

Analysis of Spatial Relationship Between Groundwater Potential Zones and Borehole Yields in Adamawa Sub-Catchment of the Upper Benue River Basin, Northeastern Nigeria

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Abstract

The sustainable provision of water resources is a critical challenge in many parts of Nigeria, particularly in semi-arid and rapidly developing regions like the Adamawa sub-catchment of the Upper Benue River Basin. Consequently, the accurate delineation of Groundwater Potential Zones (GWPZ) is paramount for effective water resource management and the sustainable siting of boreholes to prevent failures, which are a common issue in areas with poor groundwater prospects. This research, therefore, focuses on the Adamawa sub-catchment to establish the spatial relationship between predicted Groundwater Potential Zones and the actual yields obtained from existing boreholes. In this study stratified and purposive sampling techniques were employed for sampling boreholes. Representative spread of 414 borehole data cutting across the entire sub-catchment were selected and used for validation. For the production of groundwater potential zones map various thematic maps of individual criterion were integrated through overlay analysis. The yields of existing boreholes and the values produced from the groundwater potential zone map were correlated using Pearson correlation analysis. The overlay analysis shows that 78.20% of the boreholes fall within groundwater potential zones that correspond to their observed yields, indicating a high level of spatial agreement between predicted potential and actual performance. This suggests that the geospatial modeling approach used to delineate groundwater potential zones is largely effective in capturing the dominant controls on groundwater occurrence within the Adamawa sub-catchment. In practical terms, most high-yield boreholes are located in high-potential zones, while low-yield boreholes tend to fall within low-potential areas. Such a level of agreement is generally considered satisfactory in groundwater studies, given the inherent heterogeneity of subsurface conditions. However, despite the overall strong relationship, 21.8% of boreholes did not correspond to their mapped groundwater potential zones, which is not unusual in groundwater studies. In addition, the result of Pearson moment correlation analysis revealed R is positive 0.782. It is imperative to note that the value of R is meant to show the direction and strength of the relationship between the yields of existing boreholes in the sub-catchment and the groundwater potential map produced. The relationship is a positive, meaning that as groundwater potential increases borehole yield increases correspondingly. The strength of the relation is strong ($R = 0.782$). The study concluded that there is strong positive relationship between groundwater potential and the existing borehole yields in Adamawa sub-catchment. Some recommendations were also proposed for both practitioners and researchers.

Keywords: Groundwater Potential, Borehole Yield, Spatial Relationship, Correlation, Adamawa State, Upper Benue River Basin.

Introduction

Groundwater is a major source of freshwater reserve used by millions of people in both rural and urban settings in many regions of the world. According to Roy et al. (2022) as cited by Diriba et al. (2024), groundwater resource is very vital and important to global economic growth and food security. However, in recent times there has been a rising trend of over-reliance on groundwater resources due to increase in population as well as industrialization amongst other factors thus, exerting significant pressure on this resource (Arulbalaji et al., 2019).

The sustainable provision of water resources is a critical challenge in many parts of Nigeria, particularly in semi-arid and rapidly developing regions like the Adamawa sub-catchment of the Upper Benue River Basin. Groundwater remains a vital, yet often over-exploited, resource for domestic, agricultural, and industrial use in this area, especially given the increasing impact of climate variability on surface water availability (Oruonye et al., 2023). Consequently, the accurate delineation of Groundwater Potential Zones (GWPZ) is paramount for effective water resource management and the sustainable siting of boreholes to prevent failures, which are a common issue in areas with poor groundwater prospects (Adaviruku et al., 2023).

Groundwater potentiality refers to the viability and possibility of an area to be an aquifer that can be harnessed for groundwater extraction (Adaviruku et al., 2023). It is the likelihood of groundwater being found in commercial quantity in an area (Rahmati et al., 2016). According to Ayadi et al. (2025); Adaviruku et al., 2023), groundwater potential involves the accurate measurement by estimation and prediction of the nature of groundwater that are essential for the efficient exploitation and management of groundwater resources. Worthy of note is that groundwater varies across the space and over time therefore, necessitating a more thorough study respect to its potentiality and spatial distribution. Groundwater potential determines how prolific or not a borehole will be (Yohana et al., 2023; Olusegun et al 2021).

