



DEVELOPMENT OF RATING CURVE FOR RIVER NGADDA

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ARTICLE INFORMATION

Submitted: 25th July 2024
Revised: 5th December 2024
Accepted: 3rd February 2025

Keywords:

Flow regime
Seasonal variation
Uncertainty analysis
Water resources
Management

ABSTRACT

Accurate river discharge estimation is critical for sustainable water resource management and infrastructure design, especially in areas where data scarcity is a major concern. This study addresses this issue by developing a rating curve for the Ngadda River in Borno State, Nigeria. The lack of continuous discharge data and reliable rating curves has historically hindered water resource project planning in the region. Leveraging stage-discharge rating curves and utilizing an optimization-based technique with Excel solver, curve parameters were calibrated to accurately depict the hydraulic relationship between river stage and discharge. The analysis of discharge data at Logojeri and Maiduguri gauging stations revealed seasonal changes in river flow, emphasizing the importance of continuous monitoring for effective water resource management. Correlation analysis between actual and predicted discharge confirmed the reliability of the developed rating curve, while uncertainty analysis revealed insights into potential errors associated with the discharge estimation. The developed rating curve which is for the two specific gauging stations (Maiduguri and Logojeri), provides a useful tool for converting stage data into discharge values, thereby assisting with water resource planning and decision-making. It is therefore urged for ongoing monitoring efforts and the installation of monitoring tools to modify and improve the developed rating curve's ability to capture the dynamic hydrological behavior of the Ngadda River.

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1.0 Introduction

Navigating the complex dynamics of water resource management demands precision, yet the scarcity of reliable data often casts a shadow over planning endeavors. In the center of Jere and Maiduguri where River Ngadda is a beacon of hope for many, this challenge is particularly felt. The absence of continuous discharge data and dependable rating curves has long hindered effective water resource project planning in the region. Accurate stream flow records are indispensable in hydrologic information systems, water resources management, disaster warning and validation of models at catchment and basin-wide scales. These discharge records are obtained by converting the measurement of the river stage using stage–discharge relationships (Negatu *et al.*, 2022). As additional data are collected, the rating curve can be refined to more accurately reflect the relation (Alfa *et al.*, 2018). These curves can be simple or complex depending on the flow regime and the characteristics of the cross section and stretch of a river (Yang and Lee, 2017). River flow is a critical requirement for surface water resources assessment, planning and management (Wara *et al.*, 2019). Engineering designs and hydrological studies for water supply development projects rely heavily on the accuracy of the river flow data obtained from rating curve (Othman *et al.*, 2019). Rating curve depends on hydraulic characteristics of the stream channel, flood plain and varies over time at almost every station (Hamilton *et al.*, 2019). This study aims to close the gap by developing a new rating curve for River Ngadda. With a focus on improving discharge estimation accuracy, our goal is to provide policymakers and stakeholders with an essential tool for making informed decisions about water resource management in Maiduguri and its surroundings. We hope to understand the complexity of River Ngadda's hydrology by thorough data collecting and analysis as well as the use of an Excel solver. By doing so, we want to improve our understanding of its

flow dynamics while also laying the groundwork for a more resilient and sustainable approach to water resource planning in the region.

2. Material and Methods

2.1 Study Area

River Ngadda stretches along Jere and Maiduguri in Borno State, Nigeria. Located in the northeastern part and experiences distinct dry and wet seasons (Bwala, 2021). River Ngadda situated on latitude 10° 24' 42"N and longitude 13° 42' 10"E (Figure 1), originates from the convergence of Rivers Yedzaram and Gombole at Sambisa swamp. It flows as River Ngadda into Alau dam, traversing the Maiduguri metropolis and eventually discharging into Jere Bowl Rice Scheme (Obroh and Sambo, 2022). The river plays a vital role in various human activities, including fishing, irrigation for vegetables, brick making and serving as a water source for residences along its banks. People use it as a source of water for washing and animals rely on it for drinking water (Abdulhakim et al., 2014).

