Flow and Flux: Delving into Rainfall Patterns and Water Table Dynamics in the Hadejia-Nguru River Floodplains, Nigeria

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ABSTRACT

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| *This study investigated rainfall patterns and water table dynamics in the Hadejia-Nguru river floodplains in Northeastern Nigeria. The study utilizes a combination of quantitative and qualitative data from primary and secondary sources. The data for this study includes rainfall data collected from the Nigerian Meteorological Agency and the Hadejia-Jama'are River Basin Development Authority from 2000 to 2015, published reports and studies. The study discovers that the region experiences two distinct peaks of rainfall throughout the year, resulting in a bimodal distribution. However, the rainfall pattern exhibits high variability between years, which can have implications for agricultural practices and food security. The study also emphasized the importance of understanding the geology, aquifers, and recharge mechanisms in managing water resources effectively. The dynamics between rainfall and the water table in the floodplains were highlighted as essential for sustainable resource management and adaptation strategies. The findings contribute to a better understanding of the relationship between rainfall and water availability in wetland ecosystems and have implications for wetland management, conservation, and sustainable resource utilization. The probabilistic modeling and forecasting framework employed in this research offer decision-makers a systematic approach to managing water resources, evaluating risks and uncertainties, and guiding planning activities amidst a changing climate and dynamic wetland ecosystem.* |

*Keywords: Floodplains, Rainfall Patterns, Probabilistic Forecasting, Water Table Dynamics, Wetland Management*

1. INTRODUCTION

Sub-Saharan Africa is a region characterized by diverse ecosystems and climates, and rainfall plays a crucial role in shaping its environmental and socio-economic dynamics. Rainfall patterns vary significantly across the region, influencing various aspects such as agriculture, water resources, and ecosystem functioning. Sub-Saharan Africa exhibits a wide range of rainfall patterns due to its geographical and climatic diversity. The region is known for its dependence on agriculture, making rainfall a critical factor for food security and livelihoods. Rainfall patterns in Sub-Saharan Africa are influenced by various climatic phenomena, such as the Inter-Tropical Convergence Zone (ITCZ), El Niño-Southern Oscillation (ENSO), and the African Easterly Jet. These climatic drivers interact with local topography and land cover, leading to spatial and temporal variations in rainfall distribution (Anyamba & Tucker, 2005).

The spatial variability of rainfall in Sub-Saharan Africa is characterized by distinct climatic zones. The equatorial region, close to the equator, experiences high and relatively evenly distributed rainfall throughout the year. As one moves away from the equator towards the Sahel region, rainfall becomes highly variable and exhibits a marked seasonality (Nicholson, 2013). The Sahel, known for its dry and semi-arid conditions, experiences a short rainy season typically occurring from June to September, with significant inter-annual variability.

The water table, defined as the depth below the land surface at which the ground is saturated with water, is a critical component of the hydrological cycle in Sub-Saharan Africa. The water table dynamics in the region are influenced by a combination of factors, including rainfall, evapotranspiration, land cover, soil properties, and geology. In areas with shallow water tables, the availability of groundwater can support agriculture, domestic water supply, and ecosystem functioning. In Sub-Saharan Africa, the water table exhibits significant spatial and temporal variations [21,22]. The spatial distribution is influenced by geological formations, such as aquifers and underlying bedrock, which determine the groundwater storage capacity. Moreover, variations in land cover, including vegetation density and land use practices, can affect water infiltration rates and subsequently impact the water table depth. Additionally, seasonal fluctuations in rainfall directly influence the recharge of aquifers and hence the water table dynamics (MacDonald & Bonsor, 2010; Tindimugaya, 2008).

The Hadejia-Nguru river floodplains is a vital ecological and socio-economic resource in the region. The wetland encompasses the floodplains of the Hadejia-Nguru rivers, covering an extensive area that supports a diverse range of flora and fauna. The interplay between rainfall and the water table in the Hadejia-Nguru river floodplains is of utmost importance for understanding its hydrological dynamics and ecological functioning. Therefore, understanding the relationship between rainfall and water availability, particularly in wetland ecosystems like the Hadejia-Nguru river floodplains, is of utmost importance for sustainable resource management and adaptation strategies. The objective of this study is to analyze the rainfall patterns and water table dynamics in the floodplains of the Hadejia-Nguru river. The present study would provide an in-depth analysis of the rainfall patterns and water table dynamics in the floodplains, in addition to enhancing understanding on their interrelationships and implications for wetland management and conservation.

