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Article

# Groundwater Potential Mapping in Semi-Arid Region of Northern Nigeria by Integrating Analytic Hierarchy Process and GIS

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**Abstract:** (1) Background: Groundwater resources management in dry lands, characterized by climate variability and population growth, is difficult. Exploration and exploitation of groundwater, due to inadequate surface water is very costly. The present study employed Analytic Hierarchy Process (AHP) and GIS to identify Ground-Water Potential (GWP) areas in a semi-arid region of Nigeria; (2) Methods: Land-use-land-cover, drainage density, slope, rainfall, static water level, soil media, vadose media and aquifer media were selected for GWP analysis. Parameters weights were determined using AHP and ranked based on their contribution to GWP by experts. The parameters were then integrated using weighted overlay tool in ArcGIS 10.5 to produce GWP map of the study area. Boreholes yield data from 245 wells were collected to determine the model accuracy and model validation; (3) Results: Results classified the study area into very high GWP (1.9%), high GWP (8.8%), moderate GWP (62%), low GWP (20.70%) and very low GWP (6.6%). Validation of the AHP model with boreholes yield data shows a correlation coefficient of 71.3% giving a good prediction; (4) Conclusions: AHP and GIS can be used to successfully map GWP areas which could serve as an exploration guide for sustainable management of groundwater resources in semi-arid areas.

**Keywords:** Groundwater exploration; AHP; GIS; Semi-arid environment; Kano; Nigeria

## 1. Introduction

Socio-economic activities, sustainability and well-being of human population rely on freshwater supply [1]. Scarcity of surface water sources, together with a decline in quality and quantity of such resources in arid and semi-arid environments intensified reliance on groundwater for domestic and agricultural use [2]. There is also the problem of surface water pollution due to anthropogenic activities and lack of wastewater treatment [3]. In sub-Saharan Africa, the increasing level of freshwater demand due to the ever-growing population necessitates more attention on groundwater sources in many communities [4,5]. Ground-based geophysical surveys give precise information on the groundwater potential (GWP) of an area, but the method is expensive and time consuming for a large area. This calls for a cost-effective multi-criteria decision-making approach in conjunction with remote sensing technology and geographic information system (GIS) for identification of potential groundwater resources areas that could pave the way for an effective and sustainable groundwater exploration and exploitation initiatives [6]. Groundwater occurrence and distribution in a geographical location depends on the anthropogenic, physiographic and climatic factors affecting hydrological conditions of the area. Analyzing relationship and overall influence of such factors on groundwater availability is essential for effective prediction of GWP of an area [7].

In their quest for a suitable prediction methodology of potential groundwater areas through modeling the effects of physiographic variables on hydrologic parameters to achieve sustainable groundwater management, hydrogeologists found the method of analytic hierarchy process (AHP)

as one of the multi-criteria decision analyses models useful for effective groundwater management [8,9]. The method provide a means for dealing with complex spatial decision problem by decomposing the spatial decision problem into a hierarchy of sub problems for easy comprehension and subjective evaluation [10].

Nithya et al. [11] studied the influence of geology, lineaments, geomorphology, slope, drainage density, soil and rainfall on GWP of Chittar basin India, using GIS based AHP. Results was validated using groundwater yield of 24 open wells. The GWP map classified the areas into very good, good, medium, poor and very poor GWP. Ifediegwu [12] used integrated RS, GIS and AHP to study the influence of eight thematic maps (geology, rainfall, geomorphology, slope, drainage density, soil, land use land cover (LULC) and lineament density) on GWP in Lafia, Nigeria. Validation was done using data from 50 boreholes. Results classified 19.3, 12.9, 57.8, and 10% of the study area in to good, moderate, poor, and very poor GWP areas. Kamaraj et al. [13] integrated remote sensing and GIS to determine the effect of 15 parameters (ie: geology, geomorphology, lineament density, topsoil resistivity and thickness, weathered zone resistivity and thickness, first fractured resistivity and thickness, second fractured resistivity and thickness, slope, LULC, drainage density and rainfall) on GWP of Mettur taluk, Salem district and Tamil Nadu, India. Result showed that top soil thickness, pediment, lithology, slope type and rainfall as the predominant factors influencing groundwater potential. Ally et al. [14] combined seven thematic map layers of lithology, soil types, lineament, magnetic intensity, slope, drainage density and elevation to develop GWP zone map of Mpwapwa District, Tanzania. The resulting GWP zone was validated using area under the curve and overlaying method. It was shown that 19% of the area was classified as very good, 31% as good, 28% as moderate, 22% as poor and 2% as very poor GWP zones.