This research, therefore, focuses on the Adamawa sub-catchment to establish the spatial relationship between predicted Groundwater Potential Zones and the actual yields obtained from existing boreholes. Previous studies in related Nigerian basins have successfully employed Geospatial Techniques, including the integration of thematic maps like geology, rainfall, Digital Elevation Models (DEM), and land use/land cover (LULC) data, to delineate GWPZs (Adaviruku et al., 2023). However, a direct, localized validation of these potential zones against actual borehole performance data within the specific Adamawa sub-catchment remains a necessary area of investigation to refine exploration strategies.

The aim of this study is to analyze the spatial relationship between groundwater potential zones and existing borehole yields using geospatial techniques, with a view to evaluating the effectiveness of groundwater potential mapping for predicting borehole productivity. The findings will offer crucial insights for water resource managers, helping to optimize the location and expected yield of future boreholes, thereby enhancing water security and sustainable development in the region.

Statement of the Research Problem

Groundwater remains a critical source of domestic and agricultural water supply in the Adamawa sub-catchment of the Upper Benue River Basin, yet borehole performance across the area is highly variable and often unpredictable (Joshua *et al.*, 2023). Despite the increasing application of geospatial techniques to delineate groundwater potential zones, many drilled boreholes still yield low or unsustainable discharge, leading to wasted financial resources and persistent water scarcity in some communities (Sahabo, 2025). This situation suggests a possible disconnect between mapped groundwater potential and actual borehole productivity, which may arise from inadequate integration of hydrogeological factors, data limitations, or poor validation of predictive models. Furthermore, existing studies in the region have largely focused on groundwater potential mapping without rigorously comparing these outputs with observed borehole yield data. As a result, the reliability of groundwater potential maps as decision-support tools for borehole siting remains uncertain. Therefore, there is a need to systematically evaluate the spatial relationship between groundwater potential zones and existing borehole yields in the Adamawa sub-catchment to enhance the accuracy of groundwater exploration and improve water resource management in the basin.

Materials and Methods

Adamawa State is part of a sub-catchment of the upper Benue River basin located in the North Eastern part of Nigeria. It lies between Latitudes 07° 00' 00" and 11° 00' 00" North of the Equator and Longitudes 11° 15' 00" and 13° 30' 00" East of the Greenwich Meridian (Figure 1). It shares boundary with Taraba State to the south-west, Gombe State to North-west and Borno state to the North. The State has an international boundary with the Republic of Cameroon along its eastern side. It has a land area of about 38,741 km² (Adebayo, 1997). The sub-catchment will encompass the corridor of river Benue flood plain (which is the major river that drains through the sub-catchment) as it traverses through the sub-catchment.