* 1. **Theoretical Framework**

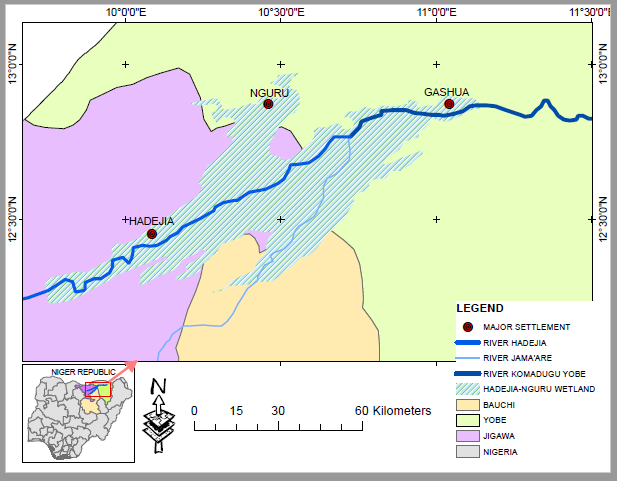
The theoretical framework that can support the findings regarding the probabilistic forecasts for rainfall and water levels in the Hadejia-Nguru river floodplains is the concept of probabilistic modeling and forecasting. Probabilistic forecasting is a statistical approach that accounts for uncertainties and provides a range of possible outcomes along with their associated probabilities. This framework allows decision-makers to make more informed decisions by considering the likelihood of different scenarios. The use of historical data on the number of rainy days for each month in the Hadejia-Nguru river floodplains enables the calculation of mean and standard deviation values. These statistical parameters are then utilized to generate probabilistic forecasts for rainfall. By assuming a normal distribution, confidence intervals for different levels of probability can be calculated, providing a range within which the likely number of rainy days falls with a certain level of certainty. This approach acknowledges the variability of rainfall patterns and accounts for both natural and anthropogenic factors that may influence the wetland's hydrological dynamics.

The theoretical framework of probabilistic modeling and forecasting has been widely applied in various fields, including hydrology, climate science, and risk assessment. It provides a robust methodology for incorporating uncertainties and generating forecasts that go beyond deterministic point estimates. The probabilistic forecasts presented in the study offer decision-makers valuable information to plan and adapt effectively to rainfall patterns and associated risks in the Hadejia-Nguru river floodplains. It is important to note that while the probabilistic forecasts based on historical data provide valuable insights, there are limitations to consider. Factors such as climate change, land-use changes, and other external drivers may impact the accuracy and reliability of the forecasts. Therefore, it is crucial to integrate these forecasts with other sources of information, expert knowledge, and ongoing monitoring to improve the accuracy and robustness of the predictions. Therefore, the theoretical framework of probabilistic modeling and forecasting would support this study findings through offering a systematic approach to understanding and predicting rainfall and water table dynamics in the Hadejia-Nguru river floodplains. Moreover, this would further provide decision-makers with valuable insights to manage water resources, assess risks and uncertainties, and guide planning activities in the context of a changing climate and dynamic wetland ecosystem.

* 1. **Hadejia-Nguru River Floodplain**

The Hadejia-Nguru floodplain is a vast and vital ecosystem located in Northeastern Nigeria is spanning over 2,500 km² across Jigawa, Yobe, and Borno states, the Hadejia-Nguru floodplain (HNF) is a crucial mosaic of wetlands, rivers, and drylands in northeastern Nigeria (Hollis & Adams, 1993). This intricate ecosystem supports rich biodiversity and sustains the livelihoods of over one million people (FAO, 2012). However, climate change, unsustainable practices, and inadequate management threaten its future (Abdullahi et al., 2019). This river floodplain’s dynamism stems from the confluence of the Hadejia and Jama'are rivers, creating a tapestry of permanent freshwater bodies, seasonally flooded plains, and even sand dunes (FAO, 2012). This diverse landscape harbors a wealth of flora and fauna, including migratory birds from Europe and Asia (IUCN, 2015). It is the lifeblood for over a million people, providing essential resources like water for agriculture and fish for food (Hollis & Adams, 1993). It also supports pastoralist livelihoods and fuelwood supply (Aminu-Kano et al., 2005).

