Analysis of the Spatial Distribution of Groundwater Potential Zones in Cross River North, Nigeria

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Abstract
Reliable domestic water supply remains a major challenge in many communities, particularly where water infrastructure is inadequate and groundwater availability varies spatially. This study assessed groundwater potential and the level of domestic water demand and supply in Cross River North, Nigeria, using Geographic Information Systems (GIS), the Analytical Hierarchy Process (AHP), and household survey analysis. Seven groundwater determinates factors were considered; geology, drainage density, land use/land cover, rainfall, slope, lineament density, and soil type and integrated through a weighted overlay to delineate groundwater-potential zones. Household data were obtained using 400 questionnaires, of which 362 were completed and returned, representing a 90.5% response rate. Descriptive statistics, correlation analysis, and multiple regression were used to examine household water consumption, access to water sources, and factors associated with water supply. The AHP results identified geology as the most influential groundwater-conditioning factor, with a weight of 0.338, followed by drainage density (0.181) and land use/land cover (0.169). The groundwater-potential map classified 36.22% of the mapped area as low potential, 34.12% as very low potential, 11.91% as moderate potential, and 17.75% as high potential. Household results showed a combined daily water use of 33,910 litres, with cleaning accounting for 69% of reported consumption. Seasonal water availability (24.86%), absence of water infrastructure (20.44%), and rapid population growth (19.06%) were the leading reported constraints to water supply. Furthermore, 83% of respondents travelled at least 300 m to obtain water. Regression analysis reported an (R^2) of 0.626, indicating that the model explained 62.6% of the variation in household water supply. The study demonstrates the value of integrating spatial groundwater assessment with household water-demand analysis to guide groundwater exploration, prioritise underserved communities, and improve domestic water-supply planning. Field investigations and borehole-yield assessments are recommended to verify mapped groundwater potential before development.

Keywords: *Groundwater potential; domestic water demand; water supply; GIS; Analytical Hierarchy Process; household survey; Cross River North; Nigeria.*

1. Introduction

Groundwater supports domestic, agricultural, and economic activities, particularly in communities where public water-supply infrastructure is limited or surface-water sources become unreliable during dry periods (Ifediegwu, 2022). Its occurrence and productivity depend on interacting geological, structural, topographic, hydrological, climatic, and land-surface conditions. Understanding the spatial distribution of these factors is important for identifying areas that warrant further hydrogeological investigation and reducing uncertainty in groundwater exploration (Arulbalaji et al., 2019; Ifediegwu, 2022).

Groundwater-potential mapping increasingly employs Geographic Information Systems (GIS), remote sensing, and multi-criteria decision analysis to integrate spatial information from different sources (Saidu et al., 2024). Geological characteristics influence groundwater occurrence and storage, while fractures and lineaments may provide pathways for groundwater movement. Rainfall contributes to recharge, whereas slope, soil properties, drainage characteristics, and land use influence infiltration, runoff, and the distribution of surface water. Integrating these factors provides a systematic approach to identifying areas with relatively favourable groundwater conditions. GIS and the Analytic Hierarchy Process (AHP) have consequently been applied in groundwater-potential assessments across different hydrogeological settings (Arulbalaji et al., 2019; Ifediegwu, 2022; Saidu et al., 2024).

However, groundwater-potential maps represent relative spatial favourability rather than direct measurements of aquifer productivity. A location classified as having high potential does not necessarily guarantee a productive borehole, acceptable water quality, or a dependable year-round supply. Actual performance depends on aquifer characteristics, fracture connectivity, saturated thickness, well construction, pumping conditions, and seasonal groundwater fluctuations. Field investigations and borehole-yield measurements are therefore important for evaluating the reliability of mapped groundwater-potential zones (Aizebeokhai et al., 2016; Saidu et al., 2024).

Groundwater potential is only one dimension of household water security. Communities may experience inadequate access even where groundwater resources occur because of insufficient infrastructure, non-functional facilities, long collection distances, inadequate storage, poor maintenance, or limited water distribution. The World Health Organization and UNICEF identify accessibility, availability when needed, and freedom from contamination as essential characteristics of safely managed drinking-water services (WHO & UNICEF, 2023). Seasonal variability can further affect shallow wells and surface-water sources, contributing to fluctuations in the availability of water for domestic activities.

In Cross River North, households obtain water from a combination of hand-dug wells, streams, boreholes, rainfall, and piped supplies. These sources differ in accessibility, reliability, and potential exposure to contamination. Examining household water demand and supply alongside groundwater-potential mapping can therefore provide a broader understanding of water-resource challenges. Spatial analysis identifies areas that may warrant further groundwater investigation, while household surveys describe the sources people use, their reported water requirements, the distances travelled to obtain water, and the constraints they experience.

Nevertheless, the relationship between groundwater potential and household access must be interpreted carefully. A favourable groundwater zone does not automatically provide household access unless water points are appropriately sited, developed, maintained, and made accessible to users. Similarly, household reliance on a particular water source does not establish that the source is located within a high-potential zone or that its yield is sufficient to meet domestic demand.

Integrating spatial assessment with household-level evidence is therefore important for connecting groundwater exploration priorities with practical water-supply planning.

This study integrates GIS-based groundwater-potential assessment with household survey evidence from Obudu, Obanliku, Ogoja, Yala, and Bekwarra Local Government Areas in Cross River North, Nigeria. The study aims to assess the spatial distribution of groundwater potential and examine household water demand, supply. Specifically, the objectives are to: Integrate seven groundwater-conditioning factors using AHP and GIS to produce a regional groundwater-potential classification, Quantify the area and percentage distribution of the mapped groundwater-potential classes and Examine household water demand and supply in the area.

2. Materials and Methods

2.1 Study Area

The study was conducted in Cross River North, Nigeria, which covers Ogoja, Yala, Bekwarra, Obudu, and Obanliku Local Government Areas. It lies between Latitudes 05°59'00"N and 06°42'00"N, and Longitudes 08°25'00"E and 09°33'00"E of the Greenwich Meridian (Akpan–Idiok, 2012). The study-area extent is 53,448 km². The spatial database comprised Landsat 8 OLI imagery, SRTM elevation data, rainfall information, geological and soil maps, and administrative boundaries (see Figure 1).

