic zone summarized in Figure 3 reveal that the most lethal negative anomaly of -582.18 mm was recorded in 1983, followed by -342.72 mm in 1945, -308.80 mm in 1986, and a value of -291.10 mm in 1992 year respectively. The identified trends negative rainfall anomalies over the years implied episodic occurrences of pluvial disaster such as meteorological drought leading to acute water scarcity, deficit in soil moisture crops, increase in thermal discomfort, poor vegetation, and loss of exotic water-loving plants species.

In context of extreme positive anomalies, the results presented in Figure 3 depict that a climax value of 487.20 mm was established in the Northern morpho-climatic zone during the 1954 year. Further still, the very high positive values of 365.59 , 352.86 , and 301.12 mm were recorded during the 1957, 1980, and 1997 years respectively. Indeed, the established episodic high positive anomalies coupled with comparatively high, rugged, and undulating topographic features indicate the Northern morpho-climatic zone high vulnerability to dimensional impacts of erosion (by gully, rilling, channel expansion and headward migration), mass wasting (by slumping, sliding and rock fall), deep weathering (via chemical processes), and sediment yield due to denudational processes. Thus, corroborating recent studies in Italy and Portugal respectively, whose results established that extreme precipitation trigger pluvial disaster, with extreme precipitation events significantly increasing the likelihood of landslides, debris flows, and collapses (Segoni et al., 2016; Araújo et al., 2022).

In retrospect, the total of 66 years exhibited negative anomalies, while the total of 34 years possessed positive anomalies. The dominant histories of negative anomalies over positive scenarios is a clear indicator of protracted years of incidences of water shortage and the attendance multiplier effect of limited crop productivities, food insecurity, inadequate ecosystem protection, and poor vegetation growth.

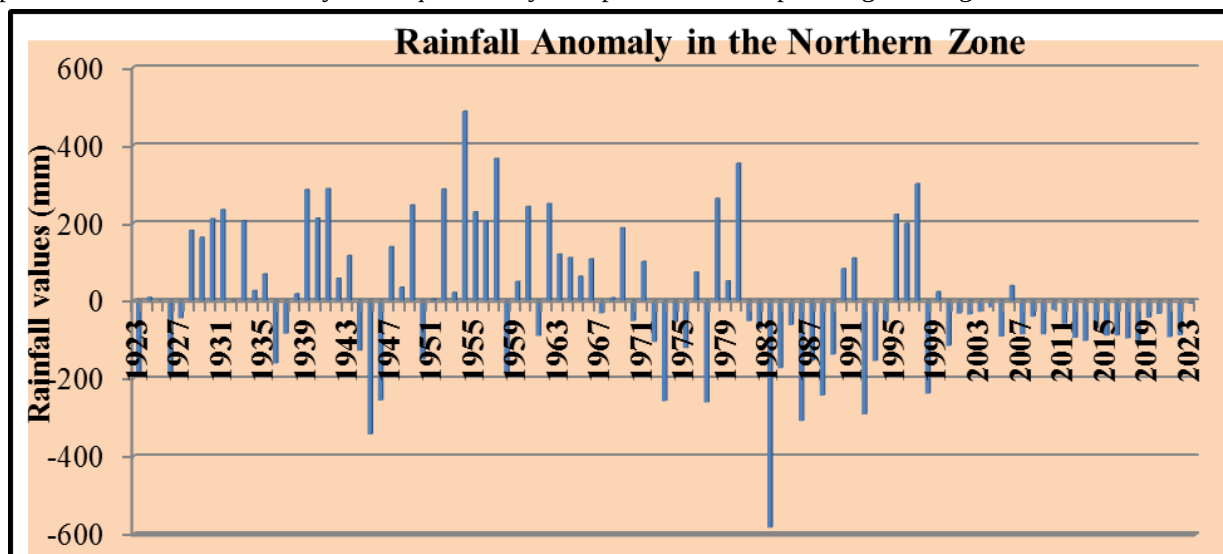


Figure 2. Annual rainfall anomalies in the northern morpho-climatic zone of Imo State

Source: Authors' analysis (2025).

