# Multi-Criteria Analysis to Determine Groundwater Potential Zone in Part of Gongola Basin, Northeast Nigeria

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Successful water management serves as a key to achieving the Sustainable Development Goal number six as defined by the United Nations that is. 'Ensure availability and sustainable management of water and sanitation for all'. It is on this premise that the study wishes to carry out a Multi-Criteria Analysis (MCA) to determine groundwater potential zone in some part of Gongola basin, North East Nigeria. The research objectives focus on preparing thematic maps of various parameters for groundwater potential zone determination and performing multi-criteria analysis to determine groundwater potential zone. Alos Polsar Digital Elevation Model with a 12.5m resolution; Sentinel level 1C image of 10m resolution; soil and geology map of Nigeria; and rainfall data were used to determine selected twelve parameters namely Topographic Wetness Index (TWI), drainage, watershed, geomorphology, geology, slope, soil, rainfall, Normalized Difference Vegetation Index (NDVI), lineament, elevation and Modified Normalized Difference Water index (MNDWI). The parameters were resampled and reclassified to a common scale. They were integrated using the ESRI ArcMap 10.4.1 coupled with the Analytical Hierarchical Process (AHP) as a veritable tool in Groundwater Potential Zone (GWPZ) determination. The GWPZ was classified into five classes with the very low potential zone covering 1275.23km$^2$ (20.6%), while the Low Potential covers an area of 1319.62km$^2$ (21.3%), moderate potential has an area of 1533.35km2 (24.8%), high potential has an area of 1336.65km$^2$ (21.6%) and very high potential has an area of 724.83km$^2$ (11.7%). The study shows that the Northwest, West and Southwest of the study area have very low potential of Groundwater (GW). Conversely, the Northeast, East and Southeast have very high potential. The study recommend that the groundwater potential zone map combine with other thematic maps can function as source of database that can be updated overtime by adding new information to serve as resource material for further research.
**Keywords:** Geospatial technique, Groundwater, Multi-Criteria Analysis (MCA), potential zones

## INTRODUCTION

Water is the most important renewable and finite natural resource since it is required for agriculture, industry, and domestic purposes. In the field of water resources, there are several areas where geospatial technologies are being used for scientific planning, monitoring, and management (Reddy *et al*., 2001 in Obi-Reddy & Singh, 2018). Groundwater (GW) is defined as beneath surface water that fills all the pore space of soils and geologic formations below the water table (Bane, 2017). Groundwater provides the most abundant source of water to man and the base flows for rivers; or it acts as an underground reservoir from which water can be pumped at a location into which GW can be drained (Kovalevsky *et al*., 2004) and it is the cheapest and the most constant in quantity and quality. Water on land masses is continuously in motion, either moving fast (vapour transport, precipitation, surface flow) or gently (groundwater flow, glaciers) (Kovalevsky *et al*., 2004). Ab -initio, Gombe state was part of the old Bauchi state. The state was created on the 1st October, 1996. Prior to the creation, as at the 1991 census, the four Local Governments forming the study area (Akko, Gombe, Kwami and Yamaltu Deba which is part of the Gongola Basin) has a total population of 745990 people; however, after the 2006 census, the population has increased to 1,054,000, an increase of 41%. At a population growth rate of 3.2%, the population was projected to 2024 and was found to be 1,800,510 people. The increase in population has put incredible pressure on water resources in the study area, while the development of infrastructure has not kept pace to accommodate this increased growth rate. Increasing population growth and improvement in the standard of living progressively drive demand for water, increasing competition for water usage for domestic, energy, agriculture, fisheries, livestock, forestry, mining, transport, and other sectors (FAO, 2017). It is worthy of note that civilization brings about sanitation and the use of clean water. Its usage has been increasing worldwide by about 1% per year since the 1980s as a result of population growth, socio-economic development and changing consumption patterns (UN World Water Report, 2018). This research aim at determining

groundwater potential zones in parts of Gongola Basin, Northeast, Nigeria through the application of geospatial technique by preparing various thematic maps of parameters used and performing multi-criteria evaluation analysis.

