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A 2D GIS Approach for Mapping Aquiferous Zones Using Remotely Sensed Data within Obubra, Southeast-Nigeria

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Abstract

Groundwater is vital to the sustenance and well-being of man-kind, although it is constantly under immense pressure. For this reason, there is need to develop an effective, reliable, scientific and sustainable means of delineating zones of groundwater occurrence and distribution with high precision in other to effectively explore for this resource. In this study, remote sensing (RS) and geographical information system (GIS) have been combined to develop thematic maps of the zones of groundwater occurrence and distribution based on variable factors such as; elevation, drainage, lineament, slope, lithology and soil. The analytical hierarchy procedure (AHP) was employed to classify and subsequently assign weight to each variable factor through weighted overlay analysis. Integration of these factors with their relative classes defined was used to produce a 2D-model for predicting surface aquifers mapped within Obubra. The study delineated three (3) surface aquifer zones representing groundwater potential zones. Zones representing high groundwater potential cover an area of approximately 331.94 Km^2, accounting for 29.58% of the study area. The region that represents moderate to good groundwater occurrence and distribution covers an estimated area of approximately 648.42 Km^2, occupying 57.78% of the study area. Zones with groundwater of low potential account for a total surface area of approximately 141.81 Km^2 which is about 12.64% of the entire study area. Regions that show good to moderate and high groundwater potentials, have a wider distribution all across the study area except at the southernmost part. The study therefore shows that it is effective in delineating surface potential zones and hitherto a 2D surface aquifer model for groundwater exploration campaigns within Obubra and its environs.

Keywords

Groundwater, Aquifer, Mapping, AHP, Remote Sensing, Zones

1. Introduction

Groundwater is an essential natural resource for the reliable and sustainable supply of potable freshwater in both urban and rural environments. According to [1], the economic and social development of any community is influenced by the availability of sufficient quantity and a good quality of water resources, its seasonal variability for drinking, domestic and agricultural purposes. Globally, it is known that the largest available source of fresh water for use occurs underground [2]. However, due to increase in population, much pressure has been exerted on the available water resource [3]. It is therefore necessary to assess this resource for its sustainable management.

Studies according to [4], reveal that the occurrence of groundwater in any given place depends on the nature of the underlying lithology, structural lineaments, topography, slope, rainfall, vegetation and soil type. Therefore during exploration campaigns for groundwater, information about groundwater occurrence should be acquired by employing a systematic approach. In Nigeria for example, the non-availability of funds and facilities has made it extremely difficult to carry out site investigations prior to drilling water well [5]. Field-based geological, hydrogeological and geophysical methods have been used conventionally to investigate and delineate groundwater zones [6] [7] [8], but these techniques are rather time consuming and too expensive to carry out easily.

Presently, the use of remotely sensed data together with conventional maps has been applied in predicting groundwater prospective zones [9] [10] [11]. Remote sensing not only provides a wide-range scale of the space-time distribution of observations, but also saves time and money [12]. In addition, it is widely used to characterize features on the earth surface such as lineaments, drainage patterns and lithology as well as to map possible groundwater recharge zones [13]. Many studies have applied remote sensing and geographic information system for the exploration of groundwater potential zones. Lineaments are used to predict and map groundwater prospective zones [14], while others studies have combined more factors such as drainage density, geomorphology, geology, slope, land-use, rainfall intensity and soil texture [15] [16]. Furthermore, with the aid of remotely sensed data, it is possible to develop better regional model of hydrological processes in a drainage basin [17]. The reliability of this method depends to a large extent on the accuracy and the amount of the data sets available.

Within Obubra and its environs, the dominant socio-economic activity is agriculture which includes both subsistence and commercial farming, and fishing [18] [19] [20]. These activities are all water dependent, for this reason there is need to strategically assess and develop groundwater resources in this area to effectively sustain agricultural and domestic needs. This will help to provide self-sufficiency in food production and boost the overall economic output of the people from the area. The aim of this study is to produce a 2D surface model of the spatial representation and delineation of surface aquifer units present the study area by employing remote sensing and GIS tools. This will involve the production and subsequent integration of various thematic maps produced from remotely sensed imageries with GIS techniques.

2. The Study Area

2.1. Description of the Study Area

The study area is Obubra local government area, Cross River State. It lies between latitudes 5˚44'N to 6˚17'N and longitude 8˚11'E to 8˚33'E, covering an area of approximately 1122 km^2. Obubra and its environs are situated in the central part of Cross River state, southeastern Nigeria (**Figure 1**). Vegetation in the area is typical of the rain forest belts of Nigeria and consists basically of tall trees and grasses, sometimes forming canopies. The area is characterized by two major climatic conditions namely; the rainy season which begins in April and ends in mid-October, while the dry season starts by mid-October up to April. Also, rainfall ranges from 120 to 220 mm annually [21]. One obvious characteristic of rainfall in the study area is the "*double maximum*" with peaks in the months of July and September. There is usually a brief break in August often termed the August break. Annual precipitation is usually over 2200 mm, while annual temperatures range between 23˚C and 32˚C [7]. The average relative humidity for