The evaluation of the dimensions in rainfall anomalies in Figure 4 for the Western Imo morpho-climatic zone reveal traces of dynamism based on years. From the results of the epoch making negative events, a peak value of -597.99 mm is associated with the 1983 year. The pattern is followed by -400.54 mm, -348.99 mm, and -338.74 mm for the 1958, 1945 and 1973 years, accordingly. The implication of historic high negative rainfall anomalies is that the Western Imo morpho-climatic zone remains highly susceptible to the pluvial disaster especially periodic decline in soil moisture and synoptic meteorological drought condition during the identified years as shown in Figure 4. Such dry spell affect farming activities such as disruption of planting season, delayed growing seasons and water scarcity.

On the basis of positive rainfall anomalies, the results presented in Figure 4 indicate that the most focal value of 421.32 mm was recorded during 1957 year in the Western Imo morpho-climate zone. Other top ranking values recorded were 394.16 mm, 334.42 mm and 323.82 mm for 1952, 1954, and 1980 years respectively. Thus, suggesting the high susceptibility of the Western morpho-climatic zone to diverging incidences of pluvial disaster risks, especially episodic River and Lake flood, sheet wash leading to massive loss of soil nutrients and organic matter, leaching of soil nutrient, and disruption of root and tuber crops (e.g. yam, cassava, and potatoes) within some notable agrarian towns in Oguta, Ohaji Egbema, Orlu, Orlu East and Orlu West respectively.

Indeed, other vital issues of major concern include air pollution due to dust in area, coupled with poor road/drainage and allied infrastructure. The established pattern in the results validated a perspective that rainfall variability is driven by local factors such as topography and land use/land cover changes as well as global systems like ITCZ, El Niño–Southern Oscillation (ENSO), IOD, and others, which need further study (Cheru et al. 2025).

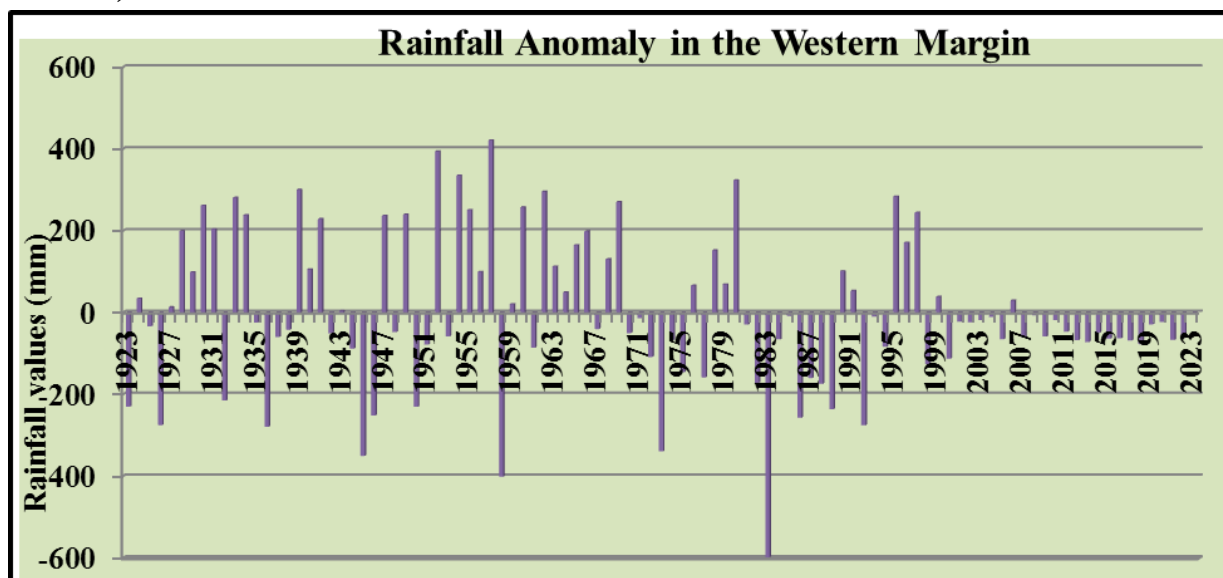


Figure 3. Annual rainfall anomalies in the western morpho-climatic zone of Imo State

Source: Authors' analysis (2025).