The study area encompasses varied terrain, including relatively low-lying landscapes and elevated, mountainous areas, particularly around Obudu and Obanliku. These topographic variations, together with differences in geological formations, soil characteristics, drainage networks, rainfall distribution, and land use and land cover, provide a basis for examining the spatial factors influencing groundwater potential. The region experiences seasonal rainfall, with climatic conditions varying locally in association with elevation and terrain. Such environmental variability makes an integrated spatial assessment appropriate for identifying areas that may be more favourable for groundwater exploration

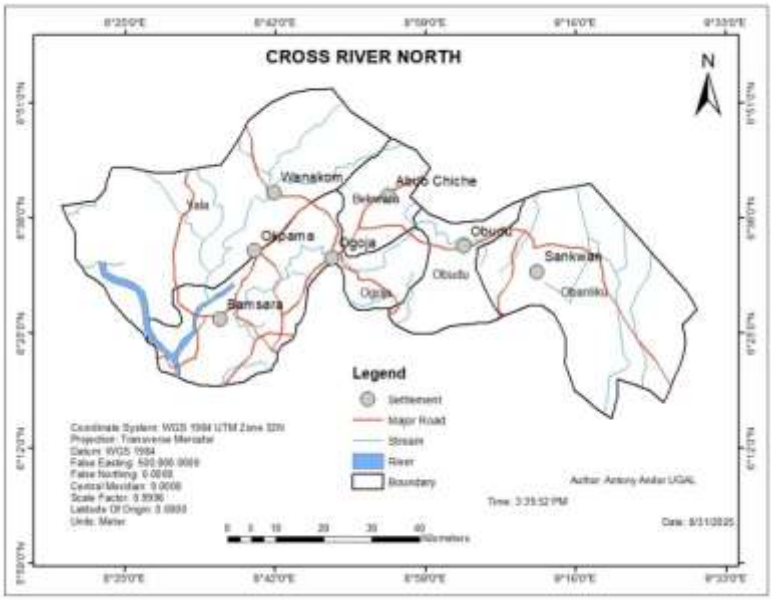


Figure 1: Location of Cross River North

Data Types and Sources

i. A 30m resolution Satellite image of the study area (Landsat 8 OLI) for the year 2023 was acquired and used to generate the land-use/ land cover map.
ii. Rainfall data from world climate data was downloaded from the http://worldclim.org/version2 and used to produce the rainfall map of the study area.
iii. Geology data was sourced from Nigeria Geological Survey Agency (NGSA) and used to produce the geology map of the study area.
iv. The Shuttle Radar Topography Mission (SRTM) with 90 meters resolution was downloaded from Global Land Cover Facility (www.ftp//glc£landsat) and used to generate DEM from which the slope, drainage density and lineament map of the study area was generated.
v. Soil map of the study area was generated from the soil map of Nigeria (Sonneveld, 1996).
vi. An administrative map which was obtained from Open Street Map was used to subset the study area.

GIS Preprocessing and Layer Generation

Landsat imagery was prepared and classified to generate a land-use/land-cover layer. DEM data were used to derive slope, drainage-related variables, and lineament density, maps from interpreted linear features; rainfall, geological, and soil datasets were prepared as thematic layers. The layers were clipped to the study area boundary, reclassified into suitability classes, and prepared for integration in ArcGIS 10.8.

Reclassification and Weighting

The seven thematic layers were integrated through a weighted-overlay framework. In general, the groundwater-potential index at each location can be expressed as:

$$GPI(x) = \Sigma (w_i \times r_i(x)), \text{ for } i = 1,\ldots,7$$

where GPI(x) is the groundwater-potential index at location x, w_i is the normalized criterion weight for criterion i, and $r_i(x)$ is the reclassified suitability score of that criterion at x. The class-level scores in the factor tables are not a substitute for criterion-level AHP weights.

AHP consistency was evaluated using the consistency index (CI) and consistency ratio (CR), where $CI = (\lambda max - n)/(n - 1)$ and $CR = CI/RI$. For seven criteria, the commonly used random index was 1.32, and a CR of 0.10 or less is often treated as an acceptable consistency level (Saaty, 1980).

Level of Water Demand and Supply Assessment

The assessment of domestic water demand and supply was based on primary data obtained through a household questionnaire survey across the study area. A total of 400 questionnaires were administered, of which 362 were completed and returned, representing a response rate of 90.5%. Information collected included household size, daily water consumption, sources of domestic water, distance to water sources, seasonal water availability, and factors affecting water supply.

Daily domestic water demand was assessed by examining household water use for drinking, cooking, and cleaning. The reported quantities were aggregated to determine total daily water consumption among the surveyed households. Water-supply conditions were evaluated using the distribution of household water sources, accessibility, and reported constraints to obtaining adequate water.

Descriptive statistics, including frequencies, percentages, and aggregate daily water consumption, were used to summarise household responses. Pearson correlation analysis was employed to examine relationships among household size, water demand, distance to water sources, and water supply. Multiple regression analysis was used to assess the predictive relationships between these variables and household water supply. The coefficient of determination (\(R^2\)), regression coefficients, significance levels, and variance inflation factors (VIF) were considered in interpreting the model results and assessing multicollinearity among the explanatory variables. Hypothesis testing was conducted at the 5% significance level (\(p<0.05\)) to determine whether the observed relationships were statistically significant.

3. Result and Discussion

3.1 Pairwise Comparison of Factors Affecting Groundwater Potential

The Analytical Hierarchy Process (AHP) was used to evaluate the relative importance of seven groundwater-conditioning factors: rainfall, slope, drainage density, geology, soil type, lineament density, and land use/land cover (LULC). Pairwise comparisons were used to establish the relative contribution of each factor to groundwater potential, with the resulting weights providing the basis for integrating the thematic layers in the GIS environment.

The pairwise comparison matrix is presented in Table 1. The assigned comparison values express the relative importance of one factor over another. These comparisons were used to derive normalized priorities for the seven factors, which were subsequently applied in the weighted overlay analysis to generate the groundwater-potential map.

Table 1: Pairwise comparison matrix for groundwater-conditioning factors

Factor	RF	SL	DD	GL	ST	LD	LULC
Rainfall (RF)	1	1	1/2	1/4	2	3/2	1/2
Slope (SL)	1	1	1/2	1/4	2	3/2	1/2
Drainage density (DD)	2	2	1	1/2	4	5/2	1
Geology (GL)	4	4	2	1	7	7/2	2
Soil type (ST)	1/2	1/2	1/4	1/7	1	2/3	1/4
Lineament density (LD)	2/3	2/3	2/5	2/7	3/2	1	2/3
LULC	2	2	1	1/2	4	3/2	1

Note: RF = rainfall; SL = slope; DD = drainage density; GL = geology; ST = soil type; LD = lineament density; LULC = land use/land cover.