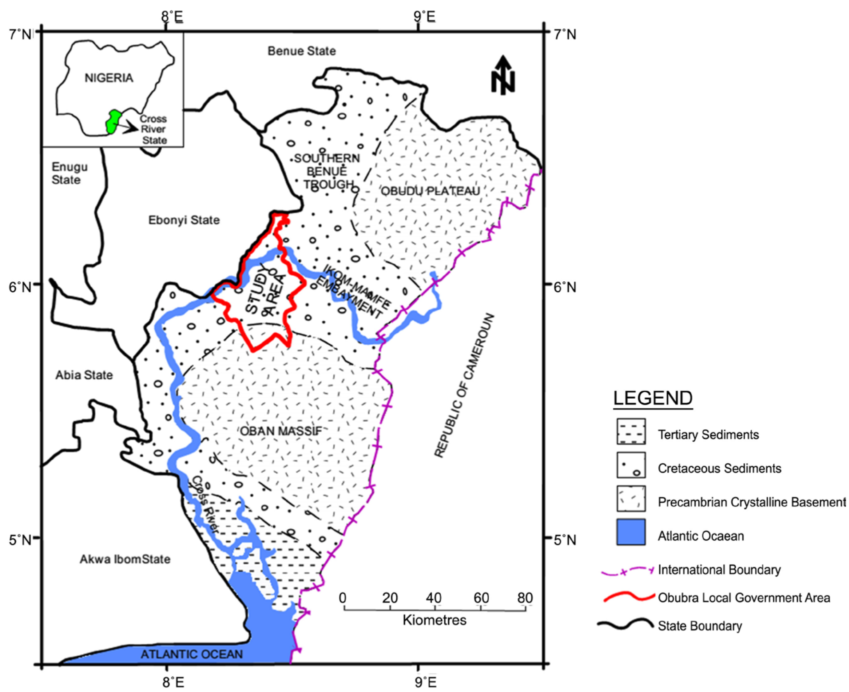

Figure 1. Location map of the study area within Cross River state [modified after 4].

the area is about 88%. The study area is characterized by low relief and gently undulating topography with surface water consisting mainly of seasonal ponds and few streams.

2.2. Geology and Stratigraphy

Geologically, the study area is situated partly within the Nigerian sector of the Ikom-Mamfe Embayment and partly within the crystalline basement terrain of the Oban Massif. The Ikom-Mamfe Embayment extends from segment of the lower Benue Trough laterally into parts of western Cameroun [22], where it covers an area of 2016 km^2 [23]. Observation has shown that the basin is bounded in the south by the Oban Massif and to the north by the Bamenda Highlands, areas of the Precambrian granites, gneisses and migmatites making up the western part of the Adamawa uplift. Crystalline rocks within the basement segment of the study area comprises of basalts, diorites, dolerites, granitic rocks, gneisses and schists [24].

According to [25], there are four (4) major litho-stratigraphic units present namely; the Asu River Group (ARG), Eze-Aku Group (EAG), Nkporo-Afikpo Shale Formation (NASF) and the Benin Formation, BF (**Figure 2**). The Albian ARG is the oldest in the area, and it directly overlie the Precambrian basement. Sediments here consists of impervious shale, limestone with some sandstone intercalations and ammonites [26].

Common lithology found in the Eze-Aku Group (EAG) comprises thick flaggy impervious calcareous and non-calcareous shale, sandy or shelly limestone and calcareous sandstone. The EAG is overlain by the post-Santonian NASF which occupy most of the western parts of the basin. The shales are often carbonaceous and pyritic which is suggests that the sediments were deposited in a poorly oxygenated shallow water environment with restricted air circulation [27]. Alluvial deposits are found along parts of the Cross River flood plains, while Tertiary volcanic rocks like basalts and dolerites intrude into the overlying

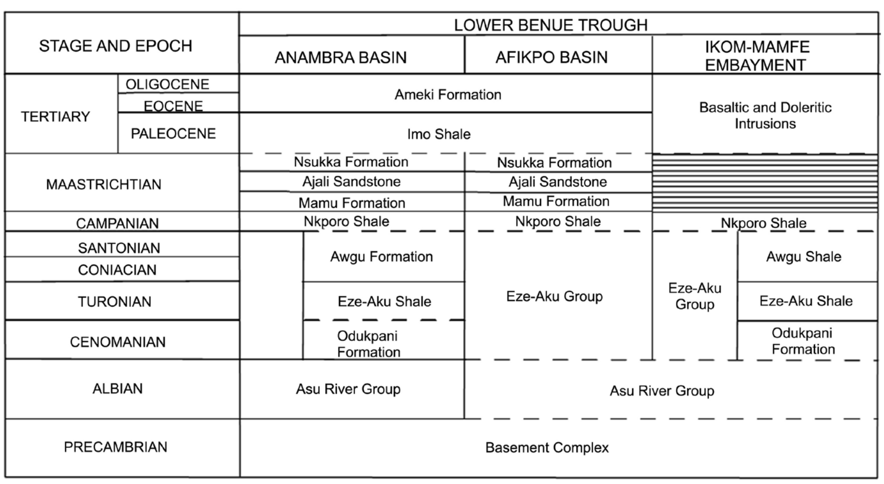

Figure 2. Stratigraphy of the Ikom Mamfe Embayment with adjoining Anambra and Afikpo Basins.

Cretaceous sedimentary units in some locations [28]. Post Cretaceous tectonic activities are believed to have originated from the adjoining Cameroun.

2.3. Hydrogeology

There are four major shallow hydrogeological provinces identified namely; crystalline basement province, Cross River Plain Province (basically dominated by the Albian Asu river group), Eze-Aku Group and Nkporo-Afikpo Shales Province [29]. Groundwater occurrence in both the crystalline basement and shales province depends on the presence of secondary structures like fractures, joints, fissures and other weathered litho-units which are very important in hydrogeological studies because of their role in the storage and transmission of groundwater. Groundwater yield from these structures occurs at shallow depth of less 50 m with poor groundwater yield in some locations [4]. Comments attributed to [6] have suggested that geophysical guided drilling campaigns in the study area reveal that a huge volume of water occurs at depth greater than 100 m.

Structural orientations in the study area are predominantly NW-SE direction and this has constrained the groundwater to flow in the same direction [30]. Precipitation is the primary source of recharge and this is evident during the dry season when seepages from the surrounding elevation terrains will cease while the entire water-logged low lying areas dry up.