Researches have also been carried out to compare AHP with other approaches. Razandi et al. [15] compared the use of AHP, frequency ratio and certainty factor to map GWP of Varamin Plain, Tehran Iran. Receiver operating characteristics was used to determine the accuracy of the GWP maps and results indicated that the frequency ratio out performed both the AHP and certainty factor methods. Kaur et al. [16] used remote sensing and GIS to compare AHP with Catastrophe theory for demarcation of GWP zones of Panipat district, India. Results showed that the percentage of area covered by each model is almost the same thus the two models can be used for delineation of GWP areas. Shekar and Mathew [17] combined slope, drainage density, rainfall, geomorphology, LULC, curvature, soil, topographic wetness index, distance from the river, and elevation as thematic layers and used AHP and fuzzy-AHP in GIS environment to assess GWP zones in Murredu river basin, India. The zones were classified as poor, moderate and good GWP areas

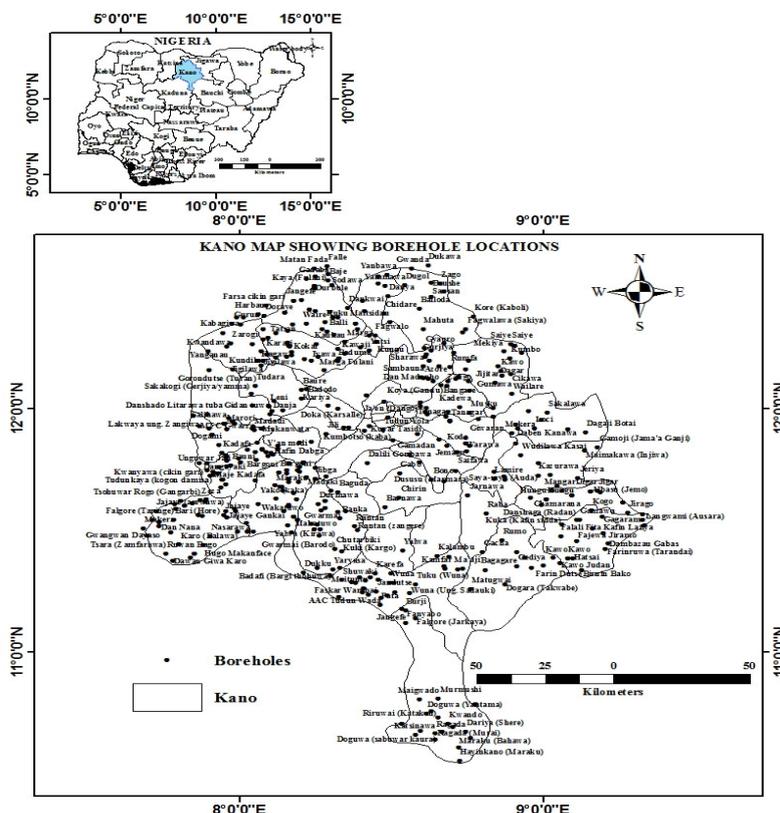
AHP has been used, in GIS environment, by many scholars in prediction of GWP areas to explore groundwater resources [18–22]. The approach is proved to be a reliable means of facilitating, interpreting, analyzing large volume of diverse dataset which are then modeled through analytic procedure to produce useful information for use by authorities concerned [23]. For this purpose, the present study employed AHP, using remote sensing and GIS, to integrate hydro-geological and climatic data to assess and map GWP areas which could serve as an exploration/exploitation guide for efficient and sustainable management of groundwater resources in Kano state, Nigeria. Little. The use of AHP in combination with remote sensing and GIS is novel in this part of the world as information is scarce in sub-Saharan Africa. The research will provide policy makers on the best way to sustainably manage the groundwater in the area.

## 2. Materials and Methods

### 2.1. Study Area

The study area is in Northern part of Nigeria, West Africa. The area lies between latitudes  $10^{\circ} 23' 40''$  and  $12^{\circ} 34' 24''$  North, longitudes  $7^{\circ} 41' 15''$  and  $9^{\circ} 21' 21''$  East (Figure 1). The total areal coverage of the state is estimated at 20,131 km<sup>2</sup> with about two-third of the area belonging to crystalline basement rocks and the remaining one-third is sedimentary formation [24]. Mean annual rainfall is 635 mm in the north and 1000 mm in the south and occurs between May and October [25]. Kano state is the most populous state in Nigeria with a population density of 764/km<sup>2</sup>. The 2023

population of the state is about 15,462,200 people with an annual growth rate is 3.2% [26]. During the 2010 – 2013 period, there was a steady annual decrease of groundwater level and groundwater beneath the floodplains dropped from 9000 MCM to 5000 MCM from 1964 to 1987 in the Chad Formation area of the region [27]. Surface water is not readily available and this puts more pressure on groundwater. There is an indiscriminate drilling of boreholes in the state and this results in the decline of water table as more boreholes and wells dry up. This underscores the need to have an assessment for the groundwater with a view to sustainably manage it.