Unfortunately, the Hadejia-Nguru floodplain faces formidable challenges. Climate change brings erratic rainfall patterns and droughts, jeopardizing water availability (Olagoke et al., 2022). Unsustainable practices like overgrazing, deforestation, and poor agricultural management degrade the ecosystem (Abdullahi et al., 2019). Additionally, inadequate water management and conservation efforts further exacerbate the situation (World Bank, 2012). The floodplain's significance demands immediate action. Sustainable practices, improved water management, and community-based conservation efforts are crucial (Aminu-Kano et al., 2005). By addressing these challenges, we can ensure this vital ecosystem continues to thrive for generations to come.



**Figure 1:** Map of Hadejia-Nguru River Floodplains, Nigeria

2. material and methods

The study utilizes a combination of quantitative and qualitative data from diverse sources. The rainfall data were collected from the Nigerian Meteorological Agency (NiMET) and the Hadejia-Jama'are River Basin Development Authority (H-JRBDA) whereas the remaining data were collected from published reports and studies. Historical rainfall data from 2000 to 2015 is analyzed to generate probabilistic forecasts for rainfall. The collected rainfall data was analyzed to generate probabilistic forecasts for rainfall in each month. The mean and standard deviation of the number of rainy days for each month were calculated based on the historical data. To conduct a probabilistic forecast for the Hadejia-Nguru river floodplains, the study analyzed the data for mean and standard deviation values for each month, which were used to generate the forecasts. The forecasts were presented as lower and upper bounds, indicating the range within which the actual water level or number of rainy days is expected to fall with a certain level of confidence.

Assuming a normal distribution, the number of rainy days in each month was modeled with a mean and standard deviation equal to the historical values. Using the mean and standard deviation values for each month, probabilistic forecasts were generated. A 95% confidence interval was considered for the forecasts. The upper and lower bounds of the confidence interval were calculated using the formula below:

Lower Bound = Mean - (z-score \* Standard Deviation)

Upper Bound = Mean + (z-score \* Standard Deviation)

A z-score of 1.96, corresponding to a 95% confidence level, was used in the calculations.

The probabilistic forecasts were interpreted based on general knowledge of wetlands and climate patterns. The lower and upper bounds in the forecasts represented the minimum and maximum expected values, respectively, for each month. The forecasts provided insights into the potential water level fluctuations and the likelihood of rainy days in both floodplains throughout the year. It is also pertinent to note that the forecasts were based on historical data from a relatively short period (2000-2015). These forecasts can inform decision-making processes, assess risks and uncertainties, and guide planning activities related to rainfall patterns and associated risks. This statistical model considered various climatic and hydrological factors to generate the probabilistic forecasts for the Hadejia-Nguru river floodplains, and can provide valuable information to decision-makers to plan and adapt effectively to rainfall patterns and associated risks.

3. results and discussion

The Hadejia-Nguru river floodplains is a significant wetland in Nigeria, providing habitat for diverse flora and fauna, and contributing to the livelihoods of local communities. One of the critical factors that influence the functioning of wetlands is rainfall. In this regard, understanding the distribution and trends of rainfall in the wetland is essential for effective planning and management.

1. **Rainfall Pattern in Hadejia-Nguru River Floodplains**

The study observed the rainfall distribution to be showing a bimodal distribution of rainfall in the Hadejia-Nguru floodplains from 2000 to 2015 (15 years), with two peaks in rainfall, one in the early part of the year and one in the later part of the year. This is consistent with the general rainfall pattern in the region, where rainfall is influenced by the monsoon winds from the Atlantic Ocean and the Sahara Desert. This study discovered that the floodplains experience an annual rainfall of between 1000 and 1500 mm with a cumulative annual rainfall amount between 3000 and 4000 mm.