3. Methodology

3.1. Image Acquisition and Processing

The study employed remotely sensed satellite data and geographical information system (GIS) to spatially and effectively carry out mapping/delineation of surface aquiferous zones. It begins with the acquisition of satellite data like Landsat 7 ETM+ and digital elevation model (DEM) of the Advanced Space-Bourne Thermal Emission and Reflection Radiometer (ASTER) at 30 m resolution, and also existing maps of geology and soils. Information relating to elevation, slope, drainage and lineament are extracted from the ASTER-DEM satellite data, while lithogic and soil map are digitized from the existing maps of the area obtained. The information alongside with the existing geologic and soil maps for the area were used to produce thematic maps by assigning defined classes. The thematic maps were produced using a combination of the software ARCMAP 10.3 and GLOBAL MAPPER 17. Various lithologic units that occur in the area were digitized from geological map produced by the Nigerian Geological Survey Agency (N.G.S.A.), while soil map was sourced from world soil map produced by Food Aid Organization (F. A. O.) and then digitized.

Each layer produced was further classified by assigning weights using the analytical hierarchy process (AHP) with aid of the software EXPERT CHOICE 11.0. A higher weight value is assigned to factors with greater influences on groundwater distribution and occurrence and vice-versa. Integration of these factors with their potential weight is then computed through weighted overlay analysis. Details of the step by step procedures followed in the study is represented in the schematic diagram (Figure 3).

3.2. Analytical Hierarchy Process (AHP)

This is a system of assigning weight to a set of parameter in order to evaluation their impact make the best decision.

Higher weights reflect those parameters with greater influence on the overlying decision to be made. The assigned weights and consistency ratios for the different thematic maps produced were computed using the software EXPERT CHOICE 11.0.

The weight classes, weight values and consistency ratio of each parameter that was used to produce the thematic map during the study are presented (Table 1). These values depend on their relative contribution to the occurrence and movement of groundwater in accordance with the approaches of [4] [31]. The term consistency ratio is expressed by the ratio of consistency index (CI) to the random index (RI) according to (32).

Normally, a perfectly consistent decision maker should always obtain CI = 0, but in reality values with;

$$\frac{CI}{RI} < 0.1$$

Inconsistencies with this condition are generally tolerable, and thus may produce a more reliable result.

4. Result and Discussion

The weight, class and consistency ratio evaluated for each parameter analyzed to

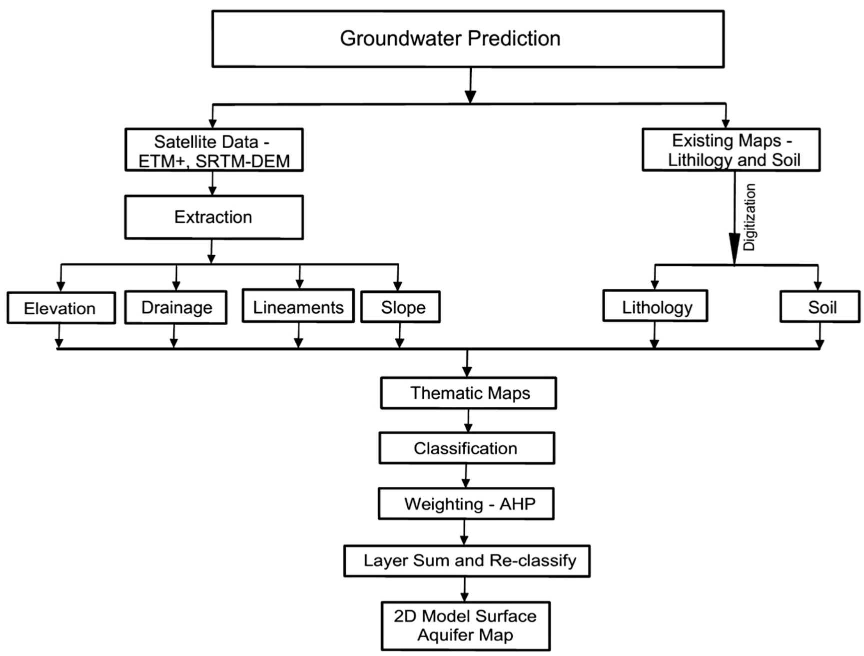

Figure 3. Flow chat representation of a GIS-based methodology.

Table 1. Assigned weights, class and consistency ratio of various features within the study area.

S/N	PARAMETER	CLASS	WEIGHT	CONSISTENCY RATIO, CR
1	Lineament Density	Very High	46	0.03
		High	31	
		Moderate	15	
		Low	8	
2	Lithology	Shale, Limestone and sandstone	35	0.05
		Shale, Limestone with sandstone intercalations	30	
		Shale and Limestone	19	
		Basalt	6	
		Diorite	6	
		Granite Gneiss	6	
3	Soils	Gleysols	52	0.02
		Nitosols	24	
		Cambiosols	15	
		Acrisols	9	
4	Drainage Distance	Very Close	49	0.02
		Close	23	
		Far	14	
		Very Far	9	
		Extremely Far	6	
5	Slope	Very Flat	47	0.02
		Flat	26	
		Steep	17	
		Very Steep	10	
6	Elevation	Very Low	46	0.03
		Low	29	
		High	17	
		Very High	8	

Source: Author.

determine the groundwater potential of Obubra and its environs have been presented in Table 1. The range of CR computed in the study is 0.02 - 0.05 and this lies the acceptable threshold consistency value of 0.1.