**Figure 1.** Study area showing boreholes locations.

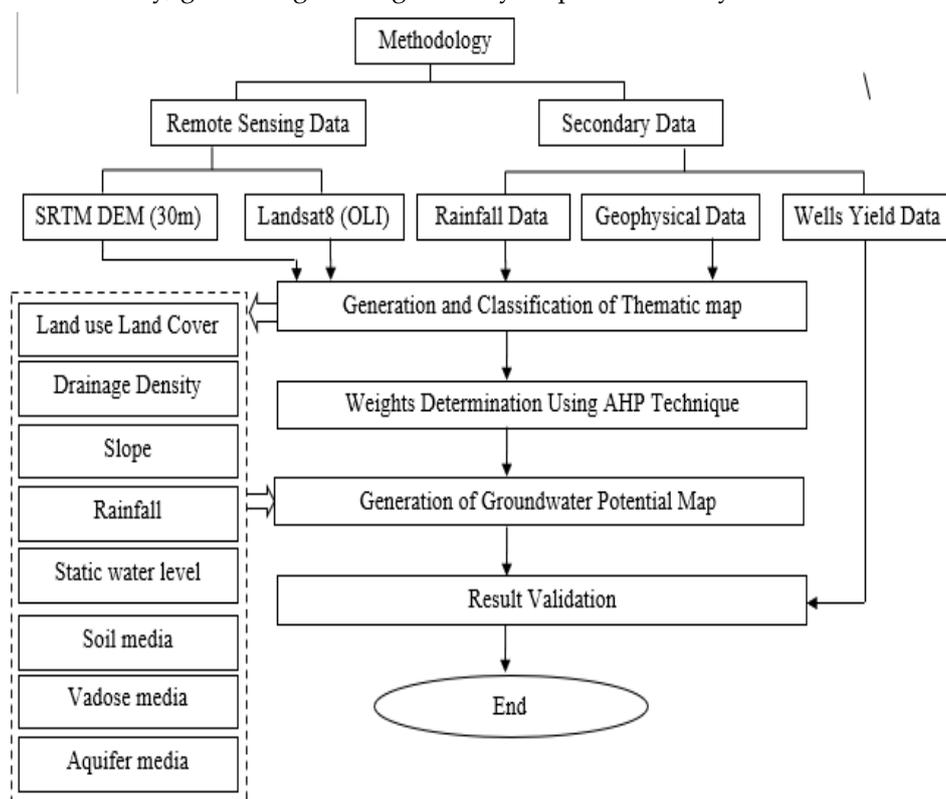
## 2.2. Data Collection

The administrative boundary map, in shape file format, downloaded from DIVA-GIS (<http://www.divagis.com>), was employed for the generation of study areal extent. Satellite imagery of Landsat 8 OLI and Shuttle Radar Topographical Mission Digital Elevation Model (SRTM DEM) both having 30 m spatial resolution were obtained from United States Geological Survey site ([www.glovis.usgs.com](http://www.glovis.usgs.com)). Two hundred and forty five (245) set of boreholes log data spread across the study area, obtained from the archives of Kano Agricultural and Rural Development Authority (KNARDA), were used to generate hydro-geological profile. The boreholes were ranked according to their yield in the order W1 to W245 with W1 having the least yield and W245 the highest. Also, rainfall data of 9 meteorological stations was obtained from Kano State Water Board.

## 2.3. Data Processing

The methodology adopted in this research includes the following stages as shown in Figure 2. For the remotely sensed data, the administrative boundary data was processed in ArcGIS environment to mask down Kano State the study area as shown in Figure 1. Landsat 8 OLI was clipped to the study area and ERDAS 9.0 were applied for the satellite image processing. Land-use-land-cover (LULC) was interpreted using visual interpretation technique and supervised classification of maximum likelihood classification was carried out for final LULC map. For this study

slope steepness and stream network information were deduced from SRTM DEM having 30m spatial resolution while the stream network information was consecutively processed to produce flow direction information for the surface drainage, flow accumulation information, stream order information and finally, generating drainage density map for the study area.



**Figure 2.** Flowchart of the methodology used for GWP mapping.

Rainfall distribution map of the area under study was produced from the rainfall data of nine meteorological stations across the study area ie (Challawa, Karaye, Gajale, Riruwai, Wudil, Ranka, Joda, Wak and BUK) using inverse distance weighting (IDW) interpolation method. While available information on static water level, soil media, vadose media and aquifer media, obtained from the KNARDA, was used to produce the static water level, soil media, vadose media and aquifer media maps of the study area respectively.

#### 2.4. Analytic Hierarchy Process (AHP)

The AHP is a multi-criteria decision-making process involving experts ranking on the relative importance of some chosen parameters. The steps involved are as follows:

Step 1: This step involves identification of thematic layers. In this work, eight thematic layers of LULC, drainage density, slope, rainfall, static water level, soil media, vadose media and aquifer media were chosen

Step 2: The experts' opinion was used to generate pairwise comparison matrix (Table 1) based on their relative importance using Saaty's scale. Maps of the parameters were classified on a uniform rank of 1 – 5, where a scale of 1 denotes very low, 2 low, 3 implies moderate, 4 represents high and 5 denotes very high GWP [4,28].

**Table 1.** AHP model pair wise comparison matrix among parameters.

Parameters	P1	P2	P3	P4	P5	P6	P7	P8	Weight
LULC (P1)	1.00	0.33	0.33	0.25	0.50	1.00	0.33	0.50	4.24

Drainage									
Density (P2)	1.00	0.50	0.50	3.00	3.00	1.00	2.00	14.0	
Slope (P3)	3.00	2.00	1.00	0.50	3.00	3.00	2.00	2.00	16.5
Rainfall (P4)	4.00	2.00	2.00	1.00	3.00	3.00	2.00	2.00	19.0
Static water level (P5)	2.00	0.33	0.33	0.33	1.00	2.00	0.50	0.50	6.99
Soil media (P6)	1.00	0.33	0.33	0.33	0.50	1.00	0.33	0.33	4.15
Vadose media (P7)	3.00	1.00	0.50	0.50	2.00	3.00	1.00	2.00	13.0
Aquifer media (P8)	2.00	0.50	0.50	0.50	2.00	3.00	0.50	1.00	10.0
<b>Sum</b>	<b>19.0</b>	<b>7.49</b>	<b>5.49</b>	<b>3.91</b>	<b>15.0</b>	<b>19.0</b>	<b>7.66</b>	<b>8.53</b>	<b>86.08</b>