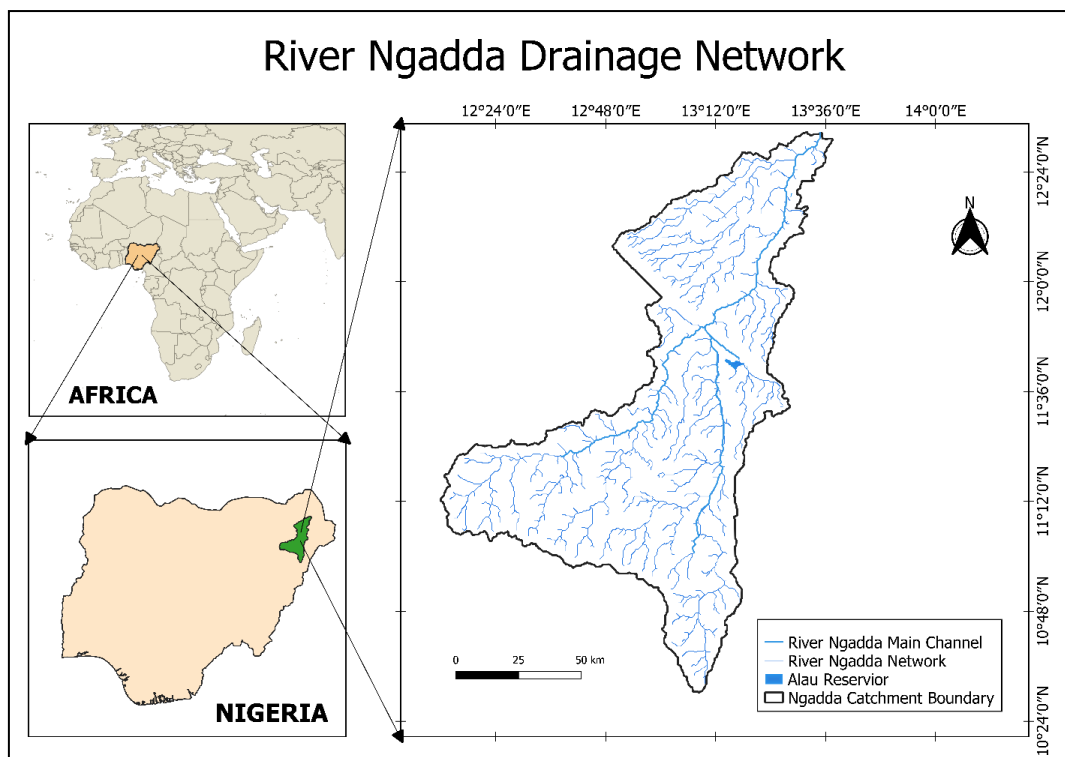


Figure 1: Map of Study Area

2.2. Data Collection

The study focuses on Maiduguri situated in Borno State, Nigeria, where River Ngadda plays a pivotal role in various activities. The study stems from the pressing issue of insufficient discharge data for the river, prompting a comprehensive approach to data collection and analysis. In this study, a time series of river discharge records was acquired from the Chad Basin Development Authority. The dataset's temporal resolution is a daily time step which constitutes of readings from two key stations and spans from August 6, 1977 to March 31, 1978 for Logojeri station and that of Maiduguri station spans from August 1, 1977 to November 30, 1977. The recorded data consisted of stage measurements and corresponding discharge measurements. Prior to this analysis, the acquired time series underwent minimal pre-processing where high peaks and lows were critically checked.

2.3 Utilization of Stage-discharge Rating Curves

The study employed stage-discharge rating curves, treating discharge as a unique function of the stage. The discharge calculation followed a power curve equation ensuring a robust representation of the stage-discharge relationship. The equation provided a quantitative framework to estimate discharge based on observed stage, addressing the central challenge of limited discharge data. The power curve equation is given as:

$$Q = c(h - a)^n \quad (1)$$

where, Q represents discharge in cubic meters per second (m³/s), H is the observed stage in meters above sea level, h is the gauge height of zero flow in meters above sea level, and c, h, and n are calibration coefficients crucial for accurately depicting the hydraulic relationship.