4.1. Lithology

Lithological make-up of the study area is unique because it consists of crystalline basement rocks and sedimentary rocks that have been intruded by recent volcanic and intermediate rocks. The lithological map of Obubra local government is presented (**Figure 4**), with the southern-most part composed of Basement Complex rocks of various suites of igneous and metamorphic rock units such as basalts, diorites and granite gneiss. Also, sedimentary rocks like shale, sandstone and limestone are found within the study area. In most parts, the shales have been baked and fractured in line with the complexity of the tectonic history as a result of the intrusive rocks that invaded the host rocks thereby enhancing its secondary porosity.

Weighting assigned for different the lithologic unit was based on the degree of the porosity and permeability for each. The porosity of a rock determines its ability to store groundwater, while permeability is the ease with which a rock unit is capable of transmitting groundwater. What determines the properties of a water-bearing unit is the number of fractures present and the inter-connectivity between them. Region associated with a high amount of fractures that are inter-connected will have a correspondingly high porosity and permeability, and

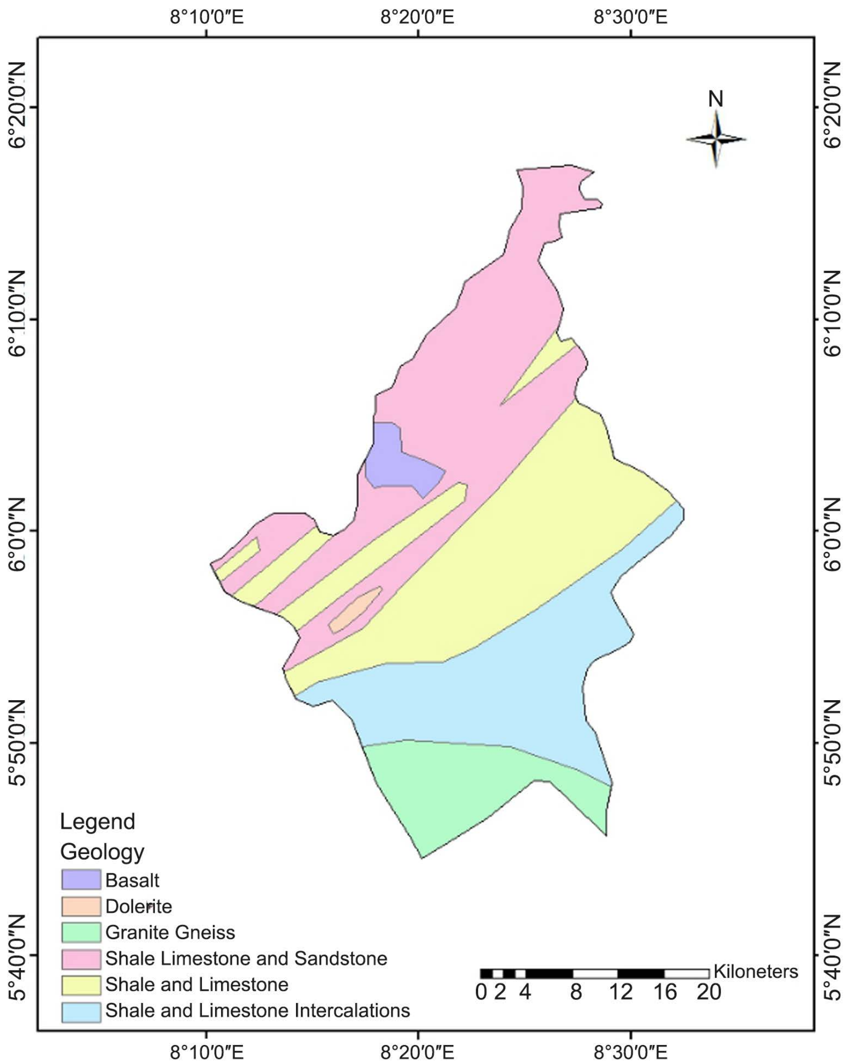

Figure 4. Distributions of the various lithological units in the study area.

vice versa. Therefore, rocks with higher porosity and permeability were assigned the highest weight, however, those with lesser porosity and permeability are assigned lower weight.

4.2. Lineament

Lineaments structures present on the landscape depicts planes of structural weaknesses like fractures, faults and joints. They create pathways or conduit for the storage and movement of groundwater. When interconnected, they create zones of permeability. The length of linear features per unit area termed the "*Lineament density*", is used to express the spatial distribution and occurrence groundwater. Further, they usually denote permeable zones [32]. The higher the number of lineament per unit area, the greater the percolation of water into the sub-surface and this can be used to predict the groundwater potential zones. Thus, interconnectivity of these lineament structures is a reflection of the groundwater yield in any given area.

The lineament density map produced for the study area is classified into four classes; low, moderate, high and very high (**Figure 5**). The weighting, classes and