Step 3: Computations of the normalized weights utilizing the criteria's geometric mean ( $G_m$ ) as shown in Equation 1. The normalized weights are presented in Table 2

$$W_n = \frac{G_m}{\sum_{i=1}^n G_m} \quad (1)$$

where  $W_n$  = Eigen vector of the matrix

**Table 2.** Normalized pair wise comparison matrix and weights of each parameter.

Parameters	P1	P2	P3	P4	P5	P6	P7	P8	Weight
LULC (P1)	0.053	0.044	0.060	0.064	0.033	0.053	0.043	0.049	0.049
Drainage									
Density (P2)	0.158	0.134	0.091	0.128	0.200	0.158	0.131	0.194	0.149
Slope (P3)	0.158	0.267	0.182	0.128	0.200	0.158	0.261	0.194	0.194
Rainfall (P4)	0.2110.267	0.364	0.256	0.200	0.158	0.261	0.194	0.239	
Static water level (P5)	0.105	0.044	0.060	0.084	0.067	0.105	0.065	0.049	0.073
Soil media (P6)	0.053	0.044	0.060	0.084	0.033	0.053	0.043	0.032	0.051
Vadose media (P7)	0.158	0.134	0.091	0.128	0.133	0.158	0.131	0.194	0.141
Aquifer media (P8)	0.105	0.067	0.091	0.128	0.133	0.158	0.065	0.097	0.106
Sum	1.001	1.001	1.000	1.000	1.000	0.981	1.000	1.003	1.002

Step 4: The principal eigen value and Consistency Index (CI) were calculated in order to capture the uncertainty in experts' judgements using following Equation 2

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

where  $\lambda_{max}$  = largest eigenvalue from the pairwise comparison matrix,  $n$  = number of classes. The consistency of the pairwise comparison matrix was measured using Consistency Ratio (CR) given by Equation 3

$$CR = \frac{CI}{RI} \quad (3)$$

where  $RI$  = random consistency index = 1.41 when  $n = 8$  [29].

Step 5: The resulting thematic maps of LULC, drainage density, slope, rainfall, static water level, soil media, vadose media and aquifer media were integrated according to Equation 4 using weighted overlay method in ArcGIS 10.5 to generate an index value signifying level of GWP per each cell.

$$GWPI = \sum_{i=1}^n W_i X_i \quad (4)$$

where  $GWPI$  = the GWP index,  $W_i$  = the determined weight of each thematic layer.  $X_i$  = the ranks for the classes within each thematic layer.

Finally, the prediction accuracy of the model was determined and the proposed GWP map was validated with recorded borehole yield data using Pearson correlation coefficient to serve as easy guide for assessment of groundwater availability within the study area (Equation 5).

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (5)$$

where  $x_i$  is the respective borehole yield value at a particular point,  $y_i$  is the GWP index value at that point.

### 3. Results

#### 3.1. LULC

LULC of an area control hydrological processes of evapotranspiration, infiltration and surface runoff, which largely governed the occurrence and distribution of groundwater resources [30]. The LULC map of the study area (Figure 3) shows vegetation and agricultural area covered an area of about 19194 km<sup>2</sup> (95.34%) and water body accounted for 317 km<sup>2</sup> (1.58%). These dominant land uses promote infiltration which lead to high groundwater prospect. The built-up areas and bare ground occupy only 587 km<sup>2</sup> (2.92%) and 33 km<sup>2</sup> (0.17%).

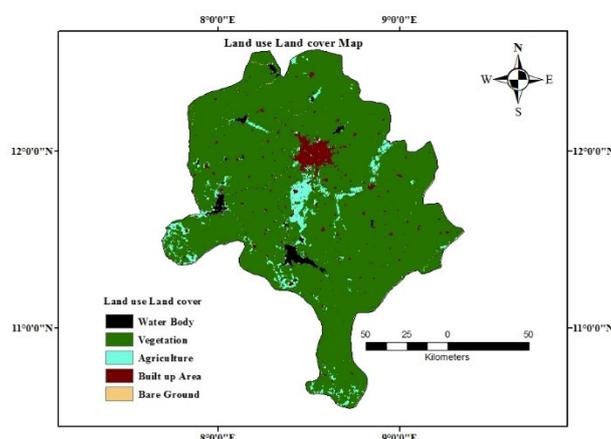


Figure 3. LULC map.

#### 3.2. Drainage Density

Drainage density of an area defines the sum of the drainage channel lengths per unit area. Drainage basins having high drainage density results in low infiltration within its subsurface formation and hence, low groundwater prospect [31]. In the study area, the high and very high drainage density areas constitute 10390 km<sup>2</sup> (51.60%), moderate 7828 km<sup>2</sup> (38.90%) while low and very low drainage density covered only 1913 km<sup>2</sup> (9.50%) of the study area (Figure 4). This low to very low drainage density zones implies high infiltration and recharge potentials which is a function of high groundwater prospect [4].