The normalized comparison matrix was obtained by dividing each entry in the pairwise matrix by the sum of its respective column. The relative weight of each factor was then calculated as the mean of the normalized values in its row. The resulting normalized values and factor weights are presented in Table 2.

Table 2: Normalized pairwise comparison matrix and derived factor weights

Factor	RF	SL	DD	GL	ST	LD	LULC	Weight
Rainfall	0.090	0.090	0.088	0.085	0.093	0.123	0.085	0.093
Slope	0.090	0.090	0.088	0.085	0.093	0.123	0.085	0.093
Drainage density	0.179	0.179	0.177	0.171	0.186	0.205	0.169	0.181
Geology	0.358	0.358	0.354	0.341	0.326	0.288	0.338	0.338
Soil type	0.045	0.045	0.044	0.049	0.047	0.055	0.042	0.047

Lineament density	0.060	0.060	0.071	0.098	0.070	0.082	0.113	0.079
LULC	0.179	0.179	0.177	0.171	0.186	0.123	0.169	0.169
Total	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

The resulting weights indicate that geology had the greatest relative influence on the groundwater-potential assessment, with a weight of 0.338. Drainage density ranked second (0.181), followed by LULC (0.169). Rainfall and slope each had a weight of 0.093, while lineament density and soil type had weights of 0.079 and 0.047, respectively. These results emphasize the importance of geological conditions in determining groundwater occurrence and storage, while drainage characteristics and land-cover conditions provide additional information relevant to surface-water infiltration, runoff, and recharge. The consistency of the pairwise comparisons was evaluated using the consistency index (CI) and consistency ratio (CR). The maximum eigenvalue was approximately 7.052, producing a CI of 0.0087 and a CR of approximately 0.0066. This indicates an acceptable level of consistency in the comparisons. The derived weights were subsequently used in the GIS weighted overlay analysis to integrate the seven thematic layers and delineate groundwater-potential zones across the study area.

3.2. Mapped Groundwater-Potential Zones in the Study Area

The weighted overlay analysis classified the study area into four groundwater-potential categories: very low, low, moderate, and high. The spatial distribution of these classes is shown in Figure 9, while their mapped areas and percentage contributions are presented in Table 3.

Table 3: Areal distribution of groundwater-potential zones

Groundwater-potential zone	Index	Weighted index range	Area (km²)	Area (%)
Very low	1	100–192.75	18,237	34.12
Low	2	192.75–285.50	19,359	36.22
Moderate	3	285.50–378.25	6,365	11.91
High	4	378.25–471.00	9,487	17.75
Total	—	—	**53,448**	**100.00**

The results as shows in Figure 2 revealed that low-potential areas occupied the largest mapped area, covering 19,359 km² (36.22%). Very-low-potential areas accounted for 18,237 km² (34.12%). Combined, these two classes covered 37,596 km², representing 70.34% of the mapped area. This distribution indicates that much of the mapped region has relatively limited groundwater potential according to the integrated criteria and weights used in the assessment.

High-potential zones covered 9,487 km² (17.75%), while moderate-potential zones accounted for 6,365 km² (11.91%). Together, the moderate- and high-potential classes occupied 15,852 km², equivalent to 29.66% of the mapped area. These zones represent the more promising areas for further groundwater investigation because their combined thematic characteristics are more favourable under the adopted assessment framework. The spatial variation in groundwater potential reflects the combined influence of geology, drainage density, LULC, rainfall, slope, lineament density, and soil type. Areas assigned higher potential scores are those in which the weighted combination of these factors is more favourable for groundwater occurrence and recharge. Conversely, areas classified as having low or very low potential received lower integrated scores from the overlay analysis. The resulting map therefore provides a regional

screening tool for identifying priority locations for detailed field investigation and borehole siting. The mapped classifications indicate relative groundwater potential rather than guaranteeing the presence, yield, or quality of groundwater at any individual location.