The availability, accessibility, movement, and occurrence of groundwater depend on geology, slope aspect, lineaments, drainage density, land-use/land cover, Rainfall, surface runoff, and geomorphology of the area (Bane, 2017). "Geospatial technologies, commonly known as Geomatics, refer to the technology used for visualization, measurement, and analysis of features or phenomena that occur on the earth" (ObiReddy & Singh 2018). Remote sensing, GIS, GPS, and information technologies have become indispensable in land resource mapping, monitoring, and management. Remote sensing (RS) provides data for a wide range of users in different fields (Fashae, *et al.*, 2014; Arkoprovo *et al.*,2012). The integration of these technologies/techniques has taken the land resource management domain to the new digital age. The application of Geospatial techniques in solving Environmental problems cannot be over-emphasized (Ahiauba, 2013; Chigbu & Onukaogu, 2013; Medjon, 2016; Nadezhda & Irina, 2018). The geospatial technique is a method that is used to analyze all parameters that influence the groundwater potential and recharge zone of an area and it can access, manipulate and analyze the spatial and temporal data from satellite image (Kamal, 2017). Gupta and Srivastava, (2010) expounded that several decision analysis approaches such us Multi-Criteria Decision Making (MCDM), AHP and Fuzzy Logic can be used to fill the gap of water scarcity and decision-making on groundwater potential and recharge zone evaluation and mapping. AHP is a useful method for complex decision-making. The Geospatial approach to groundwater exploration is beginning to increase. Fashae *et al*. (2014), Hyeman *et al*. (2020), Akinwumiju *et al*. (2016), Shelbut *et al*. (2018), Abdullateef *et al*. (2021).

At the global scale, several studies have been done on GW potential zones and modelling (Singh *et al*., 2013; Al-Abadi & Al-Shamma'a, 2015; Omid *et al*., 2014). In Africa, Boubaya (2017), Mangoua *et al*. (2014) and Fashae *et al*. (2014) carried out studies on GW. The water needs of Nigerians and within the study area have not been met despite huge capital expenditure on surface water development at the expense of GW (Peter, 2010). Hence the need to determine the GWPZ because the application of geospatial technique which is a fast, cost-effective and dependable technique has not received much attention in the study area.

## RESEARCH METHODOLOGY
### Study Area
The study area consists of four local government areas of Akko, Kwami and Gombe, Yamaltu-Deba LGAs. The four local government areas lie within latitude 9˚14″N to 10˚14″N and longitude 10˚31″E and 11˚33″E. The Geology of the study area consists of the Kerri Keri Formation, Pindiga formation, Yolde Formation, Bima Formation, Gombe Formation, Jessu Formation and PorphyrGCPB. The soil units in the study area are Fluvosols, Leptosols, Luvisols, Nitisols, Regosols, Cambisols and Luvisols, Regosols and Cambisols, Leptosols and Regosols, Luvisols and Leptosols, Luvisols and Cambisols & Luvisols and Vertisols. The drainage of the study area comprises of the Dadinkowa dam and surface rivers. The Dadinkowa Dam is a man-made lake that is situated in Yamaltu-Deba Local Government Area (Ikusemoran *et al.,*2016).

### Dataset and their Sources
In this study, the Alos Polsar Digital Elevation Model with a 12.5m resolution and Sentinel level 1C satellite image of 10m resolution from the United States Geological Survey (USGS), soil and geology map of Nigeria from the Nigerian Geological Survey and rainfall data from the Global Weather Data were used to generate parameters for the determination of the GWPZ.

### Atmospheric Correction
The SNAP (Sentinel Application Platform) software which is incorporated with the plugin "Sen2Cor" (optical/thematic land processing /sen2Cor) was used to perform atmospheric correction from the Top of the Atmosphere (TOA) to the Bottom of the Atmosphere (BOA) by adapting ATCOR (Javhar et al, (2019. The corrected image was converted to level 2A.
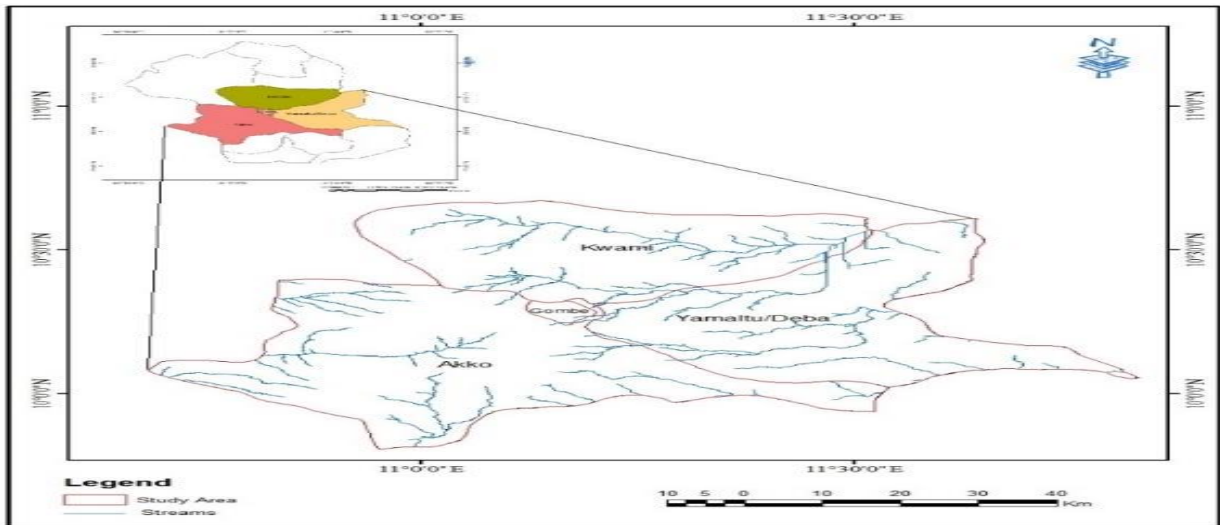
**Figure 1: The Study Area**