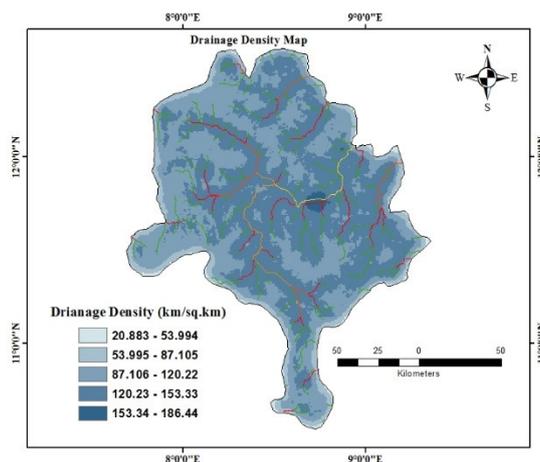


Figure 4. Drainage density map.

### 3.3. Slope

Slope is an aspect of geomorphologic features. Its nature along with other geomorphic features play a significant role in determining infiltration and potential groundwater recharge in an area.. Slope of study area as illustrated in Figure 5 revealed that about 18007 km<sup>2</sup> (89.50%) of the area is covered by a slope of less than 5<sup>0</sup> signifying a nearly level and gentle surface which give high infiltration rate and high probability of groundwater prospect. 879 km<sup>2</sup> (9.30%) covered by (5 - 8)<sup>0</sup> moderately sloping, 195 km<sup>2</sup> (0.95%) covered by (9 - 20)<sup>0</sup> slightly steep sloping while 50 km<sup>2</sup> (0.25%) of the area is covered by greater than 20<sup>0</sup> steep sloping leading to less rainfall/run off infiltration and less probability of groundwater prospect [32].

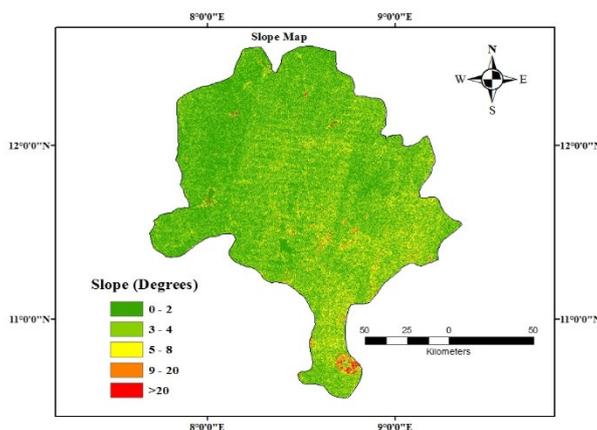
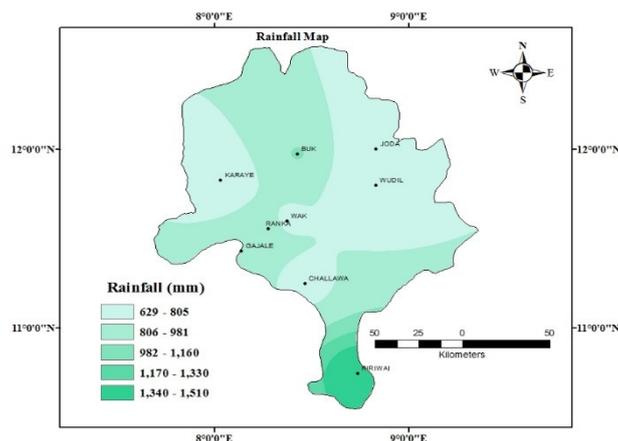


Figure 5. Slope map.

### 3.4. Rainfall

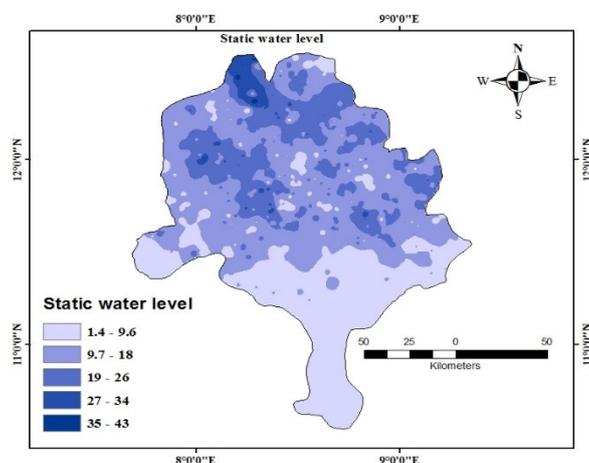
Rainfall as a meteorological factor that contributes immensely to groundwater recharge. Understanding the nature and characteristics of rainfall of an area helps in predicting its effects on evapotranspiration, infiltration and surface runoff. For hydrological analysis, areal distribution of rainfall is required so as to create potential groundwater areas [19]. The distribution of rainfall in the study area ranges from 629mm to 1510mm suggesting a seasonally arid climate with a mean annual rainfall decreasing towards the north [33]. The rainfall map (Figure 6) reveals that about 1043 km<sup>2</sup> (5.18%) received high amount of rainfall which signifies good GWP, 276 km<sup>2</sup> (1.37%) moderate, while 18812 km<sup>2</sup> (93.45%) received low amount of rainfall suggesting poor GWP.