Within the Eastern Imo morpho-climatic zone, the results summarized in Figure 5 depict elements of convergence and divergence across distinct years. Comparatively, the peak negative anomaly of -618.71 mm was recorded in 1983 year. This is followed by -409.47 mm, -370.39 mm, -352.38 mm each recorded in the 1992, 1945, and 1946 years accordingly. Considering the homogenous geologic formation (Coastal Plain Sand Deposits of Tertiary Times) and allied fairly uniform terrain however, the high negative rainfall anomaly suggests a potential high susceptibility of the element to heat stressor, leading to thermal discomfort. This is most peculiar to the highly urbanized and densely populated areas of Owerri Municipal, Owerri West, and Owerri North.

From the dimension of positive anomalies, the results in Figure 5 show that the leading positive anomaly of 479.73 mm is recorded during the 1954 year. Other notable historical records of positive anomaly comprise 432.82 mm, 373.67 mm, and 344.03 mm established during 1957, 1960, and 1941 years. The outrageous positive rainfall anomalies x-rayed in Figure 5 have strong affinity with protracted urban flood disasters that are domiciliary in areas such as Ubomiri-Akwakuma-Amakohia-Work layout, IMSU back gate-Chukwuma Nwaoha-Aladima-Ikenegbu-Road safety/ shop Rite-MCC/ Urata axes of Imo State, prior to the ongoing watershed and ecological management options.

Retrospectively, the pattern depicts strong conformity with a recent report that under varying rainfall conditions, low-risk areas generally remain stable, medium-risk zones expand with increasing rainfall intensity, and high-risk zones tend to cluster spatially with pluvial disaster risks (Wang and Hou, 2023).. However, the seriousness of pluvial disaster risk can be exacerbated by multiple geographic factors within the location.