**Preparing Thematic Maps of Various Parameters for Groundwater Potential Zones**

From the literature reviewed, the following parameters influence or contribute to Groundwater Potential Zone determination. Thus, Topographic Wetness Index, Drainage, Watershed, Geomorphology, Geology, Slope, Soil, Rainfall, Normalized Difference Vegetation Index, Lineament, Elevation and Modified Normalized Difference Water index. The parameters were prepared based on various standards and peculiarities as presented in the flowchart of methodology (Figure 2).

**Multi-criteria Analysis to Determine Groundwater Potential Zone**

*Resampling and reclassifying parameters influencing groundwater potential zone*

The thematic maps for various parameters produced was resampled so that they have the same resolution and reclassified to a common scale 1 – 9 based on Saaty (1980). The Esri ArcMap 10.4.1/Resample module was used to resample the MNDWI, NDVI and Rainfall map from its 10m resolution to 12.5m resolution.
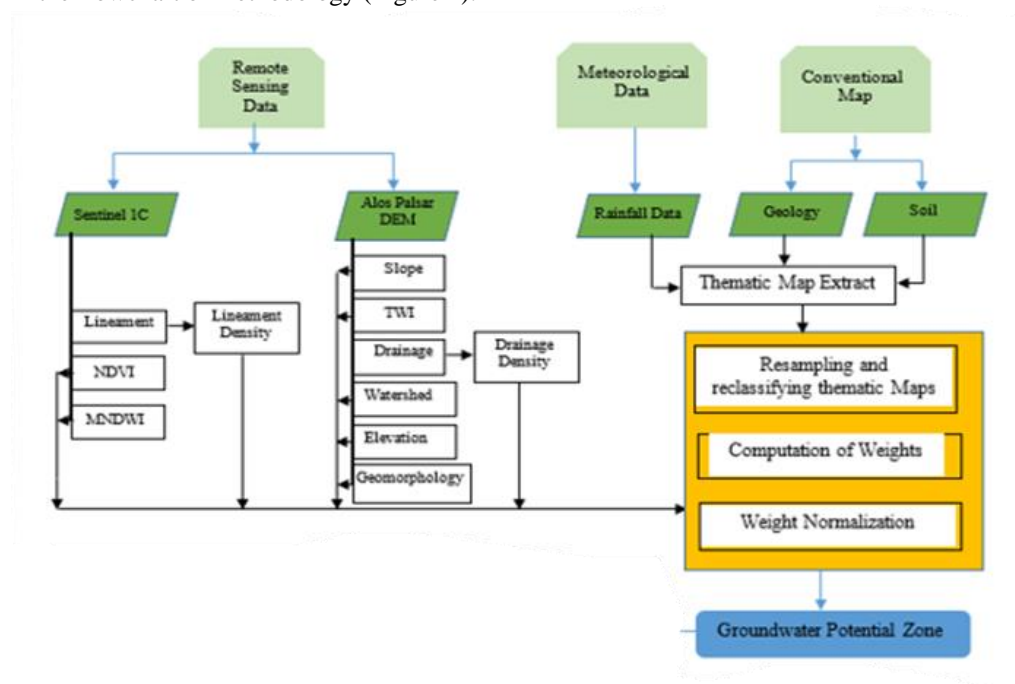


**Figure 2: Flow chart of Methodology**

*Computation of weights for parameters influencing groundwater potential zone*

The pairwise comparison matrix was carried out by using Analytical Hierarchical Process (AHP) techniques. In order to compute the cumulative weight of the various parameters influencing GW (Topographic Wetness Index, Drainage, Watershed, Soil, Geomorphology, Geology, Slope, Normalized Difference Vegetation Index, Lineament, Elevation, Rainfall and Modified Normalized Difference Water index), the relative weight of their corresponding classes was considered. Map Categorization and weight Assignment for groundwater potential and twelve parameters selected for groundwater potential zone was

done. Normalization of Assign Weight using AHP, on the basis of Saaty's scale, considering two themes and classes at a time on the basis of their relative importance to determine the Groundwater Potentials was done. Thereafter, pairwise comparison matrices of assigned weights to different thematic layers and their individual classes was constructed (Saaty, 1980) AHP and weights normalized by eigenvector approach. Consistency Ratio (CR) was calculated to examine the normalized weights of various thematic layers and their individual classes (Saaty, 1980). In order to compute CR of various thematic layers and their individual classes, the following steps was carried out using equations 1 and 2

$$A_1 \begin{bmatrix} ai11 & a12 \dots & a1n \\ \vdots & \ddots & \vdots \\ a21 & a22 \dots & a2n \\ an1 & an2.. & ann \end{bmatrix}, \text{aij}^{\cdot} = \frac{aij}{\sum aij} \text{ for i,j} = 1,2..n$$