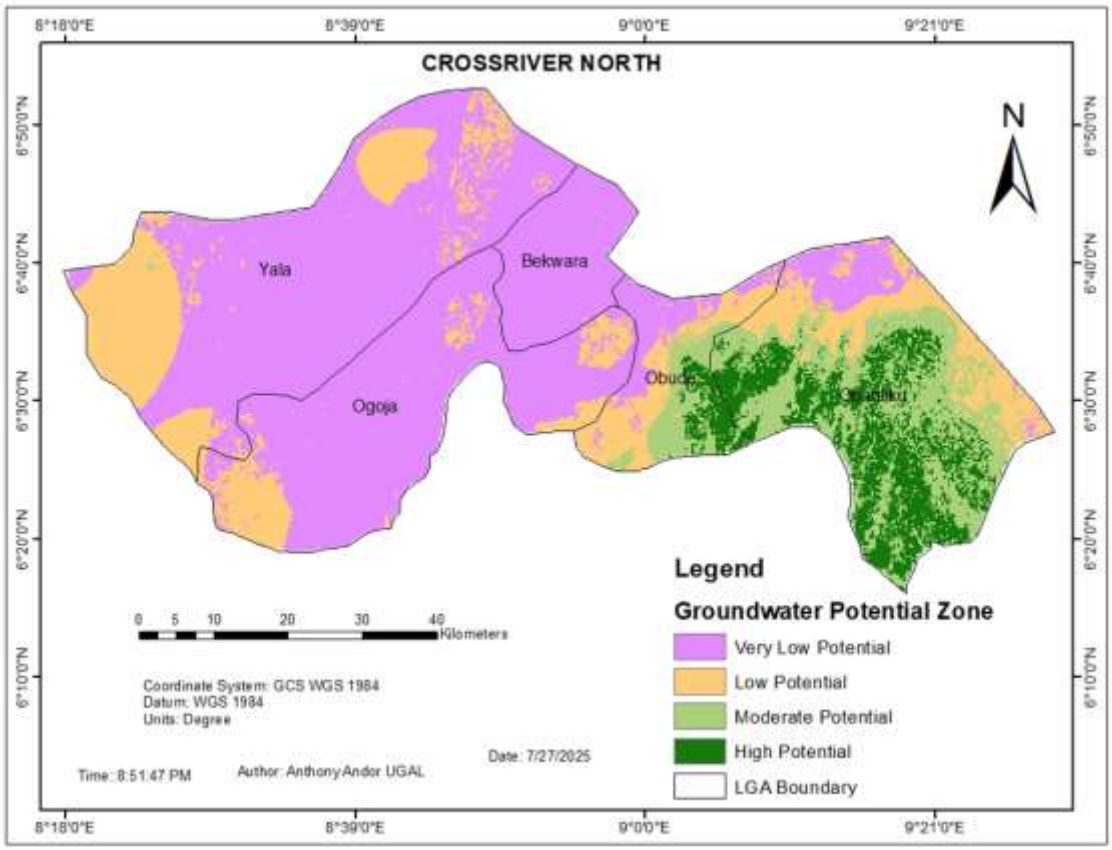


Figure 2: Spatial Distribution of Groundwater-Potential Zones

3.3. Level of Water Demand and Supply in the Study Area

Factors Affecting Water Demand and Supply

A total of 400 questionnaires were administered to assess household water demand and supply in the study area. Of these, 362 were completed and returned, representing a response rate of 90.5%. The responses were analysed to identify the major factors influencing access to and availability of water across the study area. As presented in Table 4, seasonality of water sources was the most frequently reported factor, accounting for 90 respondents (24.86%). This was followed by the absence of water infrastructure, reported by 74 respondents (20.44%), and rapid population growth, identified by 69 respondents (19.06%). Distance to streams and springs was reported by 56 respondents (15.46%), while topographic constraints accounted for 34 responses (9.39%). Inadequate or absent water-storage facilities were identified by 20 respondents (5.52%), inadequate community participation by 13 (3.59%), and poor maintenance of water-supply facilities by six respondents (1.65%).

These findings indicate that water demand and supply in the study area are influenced by a combination of environmental, infrastructural, demographic, and management-related factors. The prominence of seasonal water availability suggests that the reliability of existing sources varies

over time, while the absence of infrastructure and rapid population growth place additional pressure on available supplies. The reported distance to streams and springs further indicates that the physical distribution of water sources affects household access. Addressing these challenges requires improved water infrastructure, appropriate storage facilities, effective maintenance, and water-supply planning that considers seasonal variability and population needs.

Table 4: Factors Affecting Water Supply in the Study Area

Factor	Frequency	Percentage (%)
Seasonality of water sources	90	24.86
Topographic constraints	34	9.39
Absence of water infrastructure	74	20.44
Rapid population growth	69	19.06
Distance to streams and spring water sources	56	15.46
Inadequate community participation	13	3.59
Poor maintenance of water-supply facilities	6	1.65
Inadequate or absent water-storage facilities	20	5.52
Total	**362**	**100.00**

Household Water Use and Daily Demand

Household water demand was assessed based on three principal domestic activities: cleaning, cooking, and drinking. The results presented in Table 13 show that cleaning accounted for the largest share of reported daily water use, at 23,384 litres (69%). Drinking accounted for 5,763 litres (17%), while cooking accounted for 4,763 litres (14%). The combined reported consumption for these activities was 33,910 litres per day among the 362 surveyed households.

The predominance of cleaning in household water use indicates that domestic demand extends beyond drinking and food preparation to include other essential household activities. The findings also demonstrate the importance of considering multiple categories of domestic consumption when estimating water requirements. The reported total provides an indication of the daily water demand associated with the surveyed households and highlights the need for accessible and reliable water supplies to meet routine domestic needs (see Table 5).

Table 5: Daily Household Water Use in the Study Area

Household water use	Number of households	Quantity (litres/day)	Percentage (%)
Cleaning	362	23,384	69.0
Cooking	362	4,763	14.0
Drinking	362	5,763	17.0
Total	**362**	**33,910**	**100.0**

Sources of Water in the Study Area

The distribution of household water sources is presented in Figure 10. Hand-dug wells were the most commonly reported source, accounting for 35% of respondents. Streams were the second most frequently reported source, at 28%, followed by boreholes at 16%. Rainwater accounted for 11%, while tap water was reported by 10% of respondents (see Figure 3).

The results indicate that household water access relies substantially on hand-dug wells and streams, which together accounted for 63% of the reported sources. Boreholes represented a

smaller proportion of the sources used by respondents. This distribution highlights the importance of local water sources in meeting household needs and the potential value of expanding access to dependable groundwater infrastructure. In particular, the relatively low proportion of respondents reporting borehole use suggests that the availability of groundwater resources does not necessarily translate into widespread access to borehole facilities.

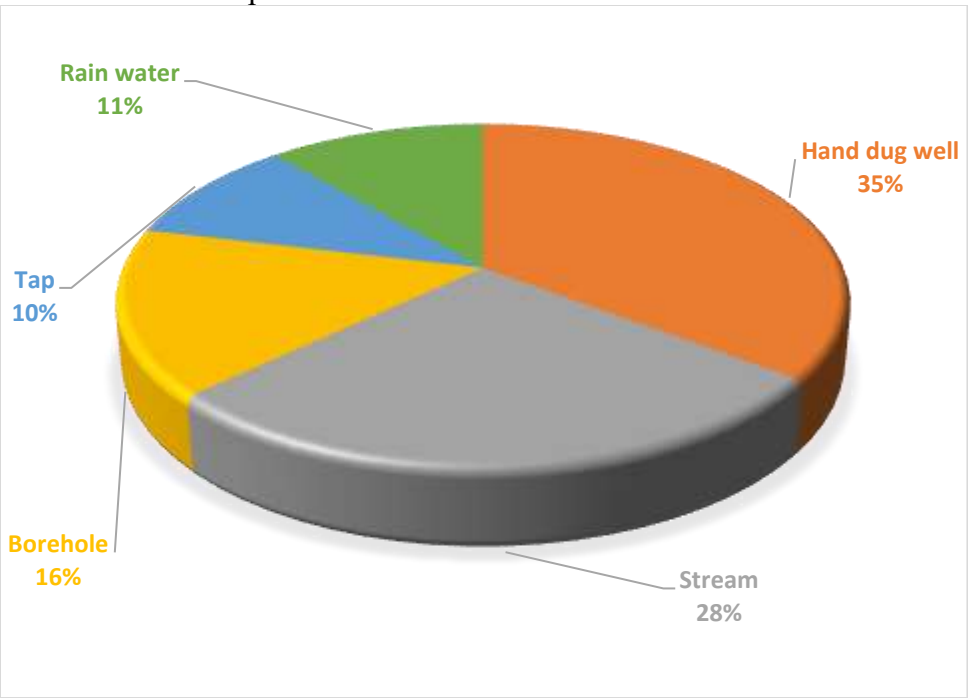


Figure 3: Distribution of Household Water Sources

Distance to Water Sources

Figure 4 presents the distances respondents reported travelling to obtain water. The largest proportion, 54%, travelled more than 500 m to reach a water source. A further 29% travelled between 300 and 500 m, while 10% travelled less than 100 m. The remaining 7% travelled between 100 and 300 m. These findings indicate that many households travel considerable distances to obtain water. In total, 83% of respondents reported travelling at least 300 m to access their water sources. Such distances may increase the time and physical effort required for water collection, particularly for households that depend on daily collection to meet domestic needs. The results therefore suggest that improving the spatial distribution of water facilities could reduce the distance travelled by households and improve access to water across the study area.

