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Research Article

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Temporal Variability in Annual Rainfall Anomaly in Selected Locations Over Lower Benue Basin, Nigeria: Implication for Flooding

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ABSTRACT

This study examined rainfall variability across the Lower Benue Basin using the Rainfall Anomaly Index (RAI) to assess dry and wet years and their implications for flooding. Data on daily rainfall were collected from the following selected locations within the Basin. They are Ibi, Makurdi, Lafia, Jos, and Lokoja from 1971-2020 (50 years). The daily rainfall data were summed to obtain monthly and annual rainfall amounts. The data for the study locations were acquired from the Nigerian Meteorological Agency (NiMet). The extent of rainfall anomaly over the basin was determined using the Rainfall Anomaly Index (RAI). Results indicate that Lokoja experienced 26 dry and 24 wet years over 50 years, with the highest RAI of 5.2 in 2012, coinciding with a major flood. Makurdi recorded more positive RAI values from 1971 to 1991 and more dry anomalies from 2001 to 2020, indicating a general decrease in rainfall but no clear climate shift. Lafia shows a marked decline in rainfall, with positive RAI from 1971 to 1995 and drier conditions from 1996 to 2020, suggesting a climate change signal. Jos also exhibits a drying trend, with predominantly positive RAI from 1971 to 1992 and negative RAI thereafter, though the topography and river morphology still lead to flooding. Ibi shows 26 dry and 24 wet years, with drier conditions prevailing post-2011. Despite increasing dry conditions across the middle and upper basin, flood frequency remains high due to topographical and hydrological factors, especially in lower areas. The study therefore recommends that enhanced flood management measures are necessary to address ongoing flood risks despite declining rainfall, particularly in low-lying areas influenced by river morphology. In addition, tailored water conservation strategies should be implemented to support agricultural and environmental resilience in increasingly dry regions of the basin.

Keyword: Temporal, Variability, Rainfall, Anomaly, Lower Benue, Basin

Introduction

The warming of the Earth's climate is undeniable, as demonstrated by observed increases in average air and ocean temperatures, extensive melting of snow and ice, and a rise in global sea levels. These changes have contributed to severe flood events and other extreme weather phenomena, such as more frequent episodes of extreme heat, heatwaves, and intense rainfall across various regions [1]. The primary driver of global warming is the surge in human activities that release greenhouse gases into the atmosphere, making it one of the most evident signs of global climate change [2]. Numerous studies globally affirm that human-induced greenhouse gas emissions are driving changes in average global temperatures, with an increase of approximately 0.6°C. These temperature shifts are significantly impacting the global hydrological cycle, influencing various aspects of human life [3,4]. The resulting alterations, such as increasing rainfall anomaly and rising temperatures, contribute to shifts in the physical characteristics of river basins, droughts, floods, extreme weather events, and disruptions in groundwater recharge processes [5]. Consequently, floods caused by the increased frequency of heavy rainfall events have emerged as one of the most prevalent consequences of climate change in river basins worldwide, including the River Benue Basin. For example, between July and October 2012, severe flooding in Nigeria led to rivers, particularly the Niger and Benue, overflowing their

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banks, submerging vast expanses of farmland. By mid-October 2012, this disaster had displaced 1.3 million people and claimed 431 lives [6]. A number of flood events of significant magnitude and severity, resulting from frequent heavy rains, have been recorded across the Lower Benue Basin, particularly in 2015, 2017, and 2022, with their attendant devastating consequences on lives, livelihoods, and infrastructure.

Rainfall anomaly refers to deviations from long-term average precipitation levels over a specific area and time. This metric is critical for understanding climate variability and its impact on ecosystems, agriculture, and water resources, particularly in the humid tropics [7]. The humid tropics, characterized by high annual rainfall and dense vegetation, include regions in Central Africa, Southeast Asia, and parts of South America [8]. Rainfall variability in these regions is driven by interactions between atmospheric, oceanic, and land processes. The El Niño-Southern Oscillation (ENSO) significantly influences rainfall anomalies in the humid tropics. During El Niño phases, regions such as the Amazon Basin and parts of Southeast Asia often experience below-average rainfall, leading to drought conditions [9]. Conversely, La Niña events typically cause increased precipitation in these areas, often resulting in flooding [10]. This variability is attributed to sea surface temperature anomalies that alter atmospheric circulation patterns [11].