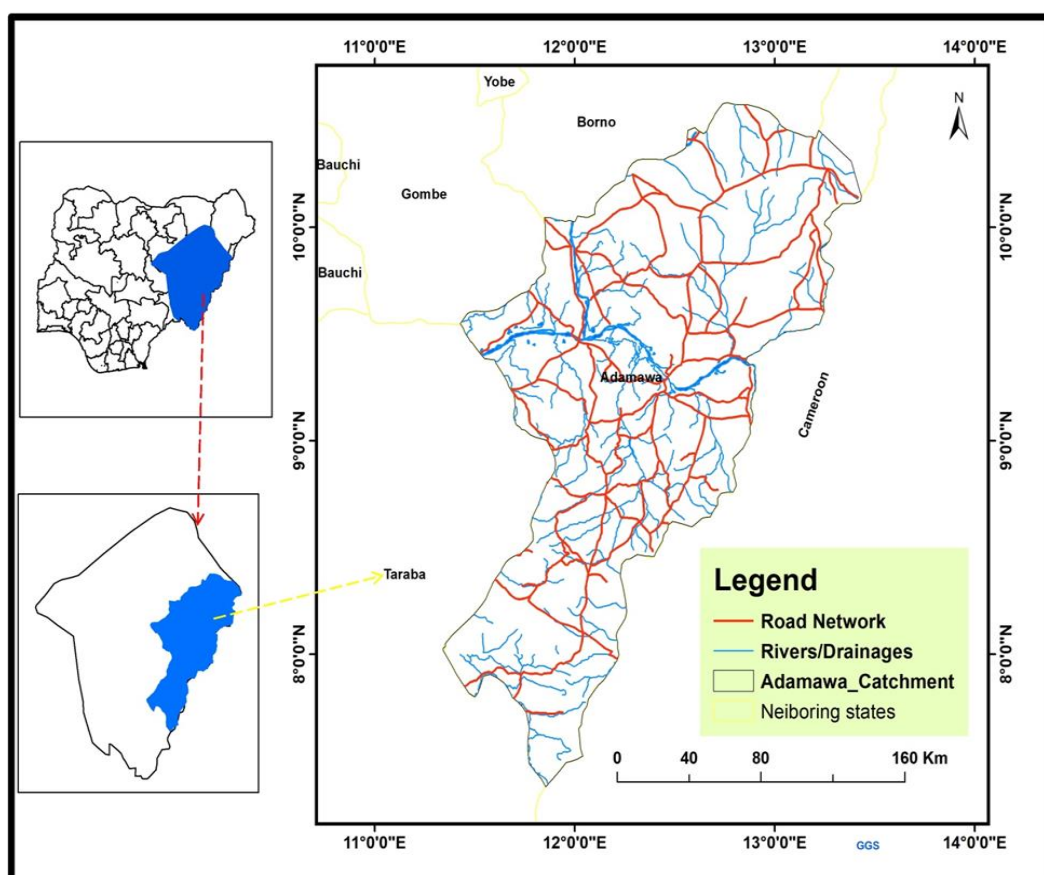


Figure 1: Adamawa sub-catchment of the upper Benue River Basin

In this study stratified and purposive sampling techniques were employed for sampling boreholes. This was done so as to capture data from various locations cutting across wards within L.G. As based on the number of borehole data (obtained from RUWASSA, Ministry of Water Resources, UBRBDA as well as from various contractors/consultancy firms) and their distribution within the sub-catchment. Representative spread of about 414 borehole data cutting across the entire sub-catchment were selected and used for validation of the research work. To assess statistical significance, a t-test was performed using the sample size ($n = 414$). The resulting test statistic is extremely high, yielding a p-value far less than 0.001 ($p < 0.001$). This indicates that the observed correlation is highly statistically significant and unlikely to have occurred by chance. Therefore, the relationship between groundwater potential zones and borehole yields is both strong and statistically reliable. Borehole data verification was done by revalidating sourced data vis-a vis field yield data sets by conducting borehole yield tests. For the production of groundwater potential zones map various thematic maps of individual criterion (Rainfall, Lineament Density, Drainage Density, Geology, Slope, Soil and land use/Land cover) were integrated through overlay analysis. The Analytic Hierarchy Process (AHP) was employed to assign weights to thematic layers influencing groundwater potential. A consistency ratio was calculated to ensure

reliability of judgments which was 0.06. The normalized weights were then integrated in a GIS environment to generate the groundwater potential zones map through weighted overlay analysis. The Groundwater Potential Map (GWPM) produced was normalized using equation 1 and then reclassified into 5 delineated zones of very low, low, moderate and high and very high groundwater potential zones.

$$\text{Normalized GWPZ map} = \frac{\text{GWPZ raster} - \text{minimum raster value}}{\text{Maximum raster value} - \text{minimum raster value}} \dots\dots\dots (1)$$

The reliability of groundwater mapping in this research was checked by validating data (obtained from the research) using data obtained from field work (existing data of boreholes within the sub-catchment). To achieve this, the yields of existing boreholes and the values produced from the groundwater potential zone map were correlated using Pearson correlation analysis, (Adaviruku, 2023). The correlation value R gotten showed the direction and strength of relationship between the yields of existing boreholes and the groundwater potential zone. Table 1 summaries the types of data used for the research, their sources, resolution and purposes.