**Figure 2:** Distribution of Rainy Days in Hadejia-Nguru River Floodplains

***Source:*** *H-JRBDA and NiMET*

Figure 2 shows that the Hadejia-Nguru floodplains experiences an annual mean number of rainy days of between 120 and 150 days. Importantly, there appears to be a downward trend in the number of days it rained each year. This could be due to climate change, or it could be due to natural variability. This result is in line with Okonkwo, Anuforom and Anyadike (2019) who found that the annual rainfall in the region had a high variability

In order to generate probabilistic forecasts for rainfall in each month, this study use historical data from historical rainfall data within the floodplains to calculate the mean and standard deviation of the number of rainy days for each month. The study assumes that the number of rainy days in each month follows a normal distribution with mean and standard deviation equal to the historical values (see Table 1 for the mean and standard deviation values). Based on these assumptions, this study generated probabilistic forecasts by specifying a probability distribution and interval.

**Table 1:** Mean and Standard Deviation of rainy days in Hadejia-Nguru

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| --- | --- | --- |
| **Month** | **Mean** | **Standard Deviation** |
| April | 0.89 | 3.58 |
| May | 23.31 | 4.08 |
| June | 29.75 | 0.44 |
| July | 31.00 | 0.00 |
| August | 31.00 | 0.00 |
| September | 27.13 | 4.12 |
| October | 6.00 | 10.72 |

***Source:*** *Computed by Authors*

The table 1 reveals distinct patterns in mean and standard deviation of monthly rainy days. April starts with a relatively dry period, marked by a mean of 0.89 rainy days and notable variability (standard deviation of 3.58). May witnesses a significant surge in rainy days, with a mean of 23.31 days and a more consistent pattern (standard deviation of 4.08). June and July represent the peak, with an average of 30 rainy days, showcasing remarkable stability with minimal deviations. August continues this trend with a mean of 31 rainy days and no deviation, emphasizing a consistent daily precipitation pattern. September sees a slight decline in mean (27.13) and a moderate standard deviation of 4.12, indicating increased variability. October stands out with a low mean of 6 rainy days, coupled with substantial variability (standard deviation of 10.72). These findings, offer a comprehensive overview of the temporal number of rainy days in Hadejia-Nguru, illustrating both the peak of the rainy season and the varying levels of predictability in different months.

1. **Water Table Dynamics in the Hadejia-Nguru River Floodplains**

Water table dynamics play a crucial role in the hydrological processes of floodplain systems. In the context of the Hadejia-Nguru river floodplains, understanding the geology, aquifers, and recharge mechanisms is essential for managing water resources effectively. The geology of the Hadejia-Nguru river floodplains consists primarily of sedimentary deposits (Abaje, Usman and Abubakar, 2018). These deposits are predominantly composed of alluvial and fluvial materials, including sands, silts, and clays, whereas the geology of the floodplain influences the behavior of aquifers and the movement of water within the system (Abaje, Usman and Abubakar, 2018). The presence of clay layers, for example, can act as barriers to vertical water movement, affecting the water table dynamics (Jimoh, Adeyemo and Lar, 2018; Abaje, Usman and Abubakar, 2018).

Aquifers in the Hadejia-Nguru river floodplains play a significant role in controlling the water table dynamics. An aquifer refers to a geological formation capable of storing and transmitting water. In these floodplains, the primary aquifers are typically unconfined or shallow aquifers, located within the alluvial deposits. The water table, representing the upper boundary of the saturated zone, fluctuates in response to various factors such as precipitation, evapotranspiration, and groundwater extraction. Recharge refers to the process by which water replenishes aquifers. In the Hadejia-Nguru river floodplains, several mechanisms contribute to recharge. The primary sources of recharge include direct infiltration from precipitation, riverbank infiltration, and lateral flow from surrounding upland areas (Yusuf, Lawal and Salami, 2016). Precipitation in the form of rainfall is a vital driver of recharge, particularly during the rainy season when surface runoff infiltrates the subsurface. Riverbank infiltration occurs when river water seeps through the riverbanks and replenishes the adjacent aquifers.