Tropical cyclones also contribute to rainfall anomalies. For instance, hurricanes and typhoons can cause sudden, extreme rainfall in coastal and adjacent inland areas, disrupting seasonal averages [12]. The Madden-Julian Oscillation (MJO), a large-scale atmospheric phenomenon, further modulates rainfall by enhancing or suppressing convection in 30- to 60-day cycles [13]. The MJO's influence is particularly pronounced in the Maritime Continent, where its phases dictate alternating wet and dry periods [14]. Deforestation and land-use changes exacerbate rainfall variability in the humid tropics. Large-scale forest loss in the Amazon and Congo Basins reduces evapotranspiration, weakening the hydrological cycle and potentially increasing the frequency of rainfall anomalies [15]. Urbanization also disrupts local weather patterns, contributing to unpredictable rainfall [16].

Rainfall variability has profound implications for not just man-induced natural disasters like flooding, but also agriculture in the humid tropics. Crops such as rice, cocoa, and cassava are highly sensitive to precipitation changes [17]. Rainfall deficits can lead to crop failure and food insecurity, while excessive rainfall may cause waterlogging and reduce yields [18]. Livelihoods dependent on rain-fed agriculture are particularly vulnerable to these anomalies [19]. Water resource management is also affected by rainfall anomalies. Prolonged dry spells reduce river discharge and groundwater recharge, impacting drinking water supplies and hydropower generation [20]. Conversely, excessive rainfall increases the risk of flooding, damaging infrastructure and displacing communities [21]. Climate change is expected to amplify rainfall variability in the humid tropics. Models predict more frequent and intense ENSO events, further disrupting precipitation patterns [10]. Rising global temperatures also enhance atmospheric moisture capacity, potentially increasing rainfall intensity during extreme events [22-25].

The implications of annual rainfall variability in the humid tropics, such as Nigeria, where the Lower Benue Basin is located, underscore the need for continued investigation of rainfall anomalies to enhance climate monitoring and forecasting systems, thereby mitigating their adverse effects. Moreover, rainfall anomalies and their annual variability in the humid tropics are influenced by complex climatic interactions. Addressing these anomalies, particularly their implications for frequent flooding, requires an understanding of their annual variability, which is critical for ensuring sustainable development and building climate resilience in this vital region of Nigeria, which is home to over 17 million inhabitants, the majority of whom are farmers.

In spite of the high frequency of floods and regardless of the large population living in low-lying areas susceptible to flash and river floods with its devastating implications for lives and properties, the challenge of addressing floods resulting from heavy rains in Lower Benue Basin using Rainfall Anomaly Index (RAI) has not received attention based on information from the available literature. Previous studies on flooding in this region focused on flood damage; causes of flooding; health effects of flood incidences; rainfall pattern and its implication on flood frequency; social impact and people's perception of flooding; and socioeconomic implications of flooding [26-33]. Evidently therefore, no research effort has been carried out to understand the temporal variability in annual rainfall anomaly over the Lower Benue Basin and its implication for flood occurrence thereby creating a research gap.

Material and Methods

Study Area

The Lower River Benue Basin, also known as the Lower Benue Trough, spans latitudes 6°13'N to 10°00'N and longitudes 7°00'E to 10°40'E, covering a 77,379.32 km² area with a population of around 1.35 million (2007 data). Predominantly located in Benue State, it also includes parts of Kogi, Nasarawa, Taraba, and Plateau States, with key settlements like Gboko, Makurdi, Lokoja, Ibi and Lafia (Figure 1 & 2). Geologically, the basin is a sedimentary zone dominated by sandstone and includes other formations like shale and siltstone, with sedimentation beginning in the Lower Cretaceous period. The diverse soil types, including fertile alluvial soils and red ferrasols, support agriculture, although erosion from river banks heightens flood risks.