**Figure 6.** Rainfall map.

### 3.5. Static Water Level

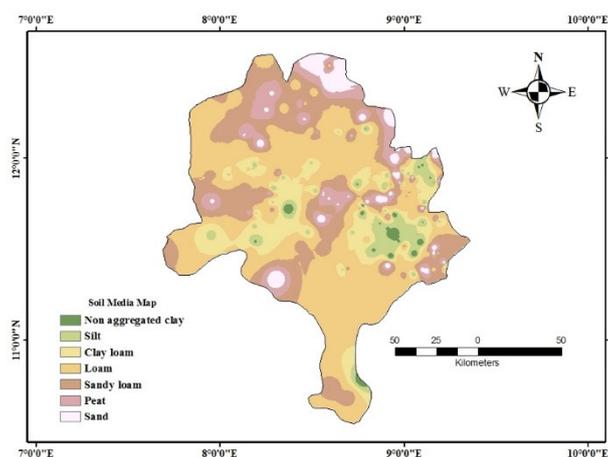
Static water level is a measure of the distance from the ground surface to the water level and a parameter that determine the potential distance for water to travel to the aquifer. Variation in static water level within the study area shows a change ranging from 1.4–9.6 m covering 6358 km<sup>2</sup> (31.6%), as very high, 9.7-18 m covering 9103 km<sup>2</sup> (45.2%) as high, 19 - 26 m covering 4187 km<sup>2</sup> (20.8%) as 'Moderate, while 27 - 34 m covering 463.0 km<sup>2</sup> (2.30%) and 35 - 43 m covering 20.00 km<sup>2</sup> (0.10%) as low and very low groundwater prospective areas (Figure 7)



**Figure 7.** Static watr level map.

### 3.6. Soil Media

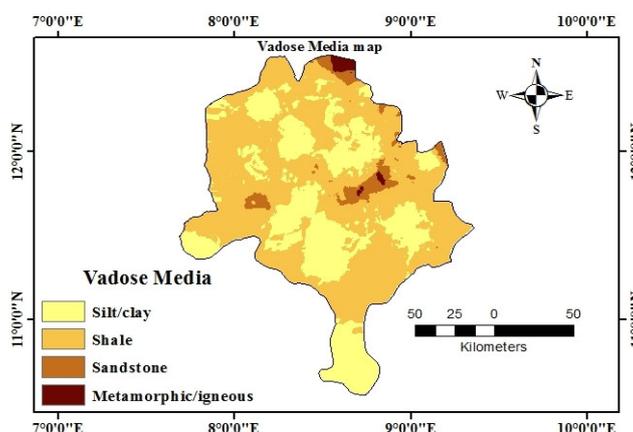
Soil media is an influencing factor that facilitates infiltration of rainfall and represent surface feature that controls the amount of recharge into the saturated zone. The soil types in Figure 8 include sand, sandy loam and peat covering 3866 km<sup>2</sup> (19.18%) which allow water to infiltrate easily due to high permeability suggesting high groundwater prospect area, loamy soil covers an area of 8968 km<sup>2</sup> (44.6%) and non-aggregated clay, clay loam and silt covered 7297 km<sup>2</sup> (36.22%) which imply limited infiltration because of low permeability and hence, low groundwater prospect [19].



**Figure 8.** Soil media map.

### 3.7. Vadose Media

The unsaturated zone of the study area (Figure 9) is underlain by basement complex rocks and sedimentary formation. Only 824 km<sup>2</sup> (4.1%) of the study area is covered by sandstone which allows high infiltration due to its high porosity hence, suggesting high groundwater availability. Metamorphic/igneous and shale formations covered 12597 km<sup>2</sup> (62.6%) giving moderate infiltration and silt/clay covered 6710 km<sup>2</sup> (33.3%) allowing low infiltration suggesting low probability of groundwater prospect [20].



**Figure 9.** Vadose media map.

### 3.8. Aquifer Media

Aquifer media properties control the rate at which groundwater flow within an aquifer formation. Figure 10 shows the major aquifer formation in the study area with thin bedded sand and sand/gravel occupying 2189 km<sup>2</sup> (11%) and 613 km<sup>2</sup> (3%) suggesting high groundwater prospects. The metamorphic/igneous and weathered rocks occupies 5647 km<sup>2</sup> (28%) and 11682 km<sup>2</sup> (58%) suggesting moderate GWP.

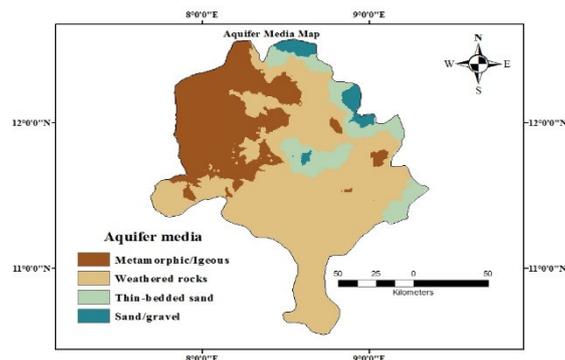


Figure 10. Aquifer media map.