2.4 Calibration Coefficients and Excel Solver

Calibration coefficients (c, h, and n) were determined using a trial-and-error procedure, employing randomly assumed values to optimize the calibration process. The Excel solver, a powerful optimization tool played a very important role in streamlining this trial-and-error process enhancing efficiency and accuracy in obtaining the calibration coefficients. The use of Excel functions facilitated the determination of discharge error by comparing actual discharge with estimated discharge.

3. Results and Discussion

3.1 Fitting of Discharge Logojeri and Maiduguri Gauging Stations

The discharge data at Logojeri and Maiduguri gauging stations were fitted using trial-and-error, revealing insightful patterns. The rating curve was used to transform the stage measurement into discharge. The analysis of discharge data at Logojeri gauging station revealed interesting patterns in the seasonal variation of the River Ngadda. The fitted discharge curves, as shown in Figures 2 and 3, highlighted a significant decrease in discharge commencing in November. This observation indicates a notable change in the flow regime during this period. The understanding of such variations is crucial for effective water resource management and infrastructure planning, emphasizing the importance of continuous monitoring. This seasonal pattern aligns with typical hydrological cycles but emphasizes the need for comprehensive data to capture and predict variations accurately. The observed discharge trends will help in refining future water resource models and inform decision-making for stakeholders.