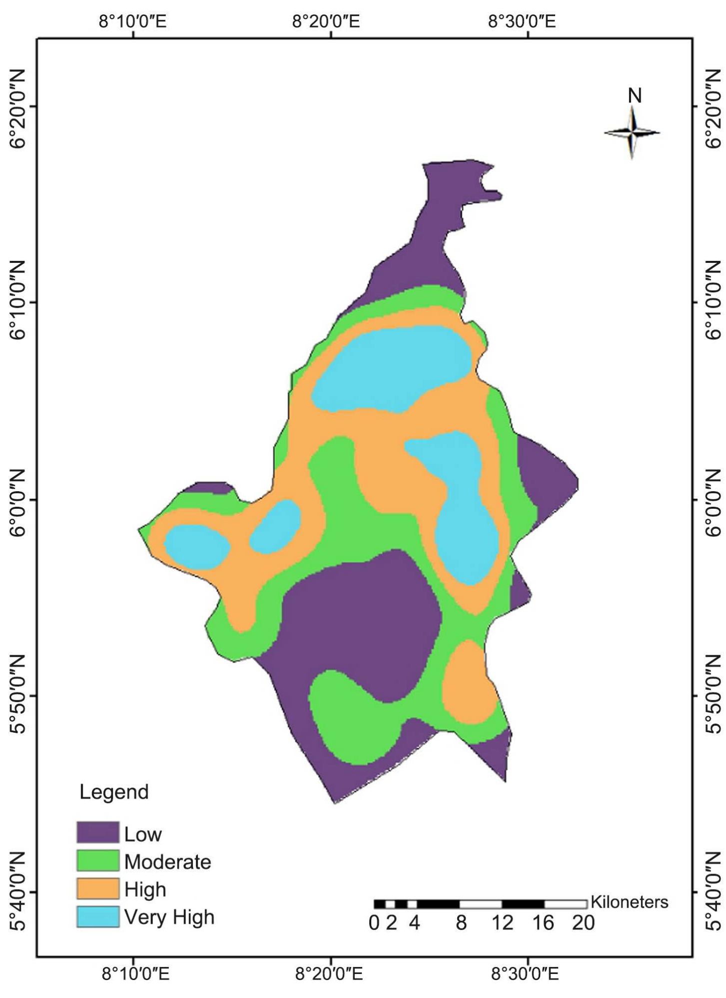

Figure 5. Distribution of lineament density within the study area.

consistency ratio is well presented in **Table 1**. Higher lineament densities are assigned a greater weight value and vice versa. Observation has shown that for most parts of the study area, the lineament density is high to very high from parts of the central to the northern part of the study area and parts of the south-east (SE). They are represented with the color orange to sky-blue respectively. These regions coincide with area which bears shale, limestone and sandstone lithologic suites that have been invaded by intrusives such as basaltic and dioritic rocks. However, regions with higher lineament density are considered as good for groundwater development in the area. The host rock in these areas have been baked owing from the enormous heat emanating from the intruding body and consequently fractured to create pathways for groundwater to occupy and flow. Regions with moderate lineament density are spatially distributed throughout most parts of the study area depicted with a green colour. At the northern, southern, eastern and a little part of the western fringes, the area is characterized by a low lineament density. These regions are depicted by the colour violet and may connote zones of poor permeability compared with the rest regions or classes.

4.3. Elevation

There are four (4) main classes namely; very high, high, low and very low, which have been delineated with respect to the elevations using satellite data (ASTER-DEM) obtained for the study area (**Figure 6**). Elevation describes the height above mean sea level of a terrain and this plays an important role in the groundwater level. Generally, elevation in the area increases from north to south (N-S) with the highest elevation occurring in the southern part which constitutes mainly of the basement rocks in the study area. Also, high elevations were noted within the central portion of the area, as well as it coincides with locations where the intrusives occur. The low-lying regions of the study area are flat or very gentle plains that are characteristic of the regions dominated by the underlying shale, limestone and sandstone. Higher elevation around the south, extends into the basement terrain of the Oban Massif. For this study, the significance of elevation feature with respect to groundwater occurrence and distribution are classified and weighted with increasing order of groundwater potential as very high (8) < high (17) < low (29) < very low (46). Therefore areas around the lowland will have a higher prospect for groundwater occurrence and distribution, and so it is assigned a higher weight than those within the highlands. Weighting for the layer is presented in **Table 1**.

4.4. Drainage

Groundwater level is also greatly influenced by the drainage system present in any given area. Drainage patterns usually reflect the characteristic of surface and subsurface geologic frame-work. Majority of the drainage within the study area were observed to originate from the central parts where pockets of igneous intrusions are rife, and elevated terrains of the southern parts which constitutes

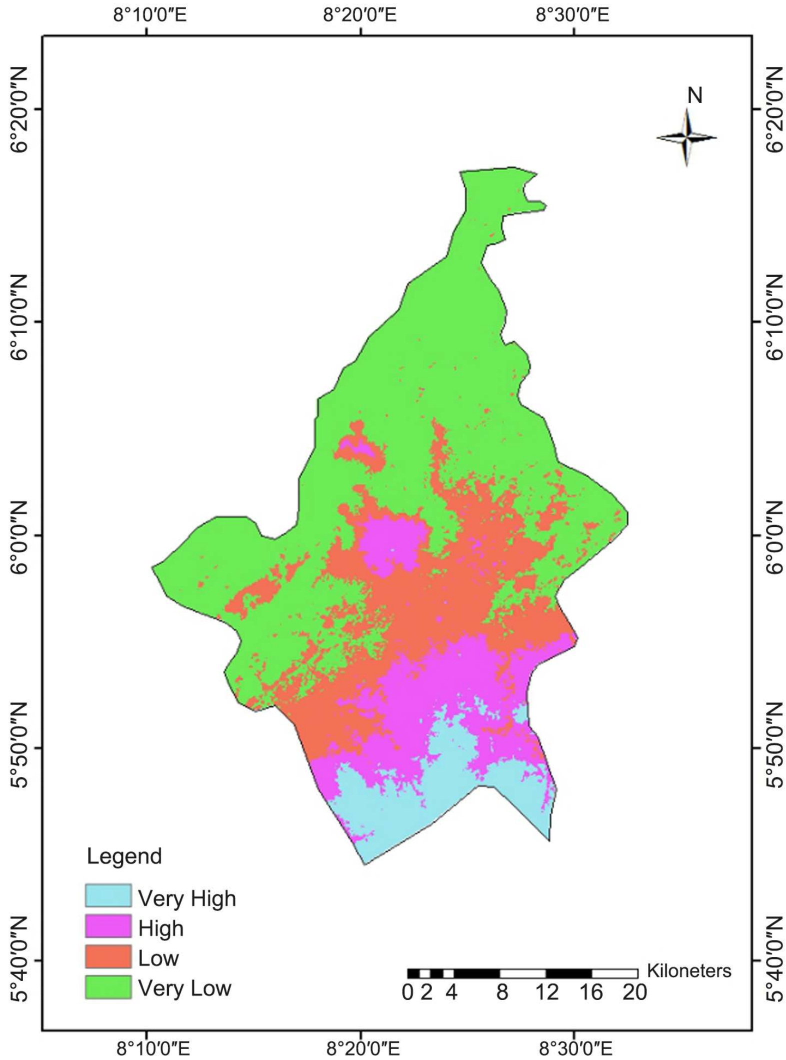

Figure 6. The elevation classes within the study area.