### 3.9. GWP Map

The GWP map in Fig 11 was generated according to Equation 4 by weighted overlay analysis of the determined weights of each of the groundwater controlling parameters and assigned ranks for the sub class of each parameter Table 3. The GWP map was classified into five as very low covering 1320 km<sup>2</sup> (6.60%), low 4164 km<sup>2</sup> (20.70%), moderate 12482 km<sup>2</sup> (62.0%), high 1783 km<sup>2</sup> (8.80%) and very high covering 382 km<sup>2</sup> (1.90%) of the study area (Figure 11).

### 3.10. Model Accuracy

The classified boreholes yield data in Table 4 were super imposed on GWP map obtained using the RS-GIS and AHP. The results show that out of 80 boreholes with (ID No W<sub>1</sub> to W<sub>80</sub>) classified as low yielding wells (yield < 50 l/min), 67 fall within very low to low GWP categories representing 83.8% accuracy. Out of the 129 wells with (ID No W<sub>81</sub> to W<sub>209</sub>) classified as moderate yielding wells (with yield between 50 l/min to 100 l/min), 82 fall within the moderate GWP category representing 63.6% and likewise, out of the 36 wells with (ID No W<sub>210</sub> to W<sub>245</sub>) classified as high yielding wells (with yield > 100 l/min), 28 fall within the high and very high GWP representing 77.8% accuracy. The overall accuracy is thus 74.4 percent (Figure 11). With good correlation coefficient of 71.3 % and prediction accuracy of 74.4%, it is evident that AHP can be used to predict the GWP of areas as surrogate measure for boreholes yield.

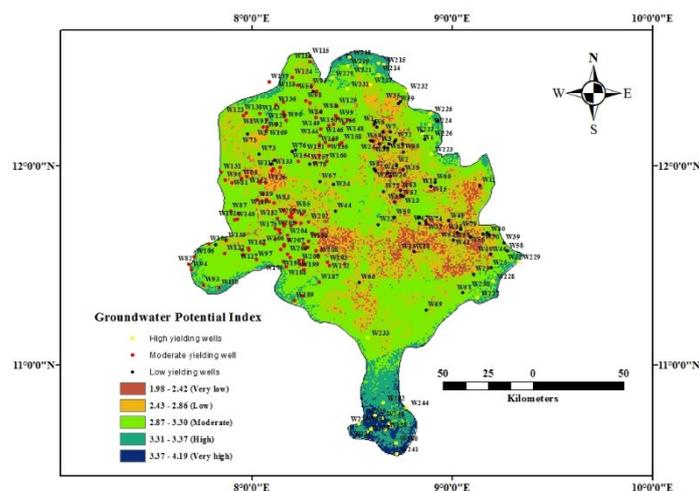


Figure 11. GWP map.

Table 3. Parameters weight and their ranking for GWP.

Parameters	Sub classes	Ranks ( $X_i$ )	Weight ( $W_i$ )	Area (km <sup>2</sup> )	Area (%)
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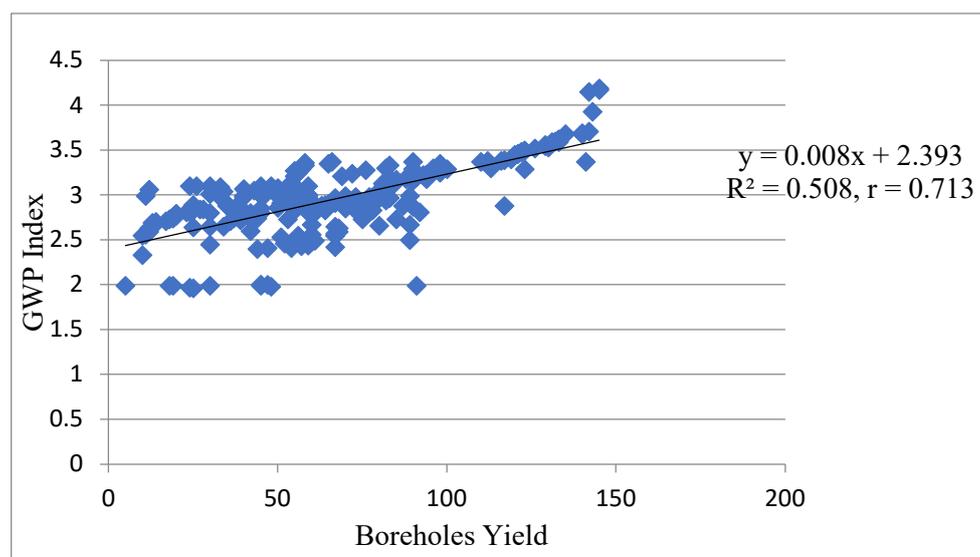
LULC	Water body	5	0.049	317	1.58
	Vegetation	4		18285	90.83
	Agriculture	4		909	4.5
	Built up area	3 587 2.92			
	Bare ground	2		33	0.17
Drainage					
Density (km/km <sup>2</sup> )	20.883 – 53.994	5	0.149	130.0	0.65
	53.995 – 87.105	4		10260	50.95
	87.106 – 120.22	3		7828	38.90
	120.23 – 153.33	2		1693	8.41
	153.34 – 186.44	1		220.0	1.09
Slope (Degrees)	(0 - 2)	5	0.194	8949	44.45
	(3 - 4)	4		9058	45.00
	(5 - 8)	3		1879	9.37
	(9 - 20)	2		195	0.97
	(>20)	1		50	0.25
Rainfall (mm)	1340 – 1510	5	0.239	748	3.70
	170 – 1330	4		295	1.48
	982 – 1160	3		276	1.37
	806 – 981	2		8825	43.85
	629 – 805	1		9987	49.60
Static water level (m)	1.4 – 9.6	5	0.073	6358	31.6
	9.7 – 18	4		9103	45.2
	19 – 26	3		4187	20.8
	27 – 34	2		463	2.30
	35 – 43	1		20	0.10
Soil media	Sand	5	0.051	184	0.92
	Sandy loam	4		1018	5.06
	Peat	4		2664	13.2
	Loam	3		8968	44.6
	Silt	2		4756	23.6
	Clay loam	2		1736	8.62
Vadose media	Non aggregated clay	1		805	4.0
	Sandstone	4	0.141	824	4.0
	Metamorphic/igneous	3		175	0.87
	Shale	3		12422	61.7
Aquifer media	Silt/clay	2		6710	33.33
	Sand/gravel	5	0.106	613	3.0
	Thin-bedded sand	4		218911.0	
	Metamorphic/igneous	3		5647	28.0
	Weathered rock	3		1682	58.0