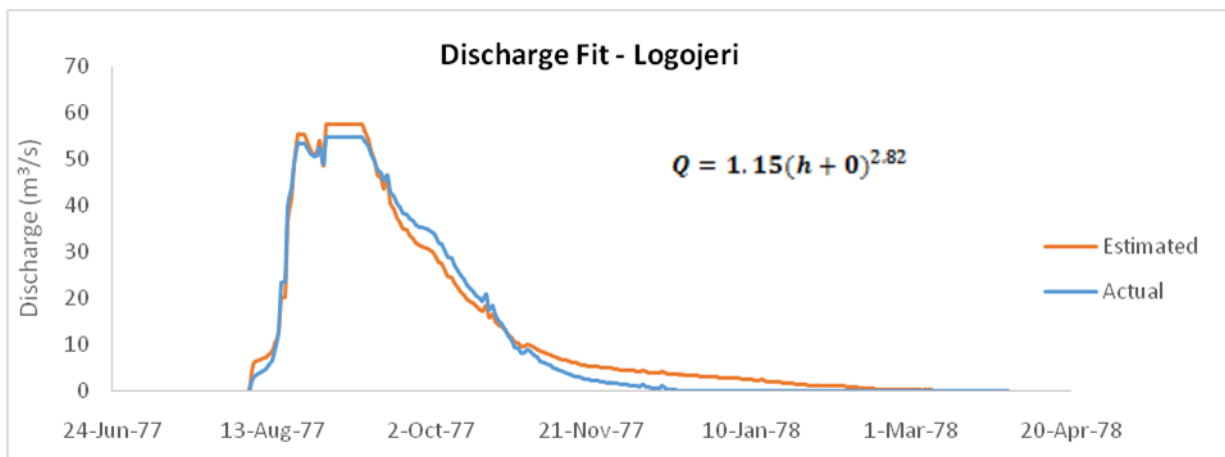


Figure 2: Logojeri station discharge calibration

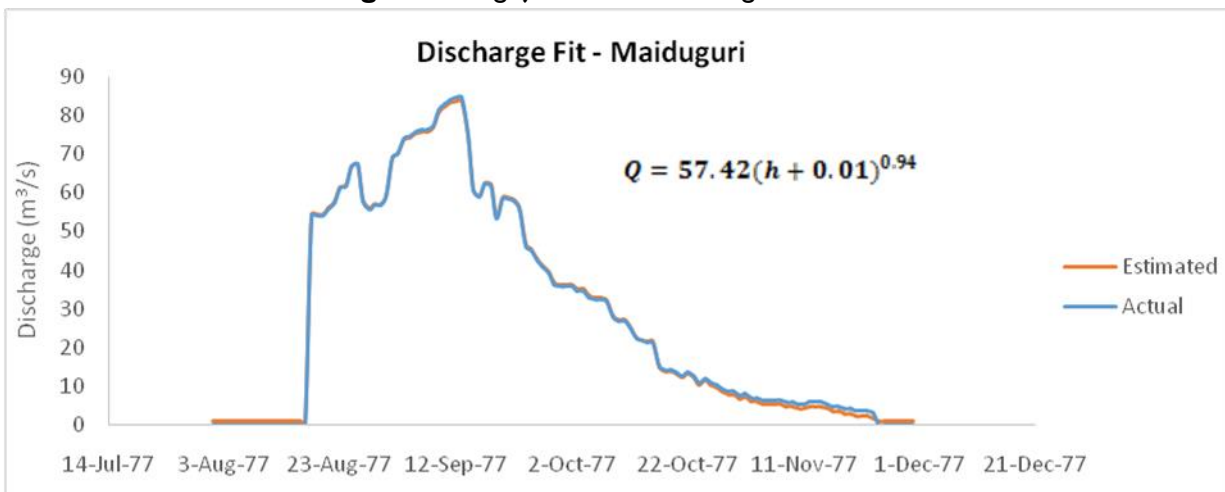


Figure 3: Maiduguri station discharge calibration

3.2 Correlation of Dataset

Correlation analysis between actual and predicted discharge at both Logojeri and Maiduguri gauging stations provided insights into the reliability of the developed rating curve. The linear relationship observed from August to November suggests a