1

The eigenvalue and the eigenvector calculated as:

$$W = \begin{bmatrix} W1 \\ W2 \\ \vdots \\ Wn \end{bmatrix} \text{ and } W_i = \frac{\sum_1^n aij}{n} \text{ for all n=1, 2\dots n and } W^{\cdot} = \begin{bmatrix} W1' \\ W2' \\ \vdots \\ Wn' \end{bmatrix}$$

2

W: Eigenvector,
wi: Eigenvalue of criterion i, and.
Computation of consistency index (CI) and consistency ratio was done using equations 3 and 4.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$  3

$$CR = \frac{CI}{RI}$$  4

$\lambda_{max}$: Average eigenvalue of the pair wise comparison matrix is given by equation 5.

$\lambda_{max} = \frac{/A/}{n}$  5

Where RI is the random index

A= matrix A was generated by Saaty's pairwise comparison table. A consistency check was computed to know the degree of inconsistency whether it is acceptable or not which must be less than 0.1. The matrix |A| was computed by using the online AHP program to determine the weight. It is worthy of note that, Goepel (2018) provided an implementation of an online software tool called the AHP online system (AHP-OS) for the Analytic Hierarchy Process. The AHP-OS was used to compute all the parameters in the above equation. Saaty's pairwise comparison method and scale of 1 to 9 was adopted as presented by Alireza *et al.* (2010).

*Performing weight normalization*

The weights were normalized based on equation 1 which was calculated by averaging the values in each row to get the corresponding ranking, and the results of normalized weights of each parameter was represented in percentage.

*Determining groundwater potential zone*

Having normalized the weight, the thematic layers of the assessment criteria have been established and assigned to weighting, The Groundwater potential zone (GWPZ) was computed. This parameter represents a dimensionless quantity that predicts the potential zones of groundwater in the study area. The computation of GWPZ was based on Equation 6.

GWPZ= $\sum_{i=1}^n WiRi$   6

where w is the weight of each thematic layer, R is the corresponding thematic or raster layer, i and n is the number of thematic layers. The ESRI ArcMap 10.4.1 weighted overlay module was used.

**RESULTS AND DISCUSSION**

The thematic maps generated for this study as shown in Figures 3-15 are: Modified Normalized Difference Water Index (MNDWI), Normalized Difference Vegetation (NDVI), Lineaments and Lineament

Density, Drainage Density and Watershed, Topographic Wetness Index (TWI), Slope and Elevation,

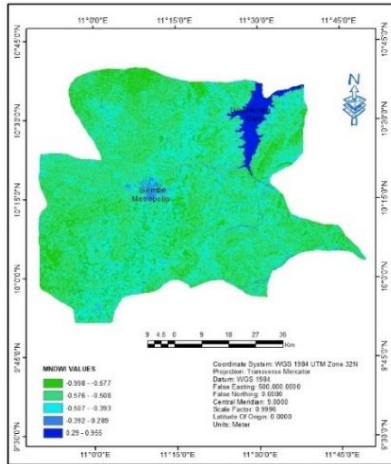Geomorphology, rainfall, soil and geology maps of the study area.



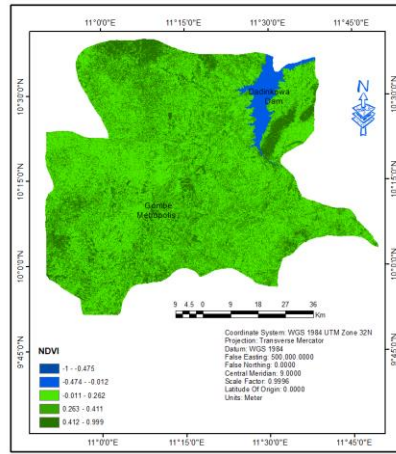**Figure 3: Modified Normalized Difference Water Index**



**Figure 4: Normalized Difference Vegetation (NDVI)**

Figure 3 shows the NDWI which uses the green and Near Infrared (NIR) bands of remote sensing images based on the phenomenon that the water body has strong absorbability and low radiation in the range from visible to infrared wavelengths. The value range computed was found to be from -0.998 to 0.995. The negative values may indicate non-water features while the positive values indicate water bodies. The range 0.29-0.955 indicates the visibility of surface water provided in the map which covers an area of 181.11km$^2$ that is 2.9%. Figure 4 is the NDVI with values ranging from -1 to 0.999 as the highest value (green) indicating high