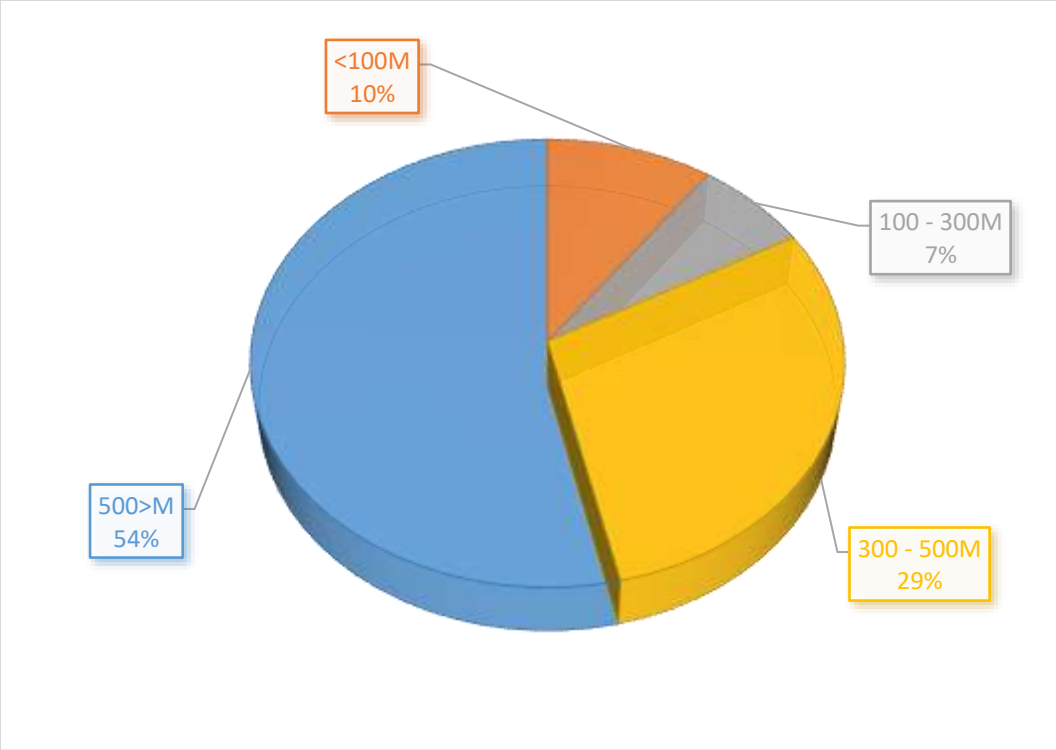


Figure 4: Distance Travelled by Households to Water Sources

Water Sources Used for Drinking and Cooking

The sources specifically used for drinking and cooking differed from the overall distribution of household water sources. As shown in Figure 5 borehole water was the most frequently reported source for these purposes, accounting for 59.1% of respondents. Tap water was reported by 18.8%, hand-dug well water by 14.6%, and stream water by 7.5%.

The findings show that boreholes were the principal reported source for drinking and cooking, despite their smaller share of overall household water sources. This pattern suggests that respondents distinguish between sources used for general domestic activities and those preferred for drinking and food preparation. However, the preference for a particular source does not, by itself, establish that the water is microbiologically or chemically safe. Water-quality testing is necessary to determine its suitability for consumption.

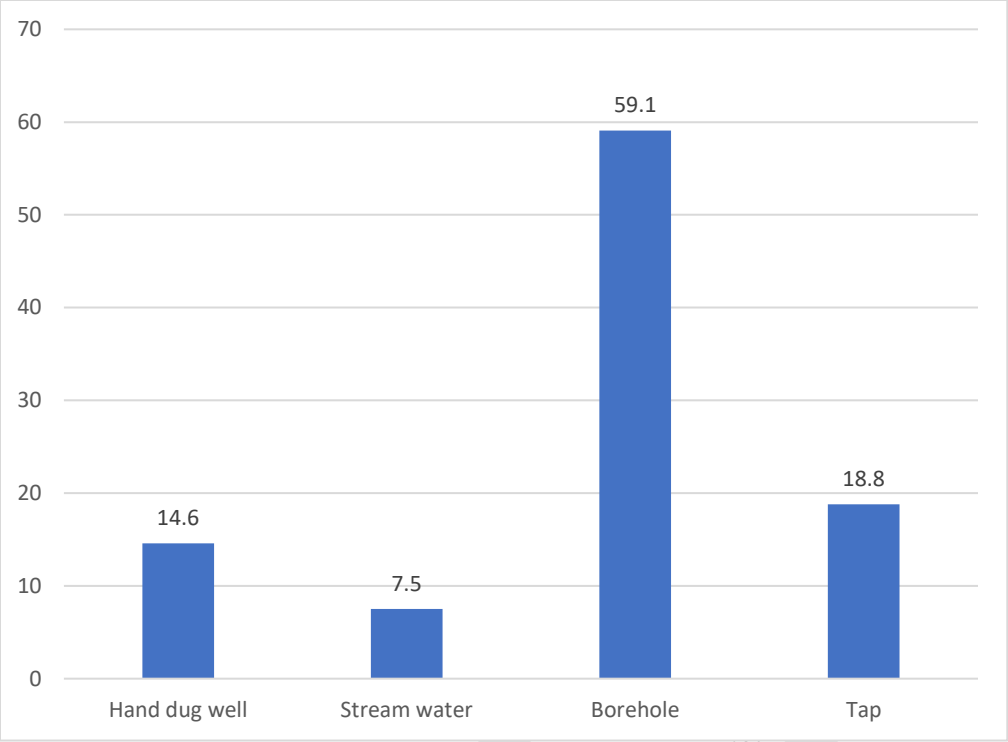


Figure 5: Sources of Water Used for Drinking and Cooking

Reasons for Selecting Water Sources

Respondents were asked to identify the main reasons for selecting their water sources. Figure 6 shows that perceived safety was the leading consideration, reported by 82.1% of respondents. Ease of accessibility accounted for 9.9%, while availability and low cost accounted for the remaining 8.0%. The strong emphasis on perceived safety indicates that respondents place considerable importance on their assessment of water quality when choosing sources for drinking and cooking. Accessibility, availability, and cost also influence household choices, although they were reported less frequently than perceived safety. These findings suggest that interventions to improve household water access should consider both the physical availability of water and public confidence in its quality. Water-quality monitoring and public education would help households make informed choices based on verified safety rather than perception alone.