consistent predictive capability of the model during this crucial period. However, further analysis and consideration of other factors affecting discharge, such as precipitation patterns and land use changes, would enhance the robustness of the rating curve for a broader range of conditions. Figure 4 visually represents this correlation.

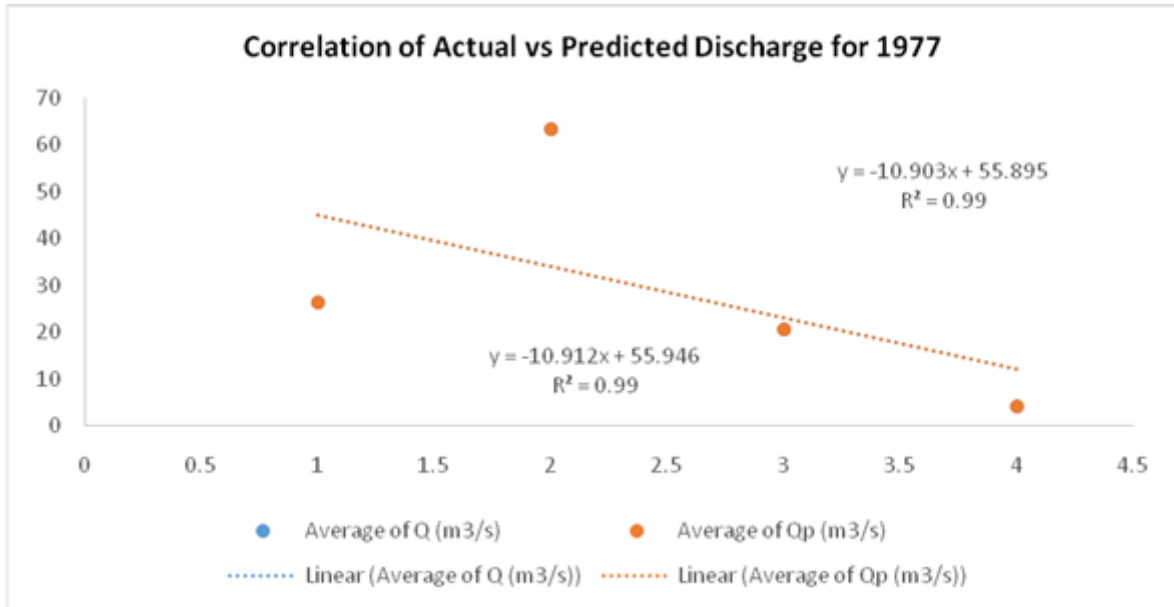


Figure 4: Actual vs predicted discharge for Maiduguri and Logojeri gauge stations