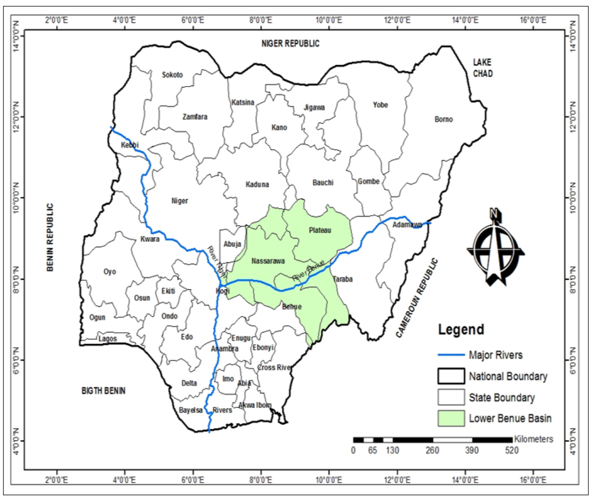

Figure 1: Nigeria showing States within the Lower Benue Basin

Source: Benue State University, Cartography and GIS Studio, 2021

Figure 2: Lower Benue Basin showing major settlements

Source: Benue State University, Cartography and GIS Studio, 2021

The area's relief is mostly below 300m, creating expansive flood plains, while elevations rise to 900m in certain uplands. The Niger and Benue Rivers, including their extensive flood plains, shape the drainage, with River Benue being the main hydrological feature, joined by smaller rivers like Katsina-Ala and Okpokwu. The basin's tropical climate is influenced by the Inter-Tropical Convergence Zone, leading to a wet season from April to October with an annual rainfall range of 1,000-1,500 mm. Climate change has intensified regional flooding through increased rainfall and higher temperatures. Vegetation is primarily Guinea savanna, with trees such as Khaya senegalensis and Parkia biglobosa, though urbanization and agriculture have reduced natural cover, further impacting flood control.

Economically, the population is primarily agrarian, focusing on subsistence farming and fishing, alongside some mining activities, especially in Nasarawa. Crops like yam, rice, and maize are widely grown, while industries are limited to small-scale enterprises linked to agriculture and textile production. The Lower Benue Basin is home to a population of around 17.3 million, with administrative divisions across multiple states, though its population data relies on figures related to past flood events.

Methods

Data on daily rainfall were collected from the following selected locations within the Basin. They are Ibi, Makurdi, Lafia, Jos, and Lokoja from 1971-2020 (50 years). The daily rainfall data were summed to obtain monthly and annual rainfall amounts. The data for the study locations were acquired from the Nigerian Meteorological Agency (NiMet).

The extent of rainfall anomaly over the basin was determined using the Rainfall Anomaly Index (RAI). This was carried out to further establish the degree of variability regarding the rainfall regime. The Rainfall Anomaly Index helped determine the frequency and intensity of dry and rainy years in the study area and its implication for flood occurrence. The Standardized Rainfall Anomaly Index (RAI) was also be used in determine the reliability of rains across the basin. It depicted periods of different wet and dry intensities in the study area. The choice of this method is justified because the study focuses on rainfall. The technique as observed by Iliya and Dankani (2012) requires that precipitation values for the period of study (1971-2020) should be ranked in descending order of magnitude with the highest precipitation being ranked first and the lowest precipitation being ranked last. The average of the ten highest precipitation values as well as that of the ten lowest precipitation values for the period of study were calculated. Van-Rooy (1965) derived a rainfall anomaly index (RAI) in the form:

$$RAI = 3\,[(P - \rho)/(M - \rho)] \qquad (1)$$

for positive anomalies, and

$$RAI = -3[(P - \rho)/(X - \rho)] \qquad (2)$$

for negative anomalies

Where

P = the actual rainfall

ρ = the long-term average rainfall

M =the mean of the ten highest values of p on record and

X = the mean of the lowest values of p on record

The arbitrary threshold values of +3 and -3 have, respectively been assigned to the mean of the ten most extreme positive and negative anomalies. Nine abnormality classes, ranging from extremely wet to extremely dry conditions, are then given against a scale of numerical values of the relative rainfall anomaly index as shown in Table 1.