Table 1: Data Types and Sources

S/N	Data types	Source	Resolution	Purpose
1	Sentinel-2 satellite image of 2020	USGS	30m	Land Use/Land Cover Thematic layer
2	SRTM DEM	USGS	10m	Slope/Elevation, Lineament and Drainage Thematic layers
3	Geology Map	Nigerian Geological Survey Agency	1:50,000	Geology thematic layer
4	Soil map	Food and Agricultural Organisation (FAO) World Digital Soil Map		Soil thematic layer
5	Metrological data	NIMET, CHRS, RUWASSA and UBRBDA		Rainfall/Precipitation Thematic layer
6	Borehole yields/Water Quality	Adamawa State Ministry of water Resources, UBRBDA/Contractors/Consultancy firms		Groundwater potential /Water Quality map validation

Source: author's compilation (2025)

Results and Discussion

The relationship between the GWPZ values and the yields of the existing boreholes was determined by Pearson correlation analysis. The geographic coordinates of all the boreholes were inputted into ArcGIS environment and overlaid on the GWPZ as shown in Figure 2. Having overlaid the coordinates on the GWPZ, it was found that 78.20% of the boreholes fell on areas corresponding to their yields. This finding is closely in alignment with that of Adaviruku *et al.* (2023), which found that 81.25% of the boreholes in Okene L.G.A (located in the Lower Niger River Basin) had yields that corresponded to their groundwater potential zones. Furthermore, the result from the finding of this research was found to be closely in agreement to the findings of a similar work done by Danso and Ma (2023) and Abrar *et al.* (2021) which established that about 76.5% and 79.2% of the boreholes fell within suitable sites for groundwater discovery in coastal municipality of Ghana and in the Western escarpment of the Ethiopian Rift valley respectively.