vegetation index. Luxuriant vegetation tends to have higher NDVI. Which has a value range of 0.412 to 0.999 covering an area of 824.845km$^2$ (13.3%) and mostly found at the extreme north and east of the study area. Figure 5 indicates the distribution of lineament in the study area. The rose diagram in Figure 5a gave a computed statistic that had placed the mean direction of the lineaments to 352.85697 degrees and the rose diagram indicated a NW – SE orientation and are many (4301 features). This confirmed the direction of orientation of lineaments (Gajere & Andongma, 2015) that the NW-SE lineament is the most dominant.
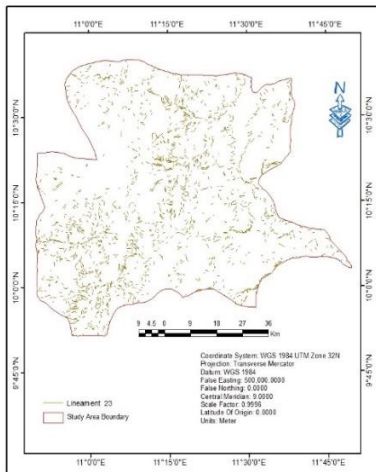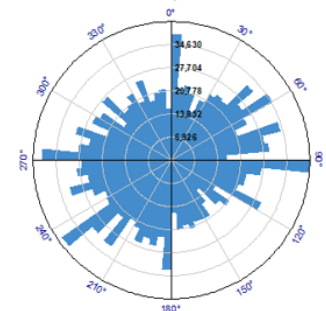


**Figure 5: Lineaments Map**



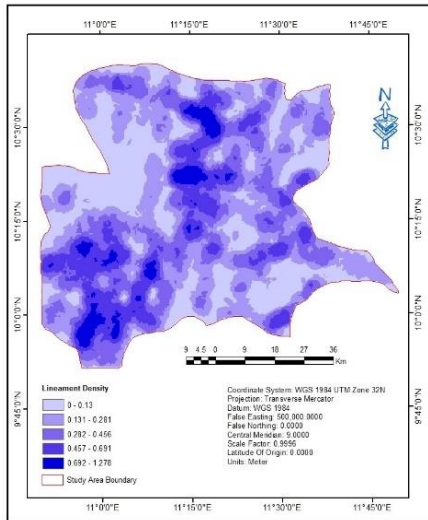**Figure 5a: Lineaments Rose Diagram**
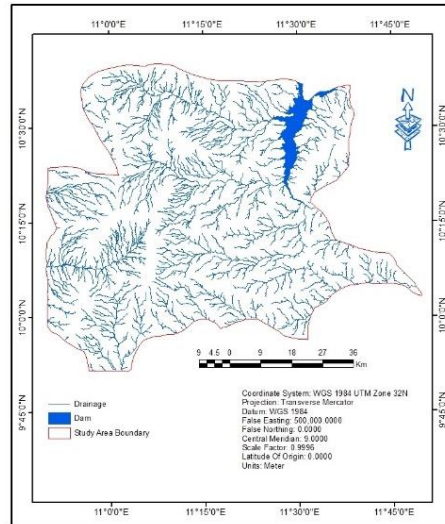
**Figure 6: Lineament Density Map**



**Figure 7: Drainage Map**

The lineament density map in Figure 4.6 indicated areas with higher density ranges from 0.457 to 0.691 classified as high density while 0.692 to 1.278 classified very high density. Figure 7 is the drainage map showing the various tributaries contributing to the dam. The drainage number (frequency) can express the drainage density property, and it has the strongest relationship with water recharge into sub-surface media as asserted by Bhunia *et al*. (2012). The drainage map in Figure 7 falls within the watershed in Figure 8. The result in Figure 9 shows a minimum value TWI of 0.793334 in green and maximum value of 24.2424 in blue. That means, TWI value of 24.2434 is high and low value is 0.77334.
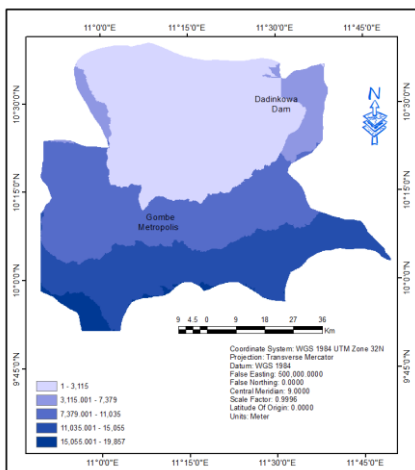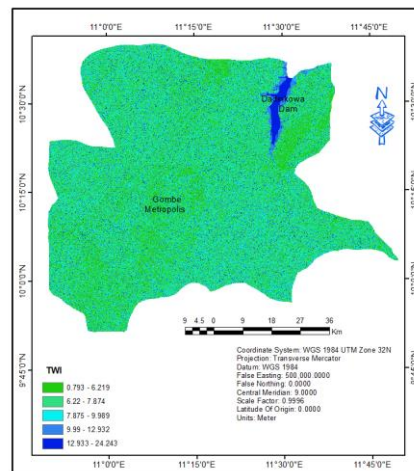