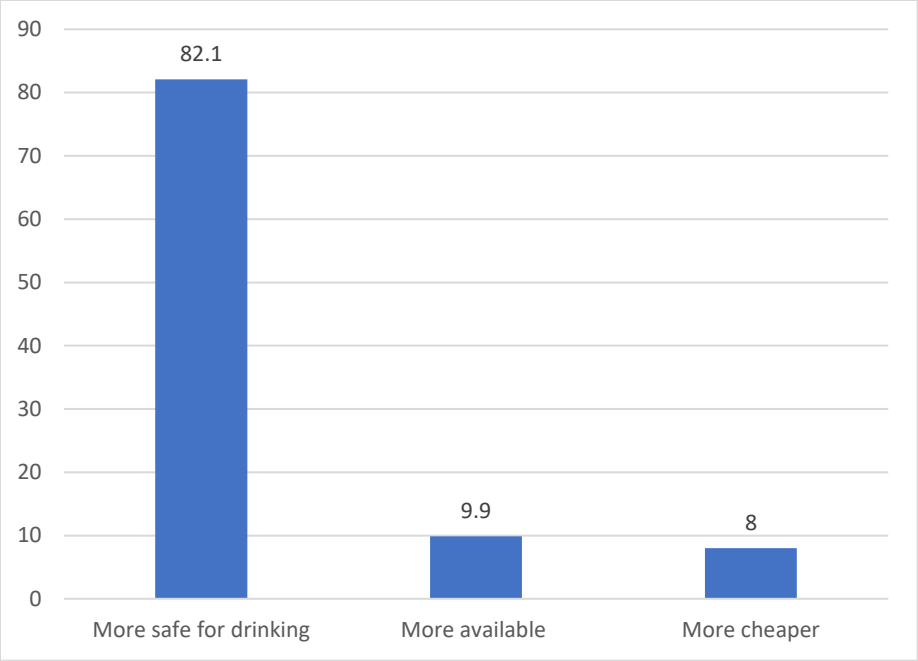


Figure 6: Reasons for Selecting Household Water Sources

Household Water-Storage Methods

Figure 7 presents the methods used by households to store water. Jerrycans were the most frequently reported storage method, accounting for 44% of respondents. Buckets were used by 34%, overhead tanks by 14%, and other containers, including pots and drums, by 8%.

The predominance of jerrycans and buckets indicates that many households rely on portable containers for water storage rather than fixed storage infrastructure. Such containers allow households to retain water for subsequent use, particularly when supply is intermittent or collection is difficult. However, the safety of stored water also depends on container cleanliness, covering, handling, and the method used to withdraw water. Improving household storage practices alongside the provision of reliable water sources could therefore contribute to safer and more dependable domestic water access.

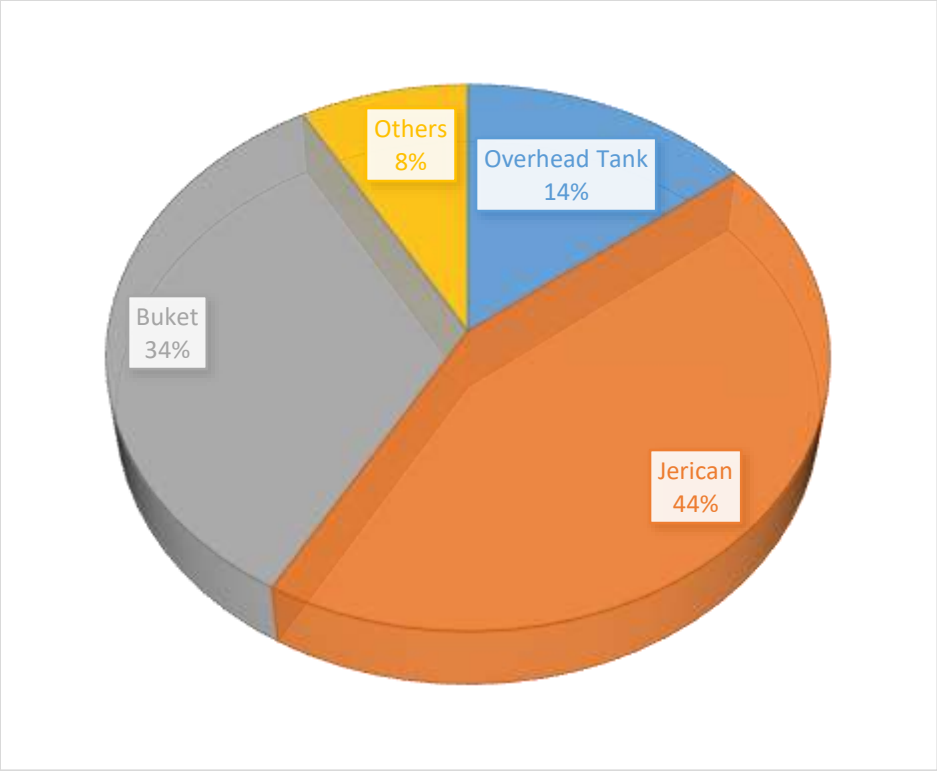


Figure 7: Household Water-Storage Methods

Determining the Quantity of Domestic Water Demand and Supply

Model Validity and Diagnostic Tests

The relationship between household water supply, household size, domestic water demand, and distance to water sources was examined using correlation analysis and multiple regression diagnostics. The diagnostic procedures included examination of the correlation matrix, the Durbin–Watson statistic, variance inflation factors (VIF), and tolerance statistics to assess the relationships among the explanatory variables and the suitability of the regression model for interpretation.