predominantly of crystalline basement rocks. Surface drainage of the study area was extracted from ASTER-DEM satellite data and presented in **Figure 7**. Regions of more closeness to the drainages are predictable zones that represent areas with very high drainage density. They are expected to have high groundwater potential than those areas further away from it. These predictable zones are the buffer areas that are considered more suitable for groundwater occurrence and distribution. This is because area close and around surface drainages, percolates and recharges the groundwater. Thus, regions close to the drainage were assigned higher weight than those further away from the drainage and weighting for the different thematic layers are presented in **Table 1**.

4.5. Slope

As an aspect of geomorphologic features, slope is another factor that can influence the infiltration and recharge of groundwater in an area. This is because the nature of slope can indicate groundwater prospect of an area. For example, a

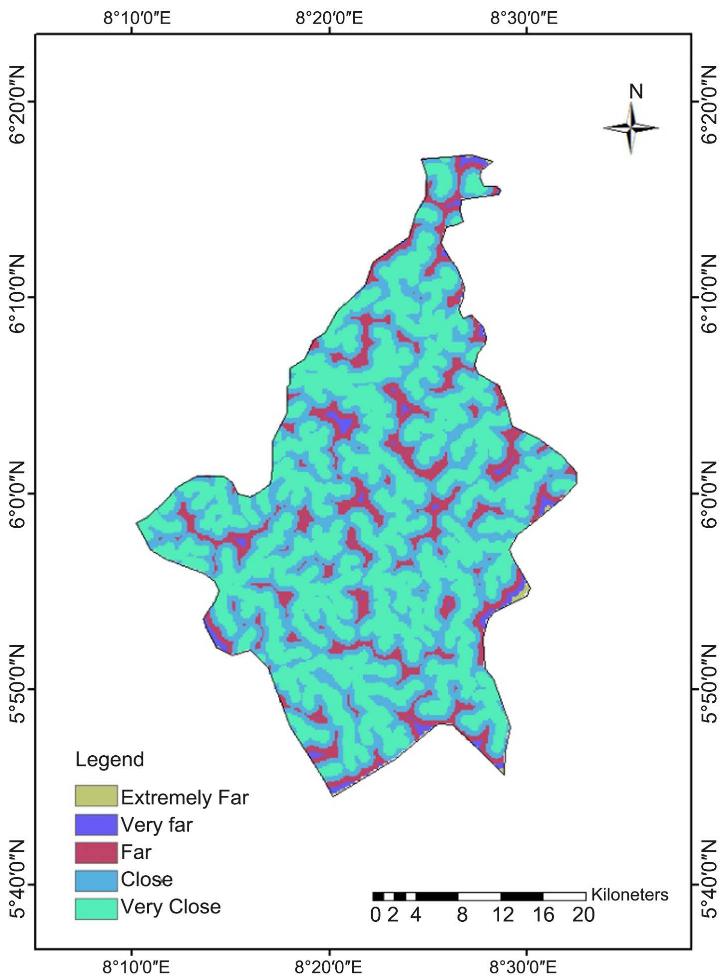

Figure 7. Thematic map for the various drainage proximity classes.

steep slope will enhance high run-off, and so thus there will be a short time for the percolation and infiltration of groundwater into the subsurface for recharge to take place. However, a flat slope on the other hand will allow more time to retain the rainwater falling on the earth surface before percolation and infiltration into the sub-surface. This favours recharge of the groundwater and therefore enhance the groundwater potential of the area. Thematic map have been produced for the slope data and is presented in Figure 8. Slope data were extracted from digital elevation model (ASTER-DEM) and were classified as very steep, steep, flat and very flat. The significance of each slope feature in relation to groundwater availability have been classified and weighted in order of increasing potential as; very steep (10) < steep (17) < flat (26) < very flat (47) and is presented in Table 1. Slopes within the study area show that steeper surfaces occurs around the basement terrain at the southern-most part and this flattens out towards the northern part of the area. Although, there is wide spatial distribution of slopes within and around the central part of the study area which is an indication of varied degree of run-off and recharge at the surface. This implies a varied groundwater potential as result of the complex geologic setting of the study area.