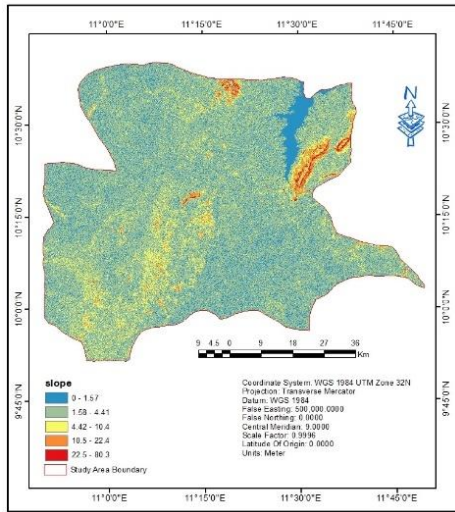**Figure 8: Watershed Map**



**Figure 9: Topographic Wetness Index Map**
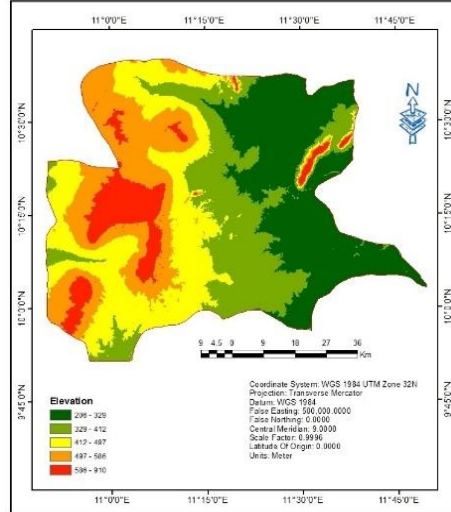
**Figure 10: Slope Map**



**Figure 11: Elevation Map**

Figure 10 shows the slope map with a minimum slope angle range of 0˚ to 1.57˚ to a maximum range of 22.5˚ to 80.3˚. Steep slope range in degrees of 10.5˚ to 22.4˚ covering 107.56km$^2$ (1.7%) and 22.5˚ to 80.3˚ covering 24.15km$^2$ (0.4%) are present, groundwater potential is low because there is more surface runoff than infiltration as noted by Fashae *et al*. (2014) that areas with less than 6% slope was rated high with great potential of groundwater. In areas characterized by flatlands and/or valleys i.e. 0˚ to 1.57˚ covering 1324.12km*2* (21.3%) and 1.58˚ to 4.41˚ covering 3921.41km*2* (63.1%), and from 4.42˚ to 10.4˚ covering 833.06km*2* (13.4%), groundwater potential is high because it is easier for the water to form pools and infiltrate than to runoff on the

surface. Banerjee *et al*. (2021) asserted that a high sloping region causes more runoff and less infiltration and have poor groundwater prospects compared to the low slope region. Figure 11 shows the elevation map with 206m as the lowest elevation and 910m as the highest elevation. The elevation was classified into range thus 206m to 329m covering 1667.93km$^2$ (26.9%), 329m to 412m covering 1373.38km$^2$ (22.1%), 412m to 497m covering 1500.43km$^2$ 24.1%), 497m – 586m covering 1175.78km$^2$ (18.9%) and 586m – 910m covering 492.78km$^2$ (7.9%). Areas that fall within 206m to 412m were classified as high potential because according to Amir (2017) and Abdo *et al*. (2021), it can retain infiltration.
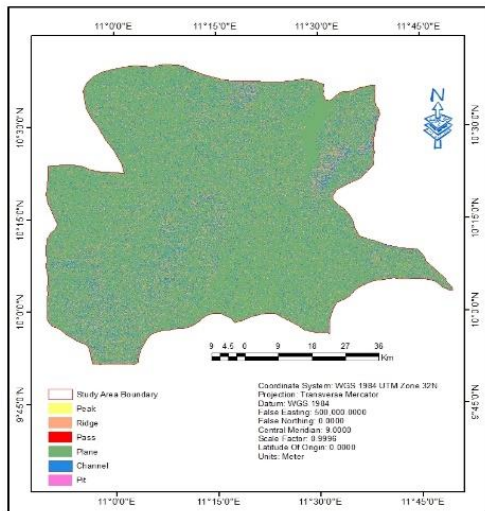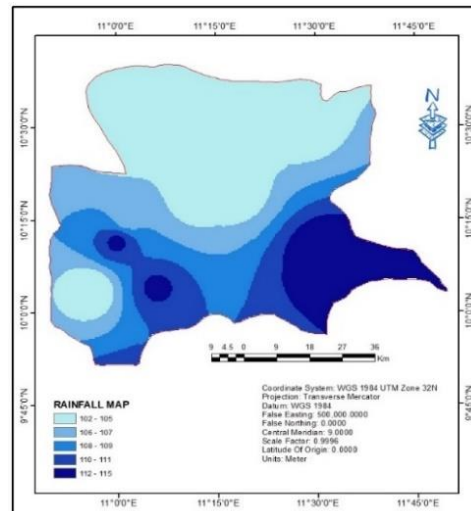