Correlation Analysis

The correlation matrix in Table 6 presents the Pearson correlation coefficients among household water supply, household size, household water demand, and distance to water sources. Household water supply was positively correlated with household size ($r = 0.686$), water demand ($r = 0.579$), and distance to water sources ($r = 0.673$). These relationships indicate that variations in household water supply were associated with variations in each of the three explanatory variables.

Among the explanatory variables, the strongest correlation was observed between household size and distance to water sources ($r = 0.682$), followed by water demand and distance to water sources ($r = 0.665$) and household size and water demand ($r = 0.574$). All pairwise correlations among the explanatory variables were below 0.70, indicating that none of the observed relationships reached the commonly applied threshold for severe multicollinearity based on correlation coefficients alone (Gujarati and Sangeetha, 2007). The correlation analysis therefore provides preliminary evidence that the explanatory variables can be examined jointly in the regression model.

Table 6: Correlation Matrix of Household Water Supply and Explanatory Variables

Variable	Water supply to households	Household size	Water demand by households	Distance to water sources
Water supply to households	1.000	0.686	0.579	0.673
Household size	0.686	1.000	0.574	0.682
Water demand by households	0.579	0.574	1.000	0.665
Distance to water sources	0.673	0.682	0.665	1.000

Autocorrelation Test

The Durbin–Watson statistic was used to assess the independence of the regression residuals. As presented in Table 7, the model produced a Durbin–Watson value of 0.165. This value is substantially below 2 and indicates a strong potential for positive residual autocorrelation. Consequently, the independence of errors cannot be assumed solely from the reported model summary, and the regression findings should be interpreted in light of this diagnostic result.

The model summary further shows a multiple correlation coefficient (R) of 0.762, an R^2 of 0.626, and an adjusted R^2 of 0.623. The R^2 value indicates that the three explanatory variables jointly accounted for 62.6% of the observed variation in household water supply within the fitted model. The remaining 37.4% was not explained by these predictors. The reported *F*-statistic of 290.689, with 3 and 328 degrees of freedom and a significance value below 0.001, indicates that the model was statistically significant overall. Generally, the correlation and regression results indicate a statistically significant relationship between the explanatory variables and household water supply. The model explains a substantial proportion of the observed variation; however, the low Durbin–Watson statistic indicates that the residual independence assumption requires further consideration before the regression coefficients can be interpreted conclusively.

Table 7: Regression Model Summary and Durbin–Watson Statistic

Model statistic	Value
Multiple correlation coefficient (R)	0.762
Coefficient of determination (R^2)	0.626
Adjusted R^2	0.623
Standard error of the estimate	0.311
R^2 change	0.626
F-change	290.689
Degrees of freedom 1	3
Degrees of freedom 2	328
Significance of *F*-change	$p < 0.001$
Durbin–Watson statistic	0.165

Dependent variable: Water supply to households.
Predictors: Household size, water demand by households, and distance to water sources.

Multicollinearity Test

Multicollinearity among the explanatory variables was assessed using the correlation matrix, variance inflation factor (VIF), and tolerance statistics. VIF values below 10 are generally

considered acceptable, although values exceeding 2.5 may warrant attention in models where multicollinearity could affect the stability of coefficient estimates (Koutsoyiannis, 1977; Gujarati and Sangeetha, 2007). Tolerance values below 0.10 are commonly regarded as indicating serious multicollinearity (Menard, 1995). As presented in Table 8, the VIF values ranged from 2.329 to 4.350. Household size recorded a VIF of 3.458, water demand had a VIF of 2.329, and distance to water sources recorded a VIF of 4.350. The corresponding tolerance values were 0.288, 0.312, and 0.231, respectively. All tolerance values exceeded 0.10, while all VIF values remained below 5. These results suggest that severe multicollinearity was not evident among the explanatory variables, although the VIF values indicate some degree of shared variation among them.

Table 8: Multiple Regression Coefficients and Collinearity Statistics

Variable	B	Std. Error	Beta	t	Sig.	Zero-order correlation	Partial correlation	Part correlation	Tolerance	VIF
Constant	0.020	0.067	—	0.267	0.678	—	—	—	—	—
Household size	0.589	0.057	0.519	11.460	0.000	0.836	0.537	0.333	0.288	3.458
Amount of water demand	0.140	0.041	0.159	2.660	0.000	0.679	0.202	0.108	0.312	2.329
Distance to water sources	0.105	0.039	0.133	1.756	0.049	0.773	0.108	0.057	0.231	4.350

Dependent variable: Water supply to households.

Interpretation of Regression Coefficients

The regression coefficients were examined to determine the direction and relative contribution of household size, water demand, and distance to water sources to household water supply. The estimated constant was 0.020, while the unstandardized coefficients for household size, water demand, and distance to water sources were 0.589, 0.140, and 0.105, respectively.

Household size recorded the largest standardized regression coefficient (beta = 0.519), indicating the strongest relative association with household water supply among the three explanatory variables in the reported model. Its coefficient was positive, suggesting that larger household size was associated with higher water-supply values, holding the other predictors constant. The reported t-statistic of 11.460 and significance value of $p < 0.001$ indicate a statistically significant relationship. Water demand also had a positive standardized coefficient (beta = 0.159). Its reported t-statistic was 2.660, indicating a positive association between household water demand and water supply. The reported significance value of 0.000 is inconsistent with the reported t-statistic; accordingly, the statistical significance of this coefficient should be determined from the underlying regression output.

Distance to water sources had a positive standardized coefficient (beta = 0.133) in the reported model. However, the reported t-statistic of 1.756 and significance value of 0.049 are not mutually consistent under conventional two-tailed testing. The direction and statistical significance of this relationship therefore cannot be established conclusively from the reported figures alone.

Generally, household size exhibited the strongest reported association with household water supply, followed by water demand and distance to water sources. These results indicate that household characteristics and water requirements are relevant to understanding water-supply patterns in the study area.

Test of Hypothesis One: Household Size and Water Demand and Supply

Null hypothesis (H_1): Household size has no significant relationship with water demand and supply in the study area.

The regression results in Table 16 show that household size had an unstandardized coefficient of 0.589, a standardized coefficient of 0.519, and a t-statistic of 11.460, with a reported significance value below 0.001. The positive coefficient indicates that household size was positively associated with household water supply, controlling for water demand and distance to water sources.