3.3 Stage-discharge Rating Curve

The plotted stage-discharge rating curves (Figures 5 and 6) visually represent the culmination of the study's efforts. The relatively linear trend for Maiduguri and the fluctuating pattern for Logojeri highlight the unique hydraulic characteristics of each gauging station. The developed rating curves provide a valuable tool for transforming readily available stage data into discharge, addressing the historical lack of discharge data for the river Ngadda. These curves form a basis for future water resource planning and engineering designs in the region.

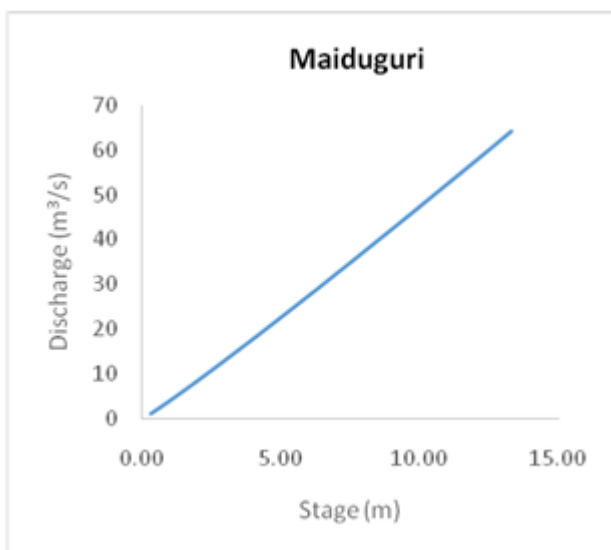


Figure 5: Rating curve for Maiduguri station

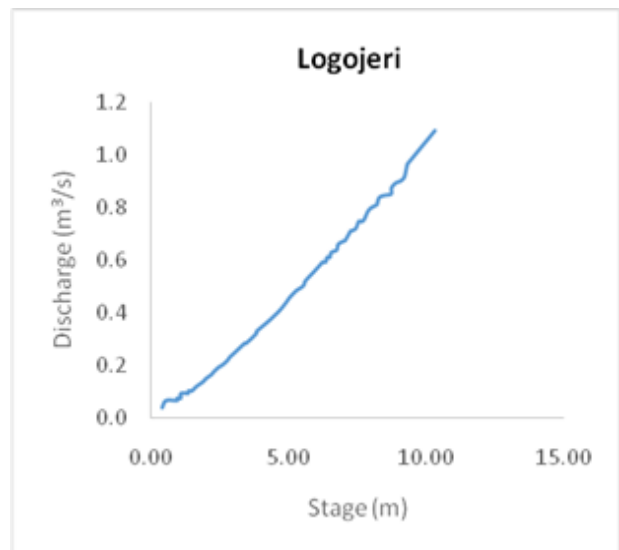


Figure 6: Rating curve for Logojeri station

3.4 Uncertainty Analysis

To assess the confidence level and potential errors, uncertainty analysis was conducted. Tables 1 and 2 presents the uncertainty analysis results for Logojeri and Maiduguri gauge stations. The results provided important statistical characteristics of the discharge data for River Ngadda. For Logojeri station, the mean values were clustered around zero suggesting a distribution centered at a baseline which reflects the peculiar flow dynamics of the river. The low standard error values indicate a high degree of precision in mean estimates crucial for capturing the nuanced variations in discharge. The median and mode proximity implies symmetry in the distribution aligning with the seasonal patterns of the river's behavior as observed in the study. Positive kurtosis and skewness values hint at potential outliers and a right-skewed pattern mirroring the intermittently intense flow events that characterize the River Ngadda. The range, minimum and maximum values offer context for the spread and boundaries of the dataset considering the diverse hydraulic conditions encountered during gauge measurements. Similarly, for Maiduguri station, the statistical patterns echo those of Logojeri emphasizing the centered distribution with moderate variability. The low standard error values underscore the precision in mean estimates crucial for understanding the river's complex behavior. Positive kurtosis and skewness continue to suggest a right-skewed distribution aligning with the unique hydraulic characteristics of River Ngadda. Altogether, these statistical measures when contextualized within the specific dynamics of River Ngadda enrich our understanding of the discharge data, providing a foundation for robust decision-making in water resource management and infrastructure planning. The calculated confidence intervals provide a range within which the actual discharge is likely to fall. These results serve as a critical component for decision-makers and water resource managers guiding them in understanding the potential variations and uncertainties associated with the developed rating curve.

Table 1: Uncertainty analysis for Logojeri gauge station

Logojeri			
<i>Confidence Interval Plus</i>		<i>Confidence Interval Minus</i>	
Mean	2.62×10^{-14}	Mean	1.69×10^{-14}
Standard Error	0.11	Standard Error	0.10
Median	-3.41	Median	-3.22
Mode	-3.85	Mode	-3.64
Standard Deviation	7.17	Standard Deviation	6.77
Sample Variance	51.47	Sample Variance	45.86
Kurtosis	4.22	Kurtosis	4.22
Skewness	2.25	Skewness	2.25
Range	31.88	Range	30.09
Minimum	-3.85	Minimum	-3.64
Maximum	28.03	Maximum	26.45

Table 2: Uncertainty analysis for Maiduguri gauge station

Maiduguri			
<i>Confidence Interval Plus</i>		<i>Confidence Interval Minus</i>	
Mean	-2.17×10^{-14}	Mean	5.39×10^{-15}
Standard Error	0.12	Standard Error	0.11
Median	-3.54	Median	-3.30
Mode	-3.54	Mode	-3.30
Standard Deviation	7.87	Standard Deviation	7.35
Sample Variance	61.94	Sample Variance	53.97
Kurtosis	5.00	Kurtosis	5.00
Skewness	2.41	Skewness	2.41
Range	39.35	Range	36.73
Minimum	-3.54	Minimum	-3.30
Maximum	35.81	Maximum	33.43