**Figure 12: Geomorphology Map**



**Figure 13: Rainfall Map**

Figure 12 shows morphometric features: peak, ridge, pass, plane, channel, or pit. The plane, channel and pit in the figure have higher groundwater potential. Soumen

(2014) inferred that alluvial plain have more impact in occurrence of groundwater, while the mountainous and residual hills areas have shown less impact in

controlling groundwater thus supporting the choice of plane, channel and pit in Figure 12 to having higher groundwater potential. Figure 13 is a rainfall map of the study area that shows this variation. Generally, high annual rainfall distribution indicates the presence of high groundwater potential zones as asserted by Rose and Krishnan (2009), Fashae *et al*. (2014) and Jahan *et al*. (2018). Therefore, the area with high amount of rainfall with possibility of infiltration of the soil with 112mm to 115mm is the south-east followed by 110mm to 111mm is given more weighted value i.e., higher groundwater potential compared to area with low annual rainfall of 102mm to 105mm is the north. The various classes of soil can be seen in Figure 14 shows that Fluvisols/Regosols covers 196.09km$^2$ (3.1%) and having high capacity for groundwater as asserted by Spaargaren (2001). The clay nature of Luvisols in the

study area combined with Leptosols make it have groundwater potential. The geology map of the study area can be seen in Figure 15 which consists of Shale, Sandy Clay, Calcareous Sandstones (also known as Yola Bima-Yolde formation) covering 634.41km$^2$ (10.1%) having more yield for groundwater. Feldpathic Sandstone, Calcareous Sandstone and Shelly Limestone (also known as Bima formation) covers an area of 1152.76km$^2$ (18.5%) and also have the capacity to transmit groundwater. The Sandstone, Siltstone, Shale and Ironstone (i.e., Gombe formation) covers an area of 1743.53km$^2$ (21.8%). The Sandstone, Siltstone and Clay (i.e., Kerri-Kerri formation) cover the largest area of 1450.11km2 (32.5%) of the study area. Generally, the study observed that all the factors used in the study tend to show the yield of groundwater to the northeast, east and southeast of the study area.



**Figure 14: Soil Map**
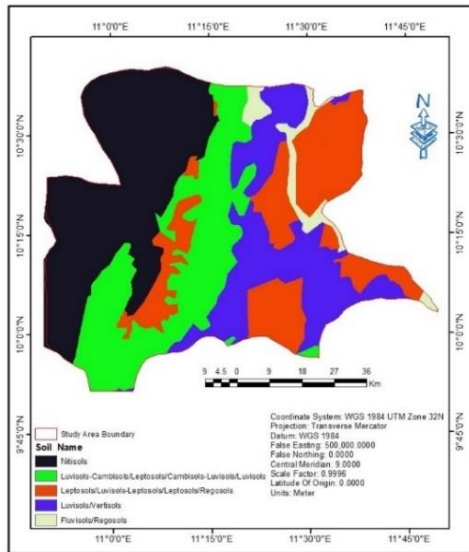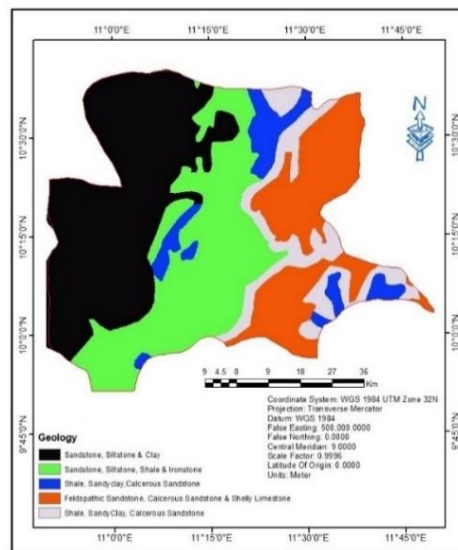


**Figure 15: Geology Map**

The Final Groundwater potential zone (GWPZ) map is presented in Figure 16. The GWPZ was classified into five classes that is Very Low Potential, Low Potential, moderate Potential, high potential and very high