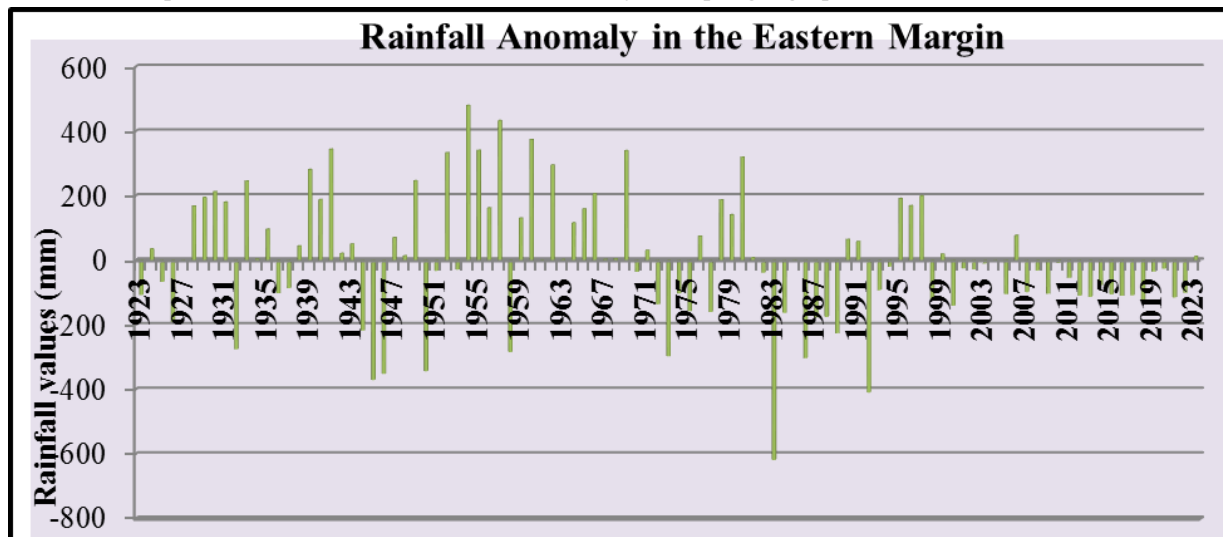


Figure 4. Annual rainfall anomalies in the eastern morpho-climatic zone of Imo State

Source: Authors' analysis (2025).

Furthermore, the high positive rainfall anomaly within the Eastern Imo Morpho-climatic zone coupled with the weak geologic formation, high population density, urbanization, and land use patterns constitute the focal accelerator of flood and erosion by gulying, headward migration, channel expansion and their multiplier impacts on human life, property, and environment as reported Edo State by Umo (2025). Retrospectively, the dimension in the results reveal partial affinity recent studies on flood hazards in the Bohai Rim and Ili River Basin in China whose reports attested that as the recurrence period increases, medium- and high-risk areas expand, low-risk areas contract, and high-risk zones predominantly occur in densely populated and economically active regions (Li et al., 2020; Li et al., 2025).

5.2 AWARENESS OF RAINFALL ANOMALIES AND PLUVIAL DISASTER RISK

The quantitative evidence of respondents' awareness levels and vulnerability to extreme rainfall (excess and deficit) events and the associated pluvial disaster show spatial differentiation in each Imo morpho-climatic zone. The comparative assessments of the result in Table 2 indicated that high level of awareness converges between a frequency of 78 for the Eastern Imo morpho-climatic zone and 85 for the Northern Imo morpho-climatic zone, each possessing a proportion of 53 and 56 percent on the order. However, the Western Imo

morpho-climatic zone possesses an intermediate high frequency of 80 respondents, expressing a total of 54 percent in the series.

Using similarity in Latitudinal location as index for inter-continental comparison, the results avow Marengo et al. (2021) notion that about 85 percent of disasters are related to rainfall or a lack of it in Brazil; with flash floods and landslides causing over 10,000 deaths in the last five decades. Specifically, collaborative empirical studies affirm that Southern Brazil is the most exposed and vulnerable to climate-related disasters triggered by extreme rainfall (Ávila et al., 2016; De Almeida et al., 2016; Debortoli et al., 2017; Alvala et al., 2019).

In context of moderate pattern, the outcomes converge between a frequency of 56 for Western Imo morpho-climatic zone and 64 for the Eastern Imo morpho-climatic zone, each accounting for a total of 38 and 43 percent, accordingly. More so, the Northern Imo morpho-climatic zone attracted an intermediate frequency of 57 respondents, representing 43 percent in the series. Within the low rating context, the results range between a least frequency of 6 for the Eastern Imo morpho-climatic zone and a peak value of 11 for the Western Imo morpho-climatic zone.

A further juxtaposition of the results using grand mean as index gives a value of 240 respondents representing a proportion of 54 percent exhibiting a dominantly high knowledge, perception, and awareness of pluvial disaster risk associated with extreme rainfall indicator in distinct Imo morpho-climatic zones. The identified pattern show solidarity with the observation that differences in underlying environmental gradients have resulted in many modified tropical forest landscapes being best characterized as highly heterogeneous mosaics (Malhi et al., 2014).

Table 2. Respondents' awareness of rainfall anomalies and pluvial disaster risk

Morpho-climatic Zones	Perception of Pluvial Disaster Risks Awareness Level			Total (%)
	High (%)	Moderate (%)	Low (%)	
Northern Imo	82 (56)	57 (39)	8 (5)	147 (100)
Eastern Imo	78 (53)	64 (43)	6 (4)	148 (100)
Western Imo	80 (54)	56 (38)	11 (8)	147 (100)
Mean Total	240 (54)	177 (40)	25 (6)	442 (100)

Source: Authors' field survey (2026).