Table 1: Description of Monthly Moisture Conditions

SN	Index	Character of the weather
1	4.0 0 or more	Extremely wet
2	3.0 0 to 3.99	Very wet
3	2.00 to 2.99	Moderately wet
4	1.0 0 to 1.99	Slightly wet
5	0.99 to -0.99	Near normal
6	-1.00 to -1.99	Mild drought
7	-2.00 to -2.99	Moderate drought
8	-3.00 to -3.99	Severe drought
9	-4.00 or less	Extreme drought

Source: Adopted from Oladipo: Oyatayo, Ndabula, Abaje, Jidauna, Iwan and Mshelia.

Result and Discussion

The results of annual rainfall anomaly over the Lower Benue Basin are presented in Figures 3 - 8. The result of the pattern rainfall based on RAI at Lokoja is presented in Figure 3.

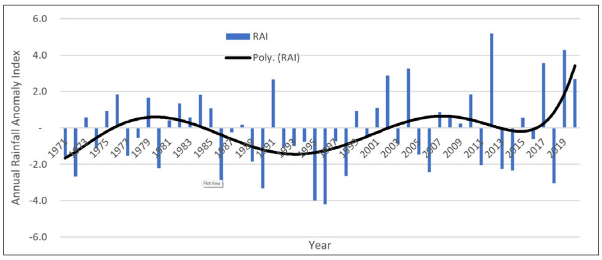

Figure 3: Rainfall Anomaly Index for Lokoja

The result shows that there are generally more dry years (26 years) of varying intensities than wet years (24 years). The dry years are years with rainfall amounts that are less than the long-term mean for the study area. This means that there are more years with annual total rainfall amounts that are less than the 50-year mean annual rainfall amount at Lokoja. The result further shows that 1971 to 1994 witnessed the first dry period with RAI intensity ranging from "dry" to "very dry" years. The rainy years occurred between 1975 and 1985 except for 1977, 1978 and 1980. This is followed by another dry episode, occurring from 1986 to 2000 with exception of 1978, 1991 and 1999. The result further shows that the last 20 years (2001 - 2020) witnessed more positive RAI values which is an indication of increasing wetter condition. This trend represents a major departure in annual rainfall regime between 1971 to 2000 on the one hand, and 2001 to 2020 on the other hand.

The highest RAI of 5.2 occurred in 2012 which coincided with the great flood event that swept through the basin. The RAI of 5.2 falls within the extremely wet year with the potential to cause a flood of high intensity and severity. This follows that RAI does not only have implications for agricultural planning but also serves as an indicator of flood occurrence in any given year. For instance, years with wet or positive RAI values above 2 are likely to experience moderate to extreme flood events depending on the RAI level. This is evident in 2012 with an RAI intensity of 5.2 and the severe flood of that year which is followed by 2019 with an RAI value of 4.3 witnessing a flood of lesser magnitude. It is however important to note that there exists a possibility of flood occurring during dry years depending on the monthly rainfall distribution the morphology of the river/stream and the topography factor which are important flood triggers in the area.

In Makurdi, the result shows that more positive RAI values occurred between 1971 and 1991 except 1971, 1973, 1976, 1980, and 1988 (Figure 4).