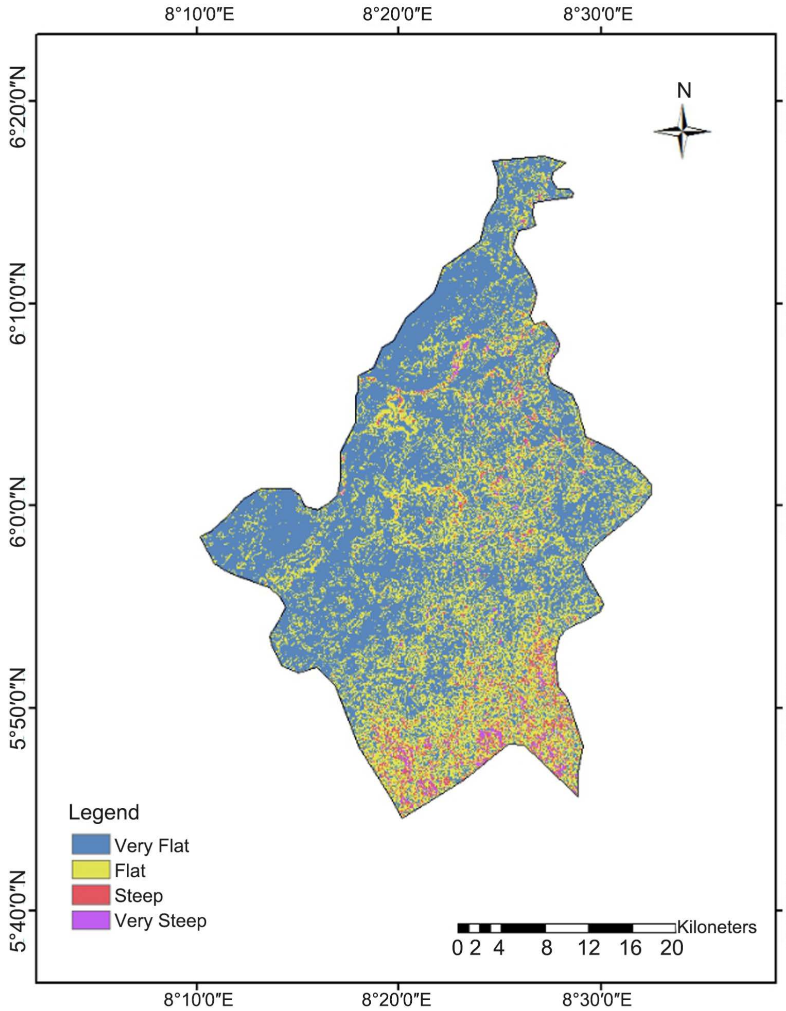

Figure 8. Distribution of slope for the study area.

4.6. Soil

Soil is a very important factor that influences the occurrence of groundwater. Soil types prominent in the study area includes; gleysols, nitosols, cambiosols and Acrisols. (**Figure 9**). Nitisols are free-draining soils that are permeable to water. They are hard when dry, very friable to firm when moist, and sticky and plastic when wet. Cambisols however have good structural stability, water-holding capacity, internal drainage and a high porosity. Further, it is not prone to erosion. With the acrisols, they have weakly developed soil structure, particularly in the upper part of the soil. Often hard-setting when dry, but prone to slaking to form a hard surface crust and erosion. The crust allows insufficient penetration of water during precipitation with devastating surface erosion as an inevitable consequence.

The type of soil present in an area has great impact on the availability of groundwater. Highly porous and permeable soils such as the gleysols, nitrosols and cambisols allow easy percolation of water into the subsurface making it a good aquiferous material. Soils containing less clay content are better than those

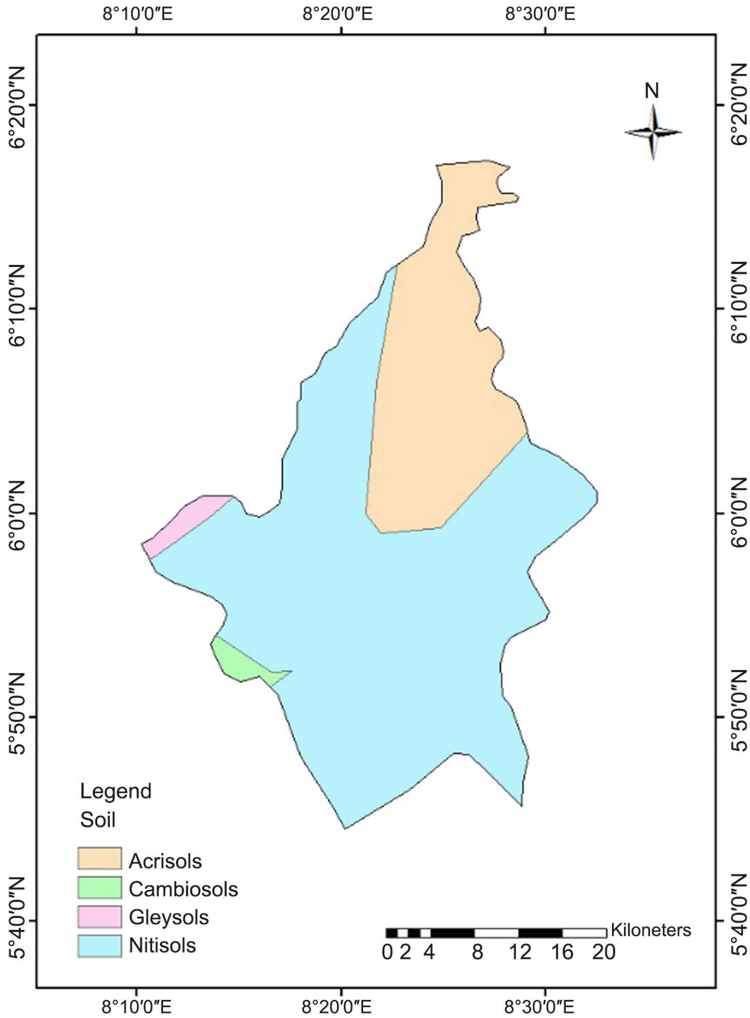

Figure 9. Soil map for the study area.

with much clay like the acrisols, except under conditions when they are fractured. The soil with relatively higher permeability of groundwater is assigned a higher weightage, while those which are less porous have a lower weighting. (**Table 1**).

5. Delineating the Ground Water Potential Zones

The use of remote sensing technique and GIS has shown the geospatial variation in groundwater occurrence and distribution within Obubra Local government area. The data sets extracted and digitized from satellite imageries and existing maps respectively were processed and successfully used to predict regions of high from those with low groundwater potential. The accuracy of any groundwater potential model depends on the availability and reliability of the data used to build the model. As a precaution, consistency ratio for each of the thematic maps should not exceed the 0.1 in order to ensure accuracy.