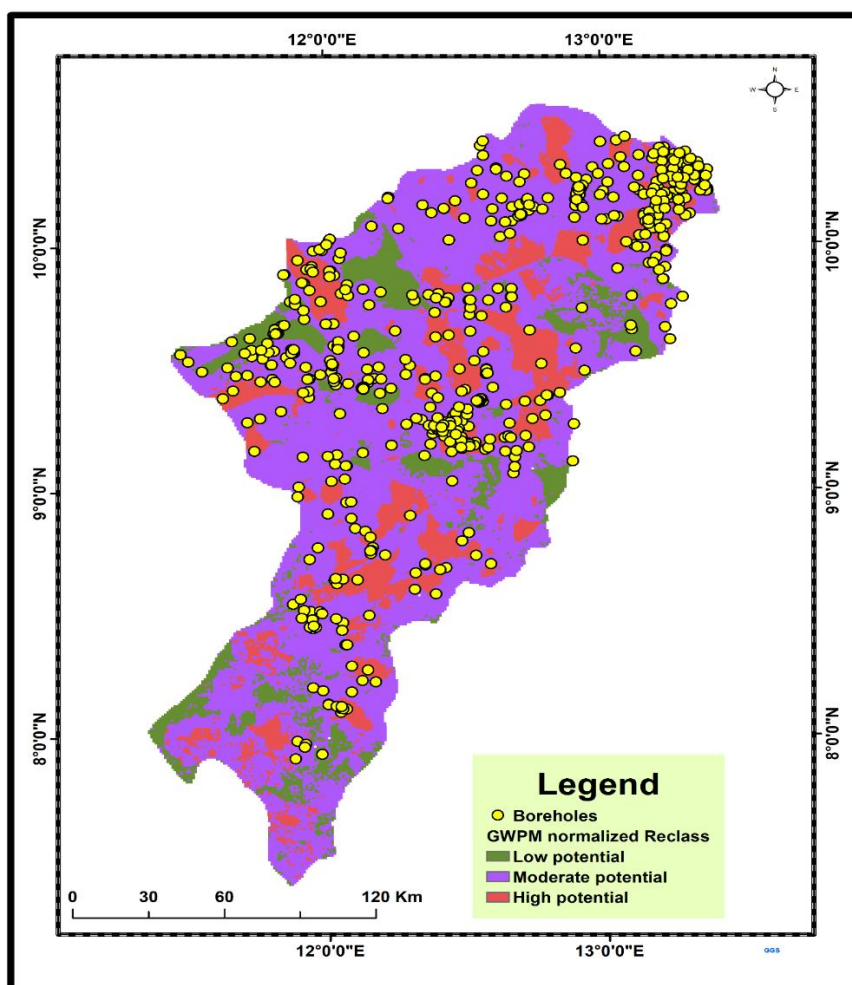


Figure 2: Borehole Points Overlaid on GWPZs Map in the Sub-catchment

The result of Pearson moment correlation analysis is shown in Table 2. As shown in the Table 2, R is positive (+) 0.782. It is imperative to note that the value of R is meant to show the direction and strength of the relationship between the yields of existing boreholes in the sub-catchment and the groundwater potential map produced. The relationship is a positive, meaning that as groundwater potential increases as borehole yield increases correspondingly. The strength of the relation is strong ($R = 0.782$).

The coefficient of determination (R^2) is obtained by squaring the correlation coefficient, giving $R^2 = 0.782^2 \approx 0.612$. This implies that approximately 61.2% of the variation in borehole yields can be explained by the spatial variation in groundwater potential zones, while the remaining 38.8% may be attributed to other factors such as local hydrogeological conditions, drilling depth, or aquifer characteristics. The resulting test statistic is extremely high, yielding a p-value far less than 0.001 ($p < 0.001$). This indicates that the observed correlation is highly statistically significant and unlikely to have occurred by chance. Therefore, the relationship between groundwater potential zones and borehole yields is both strong and statistically reliable.

Table 2: Correlation Table

	GWPMV values	Borehole Yields
GWPMV values	1	
Borehole Yields	0.78204	1

($p < 0.001$, $R^2 \approx 0.612$)

Discussion

The results of this study demonstrate a strong spatial agreement between groundwater potential zones and observed borehole yields in the Adamawa sub-catchment of the Upper Benue River Basin. The finding that 78.20% of boreholes fall within zones corresponding to their actual yields, together with a Pearson correlation coefficient ($R = 0.782$), provides compelling evidence that the groundwater potential mapping approach used in this study is reasonably reliable.

A Pearson correlation coefficient of 0.782 indicates a strong positive relationship between predicted groundwater potential and observed borehole yields. In practical terms, this means that areas classified as high groundwater potential tend to produce higher borehole yields, while low-potential zones generally correspond to lower yields. Within the context of similar African studies, correlation values in the range of 0.6–0.8 are often considered good validation outcomes for GIS-based groundwater potential models, especially in data-scarce environments. Many studies across Nigeria, Ghana, and Ethiopia report comparable validation strengths, reflecting the inherent complexity of subsurface hydrogeological systems. Therefore, the value obtained in this study suggests that the integration of thematic layers (such as geology, slope, drainage density, and lineament density) and the