5.3 DRIVERS AND PERCEIVED SUCCESS OF ADAPTATION

The descriptive exploration of the perceived facilitators of residents' adaptation to the pluvial disaster risks are summarized in Table 3 and the results differ based on indicators. In context of very high capacity enhancement rating, knowledge of the past occurrences and individual experiences of given pluvial disaster stands out as the most dominant factor, attracting a frequency of 280 respondents (63 percent). The result is closely followed by improved educational capacity attracting 27 respondents (representing 60 percent) in the series.

Within the framework of high capacity enhancement rating, the results reveal that government support before, during, and/or after given pluvial disaster attracted a highest frequency of 108 (expressing 24 percent) of the drivers of the respondents' adaptation. Other high drivers of respondents' adjustment to pluvial disaster in the study area include educational capacity (11 percent), locational factor (23 percent), personal experiences (23 percent), and asset based capacity (22 percent). The established low levels of adjustments suggest increase in health risk, amidst Amnuaylojaroen and Parasin (2024) observation that Adaptation strategies are essential to address the multifaceted health impacts and Ebi & Semenza (2008) promotion of adaptation at the community level to boost public health component.

On the basis of drivers of low capacity enhancement of adaptation to pluvial disaster risk, the results in Table 3 identified gender as a focal indicator with a frequency of 234, accounting for a proportion of 54 percent, followed by financial constraint attracting 182 (42 percent), and asset-based capacity with a frequency of 180, representing a proportion of 41 percent in the sequence. A further exploration of the results using very low drivers of adaptation as surrogate indicated that weather monitoring capacity (250), economic capacity (161), Government support (144), financial capacity (138) and locational capacity (124); each attracts a proportion of

57 percent, 36 percent, 33 percent, 31 percent, and 31 percent accordingly. The established pattern collaborated Jay et al. (2021) recommendations for heat-specific interventions, while a proposal of a more comprehensive understanding of adaptation strategies and appropriate applications across various environmental and socio-political contexts to mitigate extreme weather events has been advocated in Amnuaylojaroen & Parasin (2024).

Table 3. Drivers of adaptation to pluvial disaster impacts

Indicators of Adaptation	Capacity Enhancement Levels for Disaster				Total (%)
	Very high (%)	High (%)	Low (%)	Very low	
Educational capacity	277 (63)	102 (23)	48 (11)	15 (3)	442 (100)
Financial capacity	44 (10)	78 (18)	182 (42)	138 (31)	442 (100)
Gender capacity enhancement	62 (14)	88 (20)	234 (54)	58 (13)	442 (100)
Economic capacity	66 (15)	93 (21)	122 (28)	161 (36)	442 (100)
Locational capacity	98 (22)	100 (23)	124 (28)	120 (27)	442 (100)
Knowledge of Past experiences	280 (63)	100 (23)	50 (11)	12 (3)	442 (100)
Government support	66 (15)	108 (24)	124 (28)	144 (33)	442 (100)
Weather monitoring capacity	8 (2)	22 (5)	162 (37)	250 (57)	442 (100)
Asset-based capacity	66 (15)	98 (22)	180 (41)	98 (22)	442 (100)
Mean Total	107 (24)	88 (20)	136 (31)	111 (25)	442 (100)

Source: Authors' field survey (2026).

Discounting the dynamics and dimensions in the discussed drivers of adaptation, our assessment of the residents' past efforts in pluvial disasters risk based on distinct Imo morpho-climatic zones is summarized in **Table 4**. The results indicated spatial fluxes in geographic locations and levels of the past successes recorded. The Eastern Imo morpho-climatic zone recorded the peak level of success with a total of 44 respondents, representing 30 percent, followed 38 respondents in Western Imo morpho-climatic zone, accounting for a proportion of 26 percent.