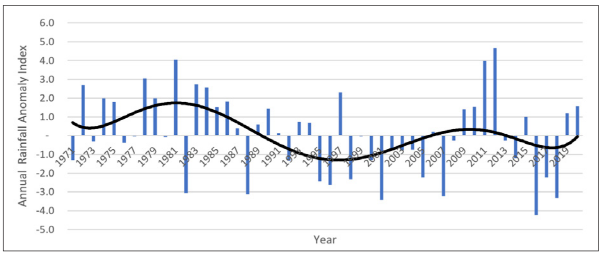

Figure 4: Rainfall Anomaly Index for Makurdi

The wet phase was followed by a drier phase occurring between 1992 and 2008 with the exception of 1993, 1994, and 1997. Again, 2012 recorded the highest positive RAI of 4.7, however, there are more dry anomalies in the last 20 years (2001 to 2020) in Makurdi than in the wet years, unlike the situation in Lokoja. The result generally indicates a higher frequency of wet years which is an indication of wetter conditions between 1971 and 2000; and more dry years/conditions between 2001 and 2020. This further provides additional evidence of the decreasing rainfall amount over Makurdi as earlier reported using time series analysis. From this result therefore, there is no marked shift in rainfall pattern over Makurdi that represents climate change, though the extent of variability coupled with other basin parameters such as morphology, topography, and sedimentation and the resultant decrease in the depth of rivers/stream are enough to increase flood frequency even in the face of insignificant decline in annual rainfall regime in this area.

The result of the RAI in Lafia (Figure 5) shows a significant decline in yearly rainfall amount in relation to the long-term average.

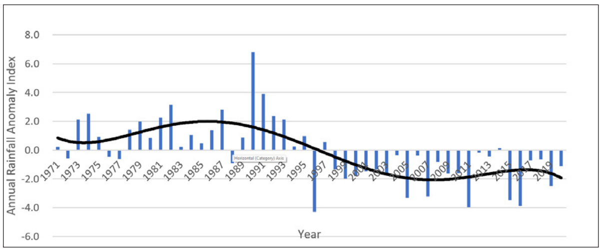

Figure 5: Rainfall Anomaly Index for Lafia

Positive RAI prevailed largely between 1971 and 1995 with exception of 1972, 1975, 1976 and 1978. During this highly humid phase (1971 to 1995), 1990 recorded the highest RAI of 6.8. On the other hand, the negative RAI prevailed from 1996 to 2020 with exception of 2014 which indicates a very low humid index of 0.1. The Lafia result provides clear evidence of drier condition with a marked shift in rainfall regime between 1971 to 1995; and 1996 to 2020. It is equally a clear evidence of climate change in terms of annual rainfall amount with drier condition prevailing in the last 25 years (1996 to 2020). With the drier conditions, flood frequency is expected to decline, which is currently not the case. The increasing flood frequency here may be linked with rivers/stream morphology and rainfall condition in other parts of the basin, but impact on Lafia area due to the interconnectivity of a drainage system.

Similarly, the result of RAI in Jos is presented in Figure 6. The result indicates a general down ward trend in annual rainfall regime which suggests a drier conditions over the area during the study period.

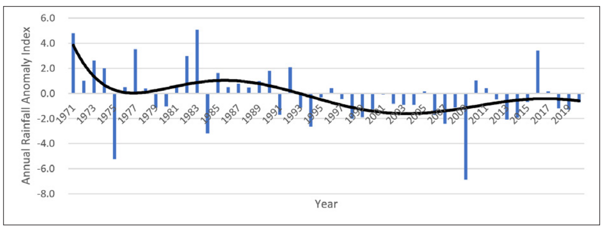

Figure 6: Rainfall Anomaly Index for Jos

The result further shows that positive RAI occurred predominantly between 1971 and 1992 with exception of 1975, 1984 and 1991, while negative RAI (drier condition) prevailed dominantly between 1994 and 2020 exception of 1996, 2005, 2010, 2011 and 2016. The highest positive RAI of 5.1 was recorded in 1983, while lowest negative RAI of -6.9 was recorded in 2009. Based on this result, flood frequency and severity are supposed to decrease proportionately in areas such as Shendam that are under the influence of rainfall from Jos Plateau since most rivers/stream that trigger flood take their source from Jos. This is however not the case as floods of different magnitude have become yearly event due to the low-lying nature of topography in Shendam and other areas at the foot of the Jos Plateau. In addition to the topography, monthly distribution of rainfall, nature of the soil and streams/rivers morphology all contribute to flood disaster in this area and areas under its influence.