applied weighting scheme have effectively captured the dominant controls on groundwater occurrence in the study area (Danso and Ma, 2023; Abrar et al. 2021). The overlay analysis shows that 78.20% of the boreholes fall within groundwater potential zones that correspond to their observed yields, indicating a high level of spatial agreement between predicted potential and actual performance. This suggests that the geospatial modeling approach used to delineate groundwater potential zones is largely effective in capturing the dominant controls on groundwater occurrence within the Adamawa sub-catchment. In practical terms, most high-yield boreholes are located in high-potential zones, while low-yield boreholes tend to fall within low-potential areas. Such a level of agreement is generally considered satisfactory in groundwater studies, given the inherent heterogeneity of subsurface conditions. Despite the overall strong relationship, 21.8% of boreholes did not correspond to their mapped groundwater potential zones, which is not unusual in groundwater studies. Several factors can explain this discrepancy. First, local hydrogeological variability plays a critical role; groundwater occurrence is often controlled by micro-scale features such as fractures, joints, and weathering profiles that may not be fully captured in regional-scale GIS models (Ejebu et al., 2017). Second, data limitations including the resolution of satellite imagery and the quality of input datasets can introduce classification errors in potential zone mapping. Third, borehole construction factors, such as drilling depth, casing quality, and screen placement, can significantly influence yield independently of the surrounding groundwater potential (Yusuf et al., 2025). Additionally, temporal variability in groundwater levels due to seasonal recharge fluctuations may cause differences between predicted potential and observed yields at the time of measurement. Finally, human errors or incomplete borehole records could also contribute to inconsistencies.

The results have important implications for groundwater development in Adamawa State. The high level of agreement (78.20%) suggests that geospatial groundwater potential mapping can serve as a valuable decision-support tool for borehole siting, helping to reduce the risk of drilling unsuccessful wells. However, the observed mismatch highlights the need for a multi-stage approach to borehole development. While GIS-based models can guide preliminary site selection, they should be complemented with detailed field investigations, such as geophysical surveys, to improve accuracy at the local scale. This integrated approach can enhance drilling success rates, optimize resource allocation, and improve access to sustainable groundwater supplies, particularly in rural communities.

Notwithstanding the promising results, some methodological limitations are acknowledged. The use of weighted overlay techniques in GIS involves a degree of subjectivity in assigning weights to influencing factors, which can affect the final output. The reliance on secondary datasets may also introduce uncertainties due to differences in data quality, scale, and temporal coverage. The Pearson correlation analysis, while useful, assumes a linear relationship and may not fully represent complex, non-linear interactions between variables.

Conclusion

This study demonstrates a strong spatial relationship between groundwater potential zones and borehole yields in the Adamawa sub-catchment, with 78.20% agreement and a high correlation ($R = 0.782$). These findings confirm the reliability of geospatial techniques for groundwater assessment and borehole siting. However, the observed mismatches highlight the influence of local hydrogeological variability, data limitations, and construction factors. Therefore, while GIS-based mapping is effective for preliminary site selection, it should be complemented with field investigations to enhance accuracy. In conclusion, integrating geospatial analysis with ground validation will improve sustainable groundwater development and decision-making in the study area.

Recommendations

Based on the findings of this study, the following evidence-based recommendations are proposed for both practitioners and researchers:

- i. Given the strong spatial agreement (78.20%) and high correlation ($R = 0.782$) between groundwater potential zones and borehole yields, practitioners should integrate GIS-based groundwater potential mapping into routine borehole siting practices.
- ii. The observed 21.8% mismatch between predicted potential zones and actual borehole yields highlights the limitations of relying solely on geospatial models. Therefore, it is recommended that practitioners adopt a multi-stage approach, where GIS-based mapping is complemented with site-specific geophysical investigations.
- iii. For researchers, the reliability of groundwater potential maps can be improved by incorporating higher-resolution datasets, up-to-date satellite imagery, and more comprehensive hydrogeological data. Additionally, future studies should explore advanced modeling techniques (e.g., machine learning, fuzzy logic, or multi-criteria decision analysis) to reduce subjectivity associated with weighted overlay methods.

Conflict of interest

The authors therefore declare that there is NO conflict of interest regarding this study. We also acknowledged that co-author Adaviruku P.E. is also the lead author of one of the cited comparison studies.

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