The 2D-Model for surface aquifer delineation and the identification of groundwater predictive zones within Obubra and its environs, were generated through the integration of various thematic maps produced for drainage distance/proximity, slope, lithology, soil, lineament density and elevation by combining remote sensing and GIS techniques as earlier discussed. Groundwater predictive mapping of the study area was therefore produced by the combination of all thematic maps acquired from remotely sensed satellite images and were classified into three (3) classes representing groundwater potential zones (Figure 10).

Statistical analysis presented in Table 2, reveals that the region corresponding to high groundwater potential occupies an area of approximately 331.94 Km^2, accounting for 29.58% of the study area. Similarly, the region that represents

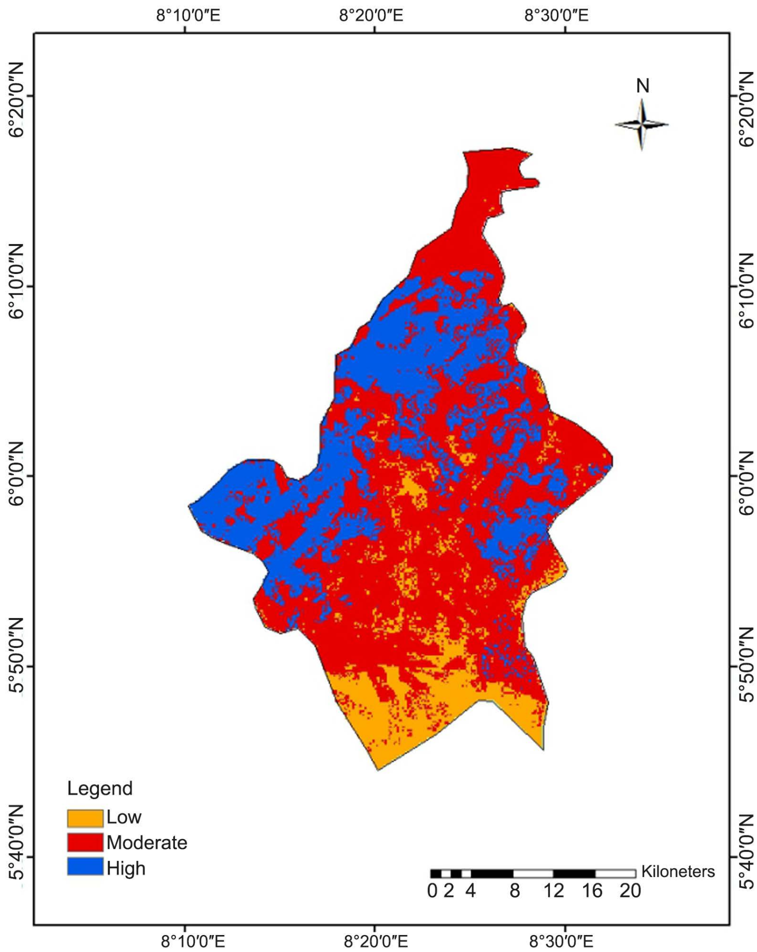

Figure 10. A 2D-Model of surface aquifer predictive map for the study area.

Table 2. Characteristic groundwater potential classes for the study area.

s/n	Classes	Percentage, %	Area, sq·Km
1	Low	12.64	141.81
2	Moderate	57.78	648.42
3	High	29.58	331.94
	Total	100	1122.17

Source: Author.

moderate to good groundwater potential covers a total area of approximately 648.42 Km^2, occupying 57.78% of the study area. Both classes represents delineated zones with good surface aquifer distribution evenly spread all across the study area except the southern-most parts. Finally the region with low groundwater potential zones covers a total surface area of approximately 141.81 Km^2 which accounts for 12.64%. The area occupies at the southern-most part of the study area, with isolated pockets extending towards the central parts. Coincidentally this region have poor aquiferous units and dominantly consists of basement and intrusive rocks respectively.

The final groundwater predictive map (**Figure 10**) shows that the groundwater potential is excellent in the north-eastern to north-western region of the study area due to the presence of suitable lithological units with high porosity and permeability. They form the aquiferous units. Further, regions that depict high to very high lineament density coincide with regions that are delineated to have high groundwater potentials. These regions coincidentally have flat to very flat slopes, intersecting lineaments, very low topography and intersecting lithology. The southern regions have poor groundwater potential. These factors play a vital role in groundwater accumulation and its favourable distribution. High concentration of lineament density favours the infiltration and percolation of groundwater. Finally, the cumulative effect of the weighted multi influencing factors through overlay analysis in the GIS platform has proven to be viable in the predictive mapping of groundwater potential zones in the study area.

6. Conclusion

A 2D surface aquifer predictive mapping employed in the spatial delineation of groundwater potential zones in Obubra and its environs using remote sensing and GIS is found to be an efficient, time-saving and cost-effective technique. This study reveals that the analytical hierarchy process (AHP) is a quick decision-making tool, and it is vital for the effective and sustainable water resources management. Satellite data and remotely sensed imageries, together with conventional maps were used to prepare thematic layers of lithology, lineament density, drainage density, slope, soil and elevation. The final predictive 2D-model map produced has classified groundwater prospectivity zones into three (3), namely; high, moderate and low. The areas that approximately correspond to these classes were determined to be 331.94 Km^2, 648.42 Km^2 and 141.81 Km^2 respectively. Thus region with good surface aquifer distributions covers a larger area extent within the study area. These are prospective zones for groundwater potential occurrence and distribution. The study has therefore shown that it is effective in delineating surface potential zones and hitherto a 2D surface aquifer model for groundwater exploration campaigns within Obubra and its environs.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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