**Table 4.** Classification of boreholes yield of the study area according to [19].

S/No	Boreholes ID	Classification (l/min)	Category
1	W1 - W80	<50	Low
2	W81 – W209	50 – 100	Moderate
3	W210– W245	>100	High

### 3.11. Model Validation

Validation is the most important process of model without which models lack scientific significance [34]. For validation, the Pearson Correlation Coefficient was employed to compare the recorded boreholes yield data with the GWP index value obtained by AHP model. The plot assessment shows a correlation coefficient of 0.713 which indicates a good prediction (Figure 12).



**Figure 12.** GWP index and yield relationship.

#### 4. Discussion

Globally, the problem of stress on fresh water supply is a well-documented issue. This problem is exacerbated by climate change which manifest itself in drought in some parts of the world. Highly populated areas, such as Kano, become more vulnerable arising from the over-abstraction of water sources due to high water demand from the high population of about 15,462,200 persons [26]. Surface water pollution and grossly insufficient municipal water supply has led to the demand for groundwater in the state [2,27]. The United Nations Sustainable Development Goal No. 6 attempts to address this issue and Nigeria is not on track to achieving this by 2030 as only 29% of the population use safely managed drinking water sources [35]. Other targets related to SDG No. 6 are also below 50% which is far from the expectations. The country has to fast-track the implementation of policies to achieve this aim.

The geology of Kano State is crystalline basement complex rock in two-third of the basin and the remaining is sedimentary formation. There is a sharp decline in groundwater level which calls for researches towards sustainability of groundwater. AHP was integrated in to RS and GIS to delineate and map GWP areas. Eight thematic layers affecting groundwater recharge potential including LULC, drainage density, slope, rainfall, static water level, soil media, vadose media and aquifer media were chosen in this research. Results of spatial analysis show that better groundwater prospective areas occupied total area of 2165 km<sup>2</sup> (10.70%) and mostly situated in Gurun, Dugol, Zago, Kumbo in the north and Dukku, Doguwa, Riruwai, Dambazau in the southern parts of Kano State (Figure 11). These are mainly attributed to the nature of the topography, drainage density, rainfall and these areas could be suitable for groundwater development for agricultural utilization. Moderate GWP areas are widely distributed across the study area and covered 12482 km<sup>2</sup> (62%) of the state and could be suitable for groundwater development for domestic use. Meanwhile poor GWP areas covered 5484 km<sup>2</sup> (27.30%) and concentrated mostly in areas having high drainage density and low rainfall at central and southeastern parts of Kano state. These poor GWP areas could not be sufficient for groundwater development for commercial agriculture and hence the need for surface water infrastructure to augment the existing water supply system. For sustainability, efforts should be stepped-up to improve water supply, using surface water sources, in areas close to existing surface waters. This will go a long way in relieving the current pressure on groundwater.

#### 5. Conclusions

Identification of GWP areas in arid environment of Kano, Nigeria was achieved through the use of expert based multi criteria evaluation approach of AHP in GIS environment. The results shows rainfall (23.9%) and slope (19.4%) as the most important factors contributing to GWP while land use

land cover (4.99%) and soil media (5.03%) exerts least significant impact. However, the developed model categorized the study area into very low 1320 km<sup>2</sup> (6.60%), low 4164 km<sup>2</sup> (20.70%), moderate 12482 km<sup>2</sup> (62.0%), high 1783 km<sup>2</sup> (8.80%) and very high 382 km<sup>2</sup> (1.90%) groundwater prospective areas. Consequently, the AHP model was validated with recorded boreholes yield data to achieve a correlation coefficient of 71.3% and prediction accuracy of 73.5%. With fairly good model validation results its evident that geospatial technology of RS-GIS and AHP technique can be employed to successfully mapped groundwater prospective areas which could serve as an exploration/exploitation guide for efficient and sustainable management of groundwater. In addition, for long term sustainability of water resources in study area an updated RS- GIS and AHP using adequate inventory data is recommended as well as development of more surface water infrastructure in poor GWP areas to curtail the prevailing groundwater development in Kano state, Nigeria.

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