At Ibi, the result shows a general decline in annual rainfall regime Figure 7. A total of 26 dry years of varying RAI intensities and frequencies occurred within the 50 years study period (1971 to 2020).

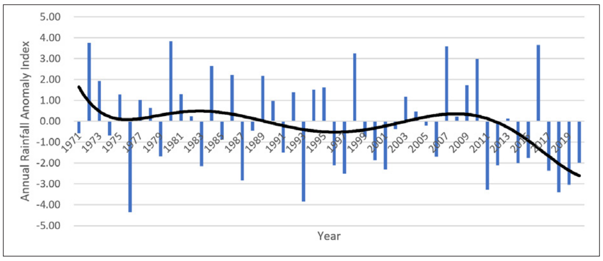

Figure 7: Rainfall Anomaly Index for Ibi

On the other hand, 24 wet years of varying RAI intensities occurred during the same time frame. Unlike Jos and Lafia, RAI in Ibi does not show clear pattern of positive and negative RAI. However, wetter condition with corresponding high positive RAI values predominantly prevailed between 1971 and 1989. while, drier condition (negative RAI) has prevailed since 2011 with exception of 2016.

From the results, it is evident that more locations within the Lower Benue Basin are becoming drier especially at the middle and upper sections of the basin, yet floods still constitute serious environmental risks and vulnerability within the basin. Again, there is no clear evidence of marked shift in climate (annual rainfall regime) except at Lafia and Jos with drier conditions especially in the last 20 years and Lokoja with wetter conditions.

Discussion

The analysis of the provided research results on temporal variability in annual rainfall anomaly over the Lower Benue Basin aligns with findings from earlier studies, highlighting similarities and distinctions. For instance, Aho et al. identified extreme rainfall events as critical contributors to flood occurrences in Makurdi, rather than total annual rainfall [34]. This aligns with the current findings that extreme positive RAI values (e.g., 5.2 in Lokoja for 2012 and 4.7 in Makurdi for 2012) directly relate to significant flood events, underscoring the role of rainfall intensity rather than just its total volume. Both studies recognize the significance of September as a peak rainfall month, corroborating the need to focus on monthly rainfall distribution to understand flood risks better. While Aho et al. noted statistically insignificant trends in annual rainfall, the current research adds granularity by identifying localized patterns of wetter and drier periods across different locations, such as Lokoja's recent wetter conditions and Makurdi's drier trends post-2001 [34].

Ologunorisa reported a downward trend in annual rainfall and extreme rainfall events between 1996 and 2001 correspond with the drier phase noted in the current study for Makurdi and Jos [27]. These observations reinforce the idea that while annual totals might decline, extreme events are increasing, affecting flood frequency. The recurrence of floods during May to October as identified by Ologunorisa also resonates with the current study, particularly regarding the impact of rainfall distribution and timing on flooding. Agbor et al. study on Port Harcourt highlighted the coastal tropical setting's unique temporal rainfall patterns and their variability [35]. While the Lower Benue Basin is inland, parallels can be drawn in recognizing the importance of localized analysis of rainfall anomalies to predict flood risks. Both studies underline the role of climate variability in shaping rainfall trends, with Agbor et al. emphasizing coastal dynamics and the current research demonstrating how basin morphology and interconnectivity amplify flood impacts despite observed drier conditions.