Additionally, the floodplains receive lateral flow from the surrounding upland areas. This process occurs when excess water from higher elevation areas flows laterally and recharges the floodplain aquifers. The presence of permeable channels or fractures in the underlying geology can enhance this lateral flow and contribute to recharge. However, the floodplains are susceptible to losses through evapotranspiration, particularly in areas with shallow water tables and high vegetation cover. The water table dynamics in the Hadejia-Nguru river floodplains are closely linked to the rainfall patterns and the hydrological processes within the wetland ecosystem.

The wetland's water table refers to the level at which the ground becomes saturated with water. It is influenced by various factors, including the amount and distribution of rainfall, evapotranspiration rates, soil properties, and geological formations. During the peak rainy season, the water table in the Hadejia-Nguru river floodplains rises, as rainfall infiltrates the ground and contributes to groundwater recharge. Studies have shown that the wetland experiences high water table levels during the rainy season, with the upper bounds often reaching the maximum level of 31 meters (Gado & Nwankwoala, 2017; Muhammad, Adeyemo and Lar, 2018; Okunlola, Ojo and Adewumi, 2019). The wetland's hydrological regime is characterized by a slow recession of water levels during the dry season, as evapotranspiration rates increase and the amount of rainfall decreases.

The interrelationship between rainfall and the water table in the Hadejia-Nguru river floodplains is crucial for sustaining its ecological integrity and supporting various wetland-dependent activities. The fluctuations in the water table influence the availability of suitable habitats for wetland species, the productivity of wetland agriculture, and the availability of water resources for domestic and livestock use. Water table dynamics in the Hadejia-Nguru river floodplains are influenced by the geology, aquifers, and recharge processes within the system. Understanding the geologic characteristics of the floodplains helps to comprehend the behavior of aquifers and the movement of water. Aquifers, primarily unconfined or shallow in nature, play a vital role in controlling the water table dynamics. Recharge occurs through direct infiltration, riverbank infiltration, and lateral flow from surrounding upland areas, while evapotranspiration poses a challenge to maintaining water levels. Further research and monitoring are crucial to better manage and sustain water resources in these floodplain systems.

1. **Probabilistic Forecasts for the Hadejia-Nguru River Floodplains**

Figure 3 shows the probabilistic forecasts for the Hadejia-Nguru river floodplains from 2000 to 2015, the study observed the lower and upper bounds for each month. It is important to note that the figure only presents the numerical values for the lower and upper bounds without any specific context or explanation of what these values represent.

**Figure 3:** Probabilistic forecast for Hadejia-Nguru river floodplains

***Source:*** *Computed by Authors*

This forecast is based on a statistical model that takes into account various climatic and hydrological factors. The forecasts are presented as lower and upper bounds for each month, indicating the range within which the actual water level is expected to fall with a certain level of confidence. The figure 3 shows that the wetland experiences variations in water levels throughout the year, as indicated by the different ranges of values for each month. The lower and upper bounds likely represent the minimum and maximum expected water levels, respectively, during the specified months. In April, the lower bound is -6.13, indicating that the water level could potentially drop below sea level. The upper bound is 7.91, suggesting that the water level could rise to approximately 7.91 meters. This indicates that April may experience relatively low water levels compared to other months, but it is important to consider other factors that may influence the wetland's water levels. Moving to May, the lower bound jumps to 15.32, suggesting a significant increase in water level compared to April. The upper bound is 31.30, indicating a further potential increase. This implies that May is likely to be a wetter month with higher water levels in the wetland.

Interestingly, the months of June and July both have upper bounds of 30.61 and 31, respectively, indicating consistent high-water levels during this period. August and September also have upper bounds of 31, suggesting that the wetland is expected to remain at or near its peak water level during these months. September, however, has a higher lower bound (19.06) compared to August, suggesting the possibility of a slightly lower water level as the wet season progresses. In October, the wetland experiences a wider range of water level possibilities. The lower bound is -15.01, indicating a potential significant drop in water level, possibly even below sea level. The upper bound is 27.01, suggesting that there could still be a relatively high-water level during October.