The dimension within the Imo morpho-climatic zones reveal strong affinity with recent studies such as Liu, Lyu & Shen (2025) and Li et al. (2025) notions that geological hazard risk amplifies with increase rainfall intensity or magnitude. The implication is that localities across Imo morpho-climatic zones of Southeast Nigeria experience varying degrees of dynamism in high positive rainfall attributes such as days, weeks, months, or seasons resulting in peak hazard levels (e.g. gully erosion and flood), while those with threshold rainfall events are highly susceptible to thermal heat and water deficit.

On the basis of moderate disaster risk rating, the results reveal that Eastern Imo morpho-climatic zone has the highest value of 64 respondents, representing a total of 43 percent, seconded by Northern Imo morpho-climatic zone with a value of 57 (denoting 39 percent) of the respondents. Within the framework of threshold success rating, the results showed that the Northern Imo predominates with 58 (39 percent), followed by Western Imo 57 (39 percent) in the sequence.

Table 4. Respondents' ratings of past adaptation success

Morpho-climatic Zones	Specific Rating of Past Pluvial Disaster Risks Adaptation			
	High (%)	Moderate (%)	Low (%)	Total (%)
Northern Imo	32 (22)	57 (39)	58 (39)	147 (100)
Eastern Imo	44 (30)	64 (43)	40 (27)	148 (100)
Western Imo	38 (26)	52 (35)	57 (39)	147 (100)

Morpho-climatic Zones	Specific Rating of Past Pluvial Disaster Risks Adaptation			
Grand Total	114 (26)	173 (39)	155 (35)	442 (100)

Source: Authors' field survey (2026).

6. IMPLICATIONS, CONCLUSION, AND RECOMMENDATIONS

Annual rainfall anomalies vary substantially across time and among the three Imo morpho-climatic zones. Eastern Imo recorded the largest negative anomaly, while northern Imo recorded the largest positive anomaly. The anomaly series show significant downward trends in the northern and eastern zones, although time explains only a small proportion of the variability. Extreme wet years can intensify flooding, erosion, and slope instability, whereas marked deficits can affect water supply, crops, vegetation, and thermal comfort.

Residents generally reported high awareness of rainfall-related hazards, but adaptation capacity was constrained by finance, assets, weather-monitoring capability, government support, location, and wider economic conditions. Past adaptation was rated mainly moderate or low. Awareness campaigns alone are therefore insufficient; households require actionable forecasts, accessible support, effective infrastructure, and enforceable land-use measures.

The study recommends the following actions:

1. Establish coordinated, zone-specific early-warning and risk-communication systems linking meteorological agencies, state and local governments, universities, emergency services, community organisations, and the media. Environmental education should translate forecasts into practical household and livelihood decisions.
2. Strengthen drainage maintenance, gully and slope stabilisation, watershed restoration, and risk-sensitive development control. Preparedness, emergency response, and recovery plans should address flood, erosion, mass movement, drought, heat stress, and water scarcity. Targeted financial and technical support should prioritise households and communities with limited adaptive assets.

6.1 STUDY LIMITATIONS

The analysis uses one $0.5^\circ \times 0.5^\circ$ CRU grid cell to represent each morpho-climatic zone and relies partly on purposively selected respondents. The findings support zonal comparison but should not be interpreted as property-level hazard estimates or as statistically representative of every household. Future studies should combine denser station networks, remotely sensed rainfall, hydrological observations, probability-based household sampling, and multivariate modelling.

Ethics and Consent

Participation was voluntary. Respondents were informed about the study purpose, and confidentiality was maintained during data collection, analysis, and reporting.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The CRU TS 4.08 rainfall dataset is available from the NERC EDS Centre for Environmental Data Analysis. Anonymised survey data may be made available by the corresponding author upon reasonable request, subject to ethical and confidentiality considerations.

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