4. Conclusion

The development of the rating curve equation in this study represents a significant stride in addressing the persistent challenge of scarce discharge data for River Ngadda. The equation, specifically crafted for Logojeri and Maiduguri stations, offers a practical solution for transforming readily available stage data into discharge values, providing a valuable resource for water resource management and infrastructure planning. The distinct characteristics observed in the rating curves of Maiduguri and Logojeri stations contribute nuanced insights into the behavior of River Ngadda. Maiduguri's rating curve, marked by a linear trend, signifies a consistent discharge pattern, while Logojeri's curve exhibits fluctuations, indicative of its unique hydraulic dynamics. These variations underscore the importance of site-specific considerations in developing accurate and reliable rating curves. The study leveraged an optimization-based Excel solver for estimating the rating curves, showcasing its efficiency in predicting curve parameters with precision. The application of Excel solver not only streamlines the process but also eliminates the need for a time-consuming trial-and-error approach, enhancing the overall robustness of the developed rating curve. Quantitative and qualitative assessments of the performance of Excel solver underscore its promise as a reliable tool for predicting parameters, further emphasizing its potential utility in similar hydrological studies. The study advocates for the continued utilization of Excel solver in advancing the accuracy of rating curves and highlights its role in reducing uncertainties associated with stage-discharge relationships. The research outcomes reinforce the paramount importance of routine activities, including stage-discharge measurements, flood marking, and vegetation density surveying, in ensuring the continuous improvement of rating curves. The seasonally varying discharge patterns observed in River Ngadda underscore the necessity for ongoing monitoring to capture dynamic changes in flow regimes and maintain the relevancy of the developed rating curve. As the uncertainties identified in the analysis pave the way for future research, it is imperative to recognize the study's contribution to advancing the understanding of River Ngadda's discharge dynamics. The results not only underscore the significance of continuous monitoring but also guide forthcoming research and data collection efforts, aiming to further refine and enhance the accuracy and applicability of the developed rating curve in the dynamic context of River Ngadda. The continuation of routine activities for continuous improvement such as stage-discharge measurements, flood marking, and vegetation density surveying. These activities play a foundational role in data collection and contribute to refining and enhancing the confidence of the rating curves over time. Continuous, consistent monitoring ensures that the rating curve remains adaptive to changing environmental conditions and reliably represents the river's behavior. The final recommendation advocates for the development and implementation of comprehensive monitoring strategies. These strategies should encompass both routine activities and specialized observations, ensuring a holistic approach to data collection. Such comprehensive monitoring strategies adapt to changing environmental conditions and incorporate evolving insights into the river's hydraulic behavior. The aim is to establish a robust and adaptive framework for continuous improvement in understanding river Ngadda's discharge dynamics.

References

- Abdulhakim, A., Toyosi, I., Addo, S. and Ebenezer, A. 2014. Water quality assessment of River Ngadda, northeastern Nigeria. *Elixir Aquaculture*, 76: 28716–28719.
- Alfa, Ml., Adie, DB., Ajibike, MA. and Mudiare, OJ. 2018. Development of rating curve for Ofu River at Oforachi hydrometric station. *Nigerian Journal of Technological Development*, 15(1): 1-14. <https://doi.org/10.4314/njtd.v15i1.3>
- Bwala, M. 2021. Impact of irrigational runoff on fish biodiversity in river Ngadda , Maiduguri – Borno state. *Nigerian Journal of Pure and Applied Sciences*, 34(1): 3981-3988. <https://doi.org/10.48198/NJPAS/20.B04>
- Hamilton, SE., Watson, M. and Pike, RG. 2019. The Role of the Hydrographer in Rating Curve Development. *Confluence: Journal of Watershed Science and Management*, 3(1): 1-15. <https://doi.org/10.22230/jwsm.2019v3n1a11>
- Negatu, TA., Zimale, FA. and Steenhuis, TS. 2022. Establishing stage–discharge rating curves in developing countries: Lake Tana Basin, Ethiopia. *Hydrology*, 9(1). <https://doi.org/10.3390/hydrology9010013>

Obroh, OG. and Sambo, G. 2022. Flood vulnerability mapping of River Ngadda using geospatial and remote sensing techniques Maiduguri metropolis, Borno State. *Journal of global ecology and environment*, 14(4): 44–58. <https://doi.org/10.56557/jogee/2022/v14i47453>

Othman, NY., Abd Saleh, Z. and Omran, ZA. 2019. Development of Stage – Distance – Discharge Relationship and Rating Curve using Least Square Method. *Civil Engineering Journal*, 5(9): 1959-1969. <https://doi.org/10.28991/cej-2019-03091385>

Wara, C., Thomas, M., Mwakurya, S. and Katuva, J. 2019. Development of river rating curves for simple to complex hydraulic structure based on calibrated HEC-RAS hydraulic model, in Kwale, Coastal Kenya. *Journal of water resource and protection*, 11(4): 468–490. <https://doi.org/10.4236/jwarp.2019.114028>.

Yang, C. and Lee, KT. 2017. Analysis of flow-sediment rating curve hysteresis based on flow and sediment travel time estimations. *International Journal of Sediment Research*, 33: 171-182. <https://doi.org/10.1016/j.ijsrc.2017.10.003>.