potential as stated by Motilal *et al*. (2019). The study shows that the Northwest, West and Southwest of the study area have very low potential of GW.
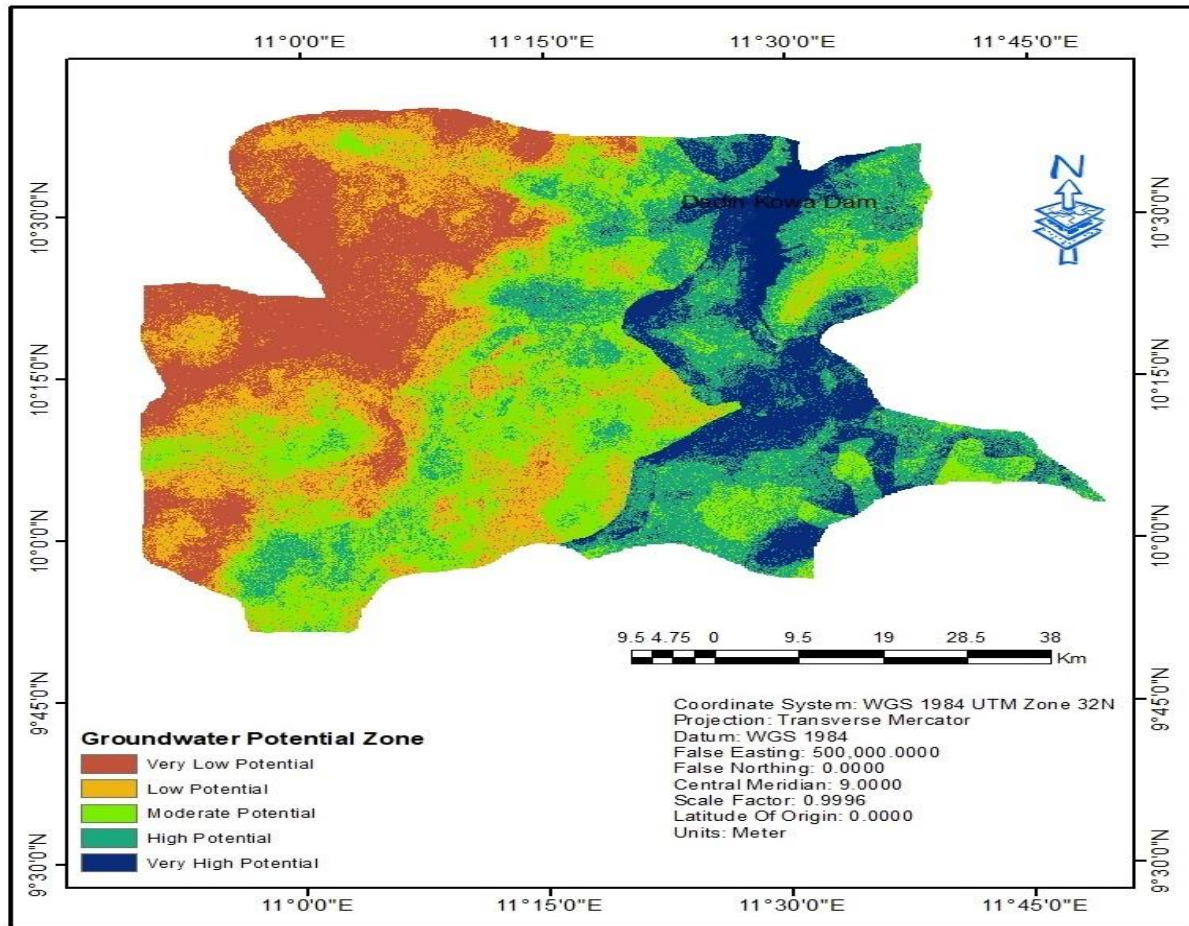
**Figure 16: Groundwater Potential Zone Map**

## CONCLUSION

Water is the underpinning of life and livelihoods and is fundamental to sustainable development. Successful water management will serve as a key to the achievement of the Sustainable Development Goals (SDGs) number 6 as defined by the United Nations - which is to 'Ensure availability and sustainable management of water and sanitation for all. It is on this premise that the issue of GWPZ determination cannot be over-emphasized.

The integration of these criteria; Topographic Wetness Index, Drainage, Watershed, Geomorphology, Geology, Slope, Soil, Rainfall, Normalized Difference Vegetation Index, Lineament, Elevation and Modified Normalized Difference Water index using the Geospatial technique coupled with the Analytical Hierarchical Process is a veritable tool in GWPZ determination. The GWPZ was classified into five classes that is Very Low Potential, Low Potential, Moderate Potential, High Potential and Very High Potential. The study shows that the Northwest, West and Southwest of the study area have very low potential of GW. This can be attributed to the Soil, Geomorphology, elevation, slope and Geology in

the area. Conversely, the Northeast, East and Southeast have very high potential GW. The study reveals a very low potential of Groundwater (GW) in the Northwest, West and Southwest of the study area, thus, prospecting for Groundwater (GW) in such area will be an effort in futility. The study therefore, recommended the use of the Dadin-kowa Dam for pipe borne water reticulation to provide water for agriculture, industry, and domestic purposes.

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