Consequently, the null hypothesis is rejected. The results support the conclusion that household size has a statistically significant positive relationship with household water supply in the study area.

Test of Hypothesis Two: Water Demand and Water Supply

Null hypothesis (H_2): The amount of household water demand has no significant relationship with water supply in the study area.

The regression results show that water demand had an unstandardized coefficient of 0.140, a standardized coefficient of 0.159, and a t-statistic of 2.660. These estimates indicate a positive association between water demand and household water supply. However, the reported significance value of 0.000 does not correspond to the reported t-statistic under conventional significance testing.

The coefficient therefore suggests a positive relationship, but a definitive hypothesis decision requires verification of the significance value from the original regression output.

Test of Hypothesis Three: Distance to Water Sources and Water Supply

Null hypothesis (H_3): Distance to water sources has no significant relationship with water supply in the study area.

The regression results indicate an unstandardized coefficient of 0.105, a standardized coefficient of 0.133, and a t-statistic of 1.756 for distance to water sources. The positive coefficient suggests that distance was positively associated with the measured household water-supply variable after controlling for the other predictors. However, the reported t-statistic and significance value of 0.049 are inconsistent under conventional two-tailed testing.

The evidence therefore does not support a definitive rejection of the null hypothesis without verification of the original statistical output.

In summary, the regression analysis identifies household size as the strongest explanatory variable associated with household water supply. Water demand and distance to water sources also show positive estimated coefficients, although their statistical significance requires confirmation from the original output. Together with the correlation and collinearity diagnostics, these findings provide insight into the household-level factors associated with water supply in the study area.

4. Discussion

The AHP results identified geology as the most influential factor in groundwater-potential assessment, with a weight of 0.338, followed by drainage density (0.181) and land use/land cover

(0.169). Rainfall and slope each recorded a weight of 0.093, while lineament density and soil type recorded 0.079 and 0.047, respectively. The dominance of geology highlights the importance of geological formations in controlling groundwater occurrence, storage, and movement. Drainage density, rainfall, slope, and land-cover characteristics further contribute to groundwater recharge and surface-water infiltration. These findings support the integration of multiple environmental factors in identifying areas with comparatively favourable groundwater potential.

The GIS-based weighted overlay classified the mapped area into four groundwater-potential zones. Low-potential areas occupied 36.22%, while very-low-potential areas accounted for 34.12%. Combined, these zones covered 70.34% of the mapped area. Moderate- and high-potential zones accounted for 11.91% and 17.75%, respectively, representing 29.66% combined.

The results reveal considerable spatial variation in groundwater potential across the study area. The moderate- and high-potential zones provide priority areas for further geophysical investigation and exploratory drilling. However, the mapped classes represent relative potential and require field verification to establish actual aquifer productivity and borehole yield.

The household survey identified seasonal water availability (24.86%), absence of water infrastructure (20.44%), and rapid population growth (19.06%) as the leading factors affecting water supply. Furthermore, 83% of respondents travelled at least 300 m to obtain water, indicating substantial challenges in household access. The 362 surveyed households reported a combined daily water use of 33,910 litres for cleaning, cooking, and drinking, with cleaning accounting for the largest share (69%). Hand-dug wells and streams were the most frequently reported overall water sources, while boreholes were the principal reported source for drinking and cooking. These findings indicate that household water access depends on source availability, infrastructure, distance, and perceived water safety. The regression results identified household size as the strongest reported predictor of water supply (beta = 0.519), followed by water demand (beta = 0.159) and distance to water sources (beta = 0.133). The model reported an R^2 of 0.626, indicating that the included predictors accounted for 62.6% of the variation in household water supply. The hypothesis test for household size supported a significant relationship with water supply. The results for water demand and distance require confirmation of their reported significance values before definitive conclusions can be drawn. Overall, the findings demonstrate the importance of household characteristics and access conditions in understanding water-supply challenges in the study area.

Implications for Groundwater Development and Water-Supply Planning

The combined findings provide a basis for prioritising groundwater investigations and improving domestic water access in Cross River North. The groundwater-potential map can guide the selection of locations for detailed geophysical surveys and exploratory drilling, while household survey findings identify communities where water infrastructure, storage, and accessibility require attention. Priority should be given to investigating moderate- and high-potential zones, verifying borehole performance, and developing reliable supply facilities that address seasonal shortages and long collection distances. Integrating groundwater assessment with infrastructure planning, water-quality monitoring, and appropriate storage practices would support more sustainable domestic water supply across the study area.

5. Conclusion

This study integrated the Analytical Hierarchy Process (AHP), Geographic Information Systems (GIS), and household survey analysis to assess groundwater potential and domestic water demand

and supply in Cross River North, Nigeria. The AHP results identified geology as the most influential factor controlling groundwater potential, followed by drainage density and land use/land cover. The GIS-based weighted overlay revealed considerable spatial variation in groundwater potential, with low- and very-low-potential zones covering 70.34% of the mapped area, while moderate- and high-potential zones accounted for 29.66%.

The household survey further revealed persistent challenges in domestic water access, including seasonal water shortages, inadequate water infrastructure, population growth, and long distances to water sources. Of the 362 surveyed households, 83% travelled at least 300 m to obtain water, while total reported daily household water use was 33,910 litres. Regression results also indicated that household size was an important predictor of domestic water supply, highlighting the influence of household characteristics on water requirements and access.

Overall, the findings demonstrate the value of integrating spatial groundwater-potential assessment with household water-demand analysis to support water-resource development and planning. Although the mapped high- and moderate-potential zones provide useful guidance for prioritising further investigations, field verification and borehole-yield assessment remain necessary to establish actual groundwater availability. The study provides a spatial and empirical basis for improving groundwater exploration and developing more reliable domestic water-supply systems across the study area.

6. Recommendations

Following the findings of the study, these recommendations were made:

i. **Prioritise groundwater exploration:** Conduct detailed geophysical surveys and exploratory drilling in the mapped moderate- and high-potential zones, followed by borehole-yield assessments to confirm groundwater availability.

ii. **Improve domestic water-supply infrastructure:** Develop and rehabilitate boreholes and other reliable water facilities in underserved communities, prioritising locations where households travel long distances to obtain water and experience seasonal shortages.

iii. **Promote sustainable water-resource management:** Integrate household water-demand planning, rainwater harvesting, adequate storage, routine facility maintenance, and regular groundwater-quality monitoring to ensure reliable and sustainable domestic water supply across the study area.

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