The probabilistic nature of these forecasts is important to consider, as it allows for a more nuanced understanding of the likely outcomes. While point forecasts provide a single estimate of the expected water level, probabilistic forecasts provide a range of possible outcomes, along with the associated probabilities of each outcome. This can help decision-makers to better plan for potential water level fluctuations and adapt to changing conditions. One limitation of the findings in the figure 3 is that it only provides forecasts for a relatively short period of time (2000-2015). While this may be sufficient for some purposes, it is important to consider longer-term trends and patterns in water levels in order to make more robust forecasts. Additionally, the accuracy of the forecasts may be affected by various factors, such as changes in land use or climate patterns, which may not be fully captured by the statistical model used to generate the forecasts.

4. Conclusion

The analysis of rainfall patterns in the Hadejia-Nguru river floodplains from 2000 to 2015 reveals a bimodal distribution with two peaks in rainfall, one in the early part of the year and one in the later part of the year. These floodplains experience an annual rainfall amount ranging between 1000 and 1500mm, with a cumulative annual rainfall between 3000 and 4000mm. The mean number of rainy days per year falls between 120 and 150 days, and there appears to be a downward trend in the number of rainy days over the studied period. Probabilistic forecasts generated based on historical data suggest variations in water levels throughout the year in the Hadejia-Nguru river floodplains. The forecasts provide lower and upper bounds for each month, representing the range within which the actual water level is expected to fall with a certain level of confidence. The analysis indicates that April generally experiences relatively low water levels, while May tends to be wetter with higher water levels. June, July, and August exhibit consistent high-water levels, and September may have slightly lower levels compared to August. October shows a wider range of possibilities, with the potential for significant drops or relatively high-water levels.

These probabilistic forecasts offer valuable insights for understanding water level fluctuations and can aid in decision-making processes, risk assessment, and planning activities. However, it is essential to consider the limitations of the study, such as the relatively short time frame analyzed (2000-2015) and the potential influence of factors not fully captured by the statistical model, such as land use changes and climate patterns. This study emphasizes that further research should aim to extend the analysis to longer-term trends and incorporate a comprehensive range of factors to enhance the accuracy and reliability of the forecasts. Based on the findings and conclusions of the study, the following recommendations are made:

1. There is need to conduct long-term monitoring of rainfall patterns, including the distribution of rainy days and cumulative annual rainfall, in the Hadejia-Nguru river floodplains. This will provide a more comprehensive understanding of the trends and variations in rainfall over time and help identify potential shifts or changes in the patterns.
2. There is need for assessment of the potential impact of climate change on rainfall patterns in the region through investigating whether the observed downward trend in the number of rainy days is linked to climate change or natural variability. This analysis can help in developing strategies to mitigate and adapt to climate change effects on the wetland ecosystem.
3. There is need to enhance the statistical models used to generate probabilistic forecasts for water levels through considering and incorporating additional variables such as land use changes, climate indices, or other relevant factors that may influence water levels. This will improve the accuracy and reliability of the forecasts, enabling better-informed decision-making.
4. There is need to engage local communities, water resource managers, and other stakeholders to raise awareness about the findings and implications of the study. Collaborate with them to develop adaptive strategies and management plans that consider the potential water level fluctuations and associated risks. Encourage the incorporation of these forecasts into decision-making processes related to water resource management and land use planning.
5. There is need for promotion of integrated water resources management practices in the Hadejia-Nguru river floodplains. This approach considers the interconnectedness of water, land, and ecosystems and aims to balance competing water demands while maintaining the health and sustainability of the wetland. Incorporate the probabilistic forecasts into water allocation decisions, flood management strategies, and ecological conservation efforts.
6. There is need for more funding and support to all ongoing research and monitoring efforts to further understand the complex interactions between rainfall patterns, water levels, and ecosystem dynamics in the Hadejia-Nguru river floodplains. Encourage interdisciplinary collaborations between scientists, hydrologists, ecologists, and policymakers to address knowledge gaps and facilitate evidence-based decision-making.

By implementing these recommendations, stakeholders can make more informed decisions, improve water resource management, and enhance the resilience of the Hadejia-Nguru river floodplains to changing rainfall patterns and associated risks.

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