Furthermore, Shitu et al. and the current study in the Lower Benue Basin both applied RAI to assess rainfall variability [36]. In the Lower Benue Basin, the RAI identified wetter conditions from 2001 to 2020 in Lokoja, contrasting with prolonged drier periods in Lafia and Jos. Similarly, Kasye et al. used RAI to determine drought severity in Ethiopia's Cheleka Watershed. Kasye et al. observed higher seasonal variability (22.93%-29.12% for Kiremt rainfall) compared to the broader inter-annual variability in the Lower Benue Basin, where significant shifts were found, such as Lafia's drier trend post-1995. Kasye et al. highlighted drought frequency and severity, akin to the Lower Benue study's findings of increased dry years in locations like Lafia and Makurdi. However, while Kasye et al. linked drought to socio-economic risks, the Lower Benue study emphasized flooding despite drier conditions, showing a complex relationship influenced by basin morphology and connectivity. Similarly, Ologunorisa found that rainfall increased in October-December, correlating with frequent floods in the Lower Benue Valley [37]. This aligns with Lokoja's RAI results, where positive anomalies coincided with the severe 2012 flood. Both studies noted the importance of antecedent conditions and basin morphology in flood occurrences. For example, Lafia's drier trends did not reduce flood vulnerability due to inter-basin water flow impacts. Also, both studies identified socio-economic vulnerabilities, such as poor housing and poverty, exacerbating flood risks in flood-prone communities. The study by Ojoye et al. observed a significant increase in rainfall over Sokoto from 1949 to 2010 [38]. The Lower Benue study similarly found increasing wet conditions in Lokoja but diverged in Lafia and Jos, where drier trends were prominent. The Gumbel distribution in Ojoye et al. revealed increasing extreme rainfall, resonating with the Lower Benue study's 2012 extreme wet anomaly and its association with catastrophic flooding. Both studies emphasized the need for adaptive flood management policies. While Ojoye et al. proposed adaptation to extreme rainfall, the Lower Benue study highlighted integrated approaches considering morphology and hydrological variability.

The current research complements earlier works by highlighting nuanced spatial and temporal variability within the Lower Benue

Basin. Its recognition of positive RAI values correlating with floods (e.g., 2012) substantiates recommendations for mitigation strategies focusing on extreme rainfall rather than annual totals. It also aligns with prior studies in emphasizing that climatic factors, coupled with geographical and morphological characteristics, play a critical role in shaping flood dynamics. This reinforces the need for localized flood risk management strategies tailored to specific sub-basin characteristics. Overall, the Lower Benue Basin study underscores spatial and temporal heterogeneity in rainfall variability and its implications for flood risks, consistent with findings from the comparative studies. Lokoja's wetter trends align with increasing flood occurrences, while Lafia and Jos reflect drier conditions that paradoxically still experience floods due to basin-wide hydrological dynamics. This complements Kasye et al.'s emphasis on spatial variability and drought severity, Ologunorisa's focus on socio-economic vulnerability, and Ojoye et al.'s conclusions on rainfall-induced flooding. The comparative analysis reveals the multifaceted nature of rainfall variability and its implications, emphasizing a region-specific and multidisciplinary approach to climate adaptation and flood management.

Conclusion

The Rainfall Anomaly Index (RAI) analysis reveals that the Lower Benue Basin exhibits significant rainfall variability, with an overall trend of more frequent dry conditions in locations such as Lafia and Jos, and wetter conditions in Lokoja. Although the annual rainfall regime does not show a clear indication of climate change in most areas, the drier conditions in the upper and middle basin sections contribute to declining flood frequency, while topography and river morphology continue to exacerbate flood vulnerability in certain low-lying areas. The RAI findings align with time series analyses by Onah (2024), reinforcing the variability of rainfall and its complex implications for flood risks across the basin. Consequently, the study recommends enhanced flood management measures necessary to address ongoing flood risks despite declining rainfall, particularly in low-lying areas influenced by river morphology. In addition, tailored water conservation strategies should be implemented to support agricultural and environmental resilience in increasingly dry regions of the basin.

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