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Groundwater Potential Assessment using Weighted Overlay in Rural Areas of Kano State, Northern Nigeria

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Abstract

Water scarcity is a major problem for development and data on groundwater prospecting is limited for effective exploration that is why the study's major objective is to identify groundwater potential, relate it with factors and determine areal extent of each potential zone. Land sat ETM + 2003 with resolution of 28.5m was used to map out the study area. Ground water potential was assessed through overlaying thematic maps of the factors which are lineament line density, drainage density, geology, hydrogeology, soil and vegetation. This was achieved using Analytical Hierarchy Process (AHP) nine point scale. Boreholes data obtained from 16 villages which were randomly selected was used in the analysis. Five groundwater potential zones were identified with a consistency ratio of 0.04. The zones are very high in the north central, central and south central, High around north central, east central and pockets in south western part, moderate occurred as pockets in north central, low in north-north east, central areas and pockets in south east, south central and south and very low occur as pockets in the south west, southern parts. Very High class is having the largest aerial coverage of 5,676km2 (27.3%). Lineament density among the six factors is having higher weight of 0.46 (46%) while vegetation recorded least value of weight of 0.03 (3%). Areas of higher groundwater prospects are characterised by Lineament density of 22.5-28.11 km/km^2 with a weight of 0.48(48%), drainage density of 97.2-121.5km/km^2 weight 0.37 (37%), with regards to geology areas with homblend-granite are having weight of 0.25 (25%). For hydrodrogeology Pink white granite is having highest weight of 0.32 (32%), for soil hydromorphic soil is having 0.41 (41%). In vegetation Sudan Savanna >60% is having a weight of 0.56 (56%). In line with that it is recommended that areas with very low to low groundwater potential low yielding boreholes are to be the best options to avoid total aquifer drying.

Key words: Groundwater, Potential, Weighted overlay, Kano, Nigeria

Introduction

Water is the resource that sustains all life on earth and is a key element for sustainable development. Water is an infinite resource, worldwide there is an imbalance between water utilisation and water resources management. This imbalance has brought a veritable crisis with regard to water in many regions of the world. Yatsuka (2002) reported that it is projected that by 2025, about 3.5 billion people-approximately 6.5 times as many people as in the year 2000- will live in water stressed countries. This indicates the level of water resource deterioration globally.

Groundwater is a resource that make up an impressive 90% of the fresh water that is readily available for human use (Robert, 2007). Scarcity of water being it surface or subsurface resulted into water potential studies, particularly groundwater which is very crucial. Groundwater potential means having a latent possibility or likelihood of occurrence of groundwater in an area. Areas or zones of abundant groundwater available for use are referred to as areas of good groundwater potential. Productive water bearing zones referred to as good groundwater potential aquifers. Rai (2008) states that for sustainable groundwater development of an area, delineation of aquifers is pre-requisite for the assessment of regional and local groundwater potential. Groundwater potential is determined using remote sensing and GIS to evaluate the water resource potential. Water scarcity is a major problem in both developed and developing nations in which the study area is inclusive. Also data on groundwater prospecting is limited for development that is why groundwater studies of this type is very necessary for easy boreholes location.

Many studies were conducted on groundwater potential for example Ali-elnaqa, Nezar, Khalil and Masdouq (2009) Uses weighted overlay to determined groundwater potential of Wadi Arabia and classified the area in

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to 40% is of higher potential, 40% is moderate potential, 17% is of low potential and the rest are undecided. Matthew (2006) pointed out that the groundwater potential of United States is divided into principal aquifers of over 300,000km^2, principal aquifers of over 20,000km^2, principal aquifers of less than 20,000km^2 and non-principal aquifers. Khairul Anam, Juharimat and Ibrahim (2000) used Land Sat TM taken on 6th March, 1996 to predict groundwater potential zones in Langat basin India. Borehole data was analysed based on annual rainfall, lithology, lineament density, topography, elevation, slope steepness, drainage density and soil types to arrive at classifying the study area into five classes as Very poor, Poor, Good, Very Good and Excellent in terms of groundwater potential.

Sitender (2011) delineated groundwater potential zones of Medwat district Haryana India using Multi-Criteria Evaluation (MCE) and arrived at five groundwater potential zones which are very poor, poor to moderate, moderate to good, good to very good and excellent. Findings also identified that sand silt and clay formation have highest weight of 6, coarse to fine alluvial sand 4, quartzite phyllite and slate 3 and Quartzite Schist is the least with 1. Presence of high dense vegetation in areas indicates possibility of acting as major conduits for subsurface movement and for the storage of groundwater.

Oluwatola, Oluwatoyin, Moshood and Abel (2013) delineated groundwater potential zones in South-Western Nigeria (Oyo, Ogun, Osun, Ekiti and Ondo States) using GIS weighted overlay method and borehole data. They arrived at three groundwater potential zones low, moderate and high and sandy soil is having weight of 3 followed by loam with 2 and clay with 1 in terms of groundwater potential. Alkali, Gadzama and Yusuf (2011) conducted study of boreholes Data from Eastern part of Mandara hill area in Gwoza. Findings of their work indicated that those areas underlain by charnockitic rocks, quartz porphyry and porphritic granites in the study area were found to be of limited groundwater potential due to the presence of higher slopes, low infiltration and low lineament.

Tesfaye (2010) uses integrated method in evaluating groundwater potential of Blilate river catchment south rift valley of Ethiopia through generation of thematic maps using GIS. The result was validated by selective ground truth verification and four groundwater potential zones were identified which are high, moderate, low and poor. His work deduced that areas of lower terrain are areas most likely to have more groundwater potential than highland areas in a hard rock terrain regions. He stated that areas having high lineament density represent areas with relatively high groundwater potential and according to the findings the higher the drainage density the lower the groundwater potential of an area.

Also Kakwe et al (2015) uses G.I.S and Remote sensing to assesses groundwater potential of Oban massif of South Eastern Nigeria and concluded that geology, lineament density, and slope steepness are the most influential groundwater controlling factors of groundwater potential. Their degree of influence can be summarized as geology > lineament density> slope>geomorphology>drainage density>land use / land cover. Likewise Zeinolabedini and Esmaeily (2015) undertake a similar research in Baft City Kerman, Iran and arrived at a result that indicates tha Vegetation, slope land use land cover and precipitation are very important factors of groundwater delineation in any area.

In another development, Sitender (2011) delineated groundwater potential zones of Medwat district Haryana India using Multi-Criteria Evaluation (MCE) and arrived at five groundwater potential zones which are very poor, poor to moderate, moderate to good, good to very good and excellent. And also the result indicates that high drainage density equals to low groundwater potential that is areas with lineament density of 0.00 – 0.54 are nil in terms of groundwater potential and areas of 2.73 – 3.28 are having very high groundwater potential. Groundwater potential assessment using weighted overlay supported by ground truthing was adopted in achieving the major objectives of the study which are to identify groundwater potential, relate the identified potential zones with factors and determine areal extent of each potential zone.

Material and Methods

The study area

Kano state extends from latitudes $10^{o}3^{'}$ N to 12^{o} $3^{'}$ N and longitude $7^{o}35^{'}$ E to $9^{o}20^{'}$ E. The total land area of the state is about 20,760sq km (Research and Documentation Directorate Kano, 2009).(Figure1). It is underlain by basement complex rocks. These rocks have been variably metamorphosed and granitised through tectonometamorphic cycles, so that they have largely converted to migmatite and granite-gneiss (Oyawoye,

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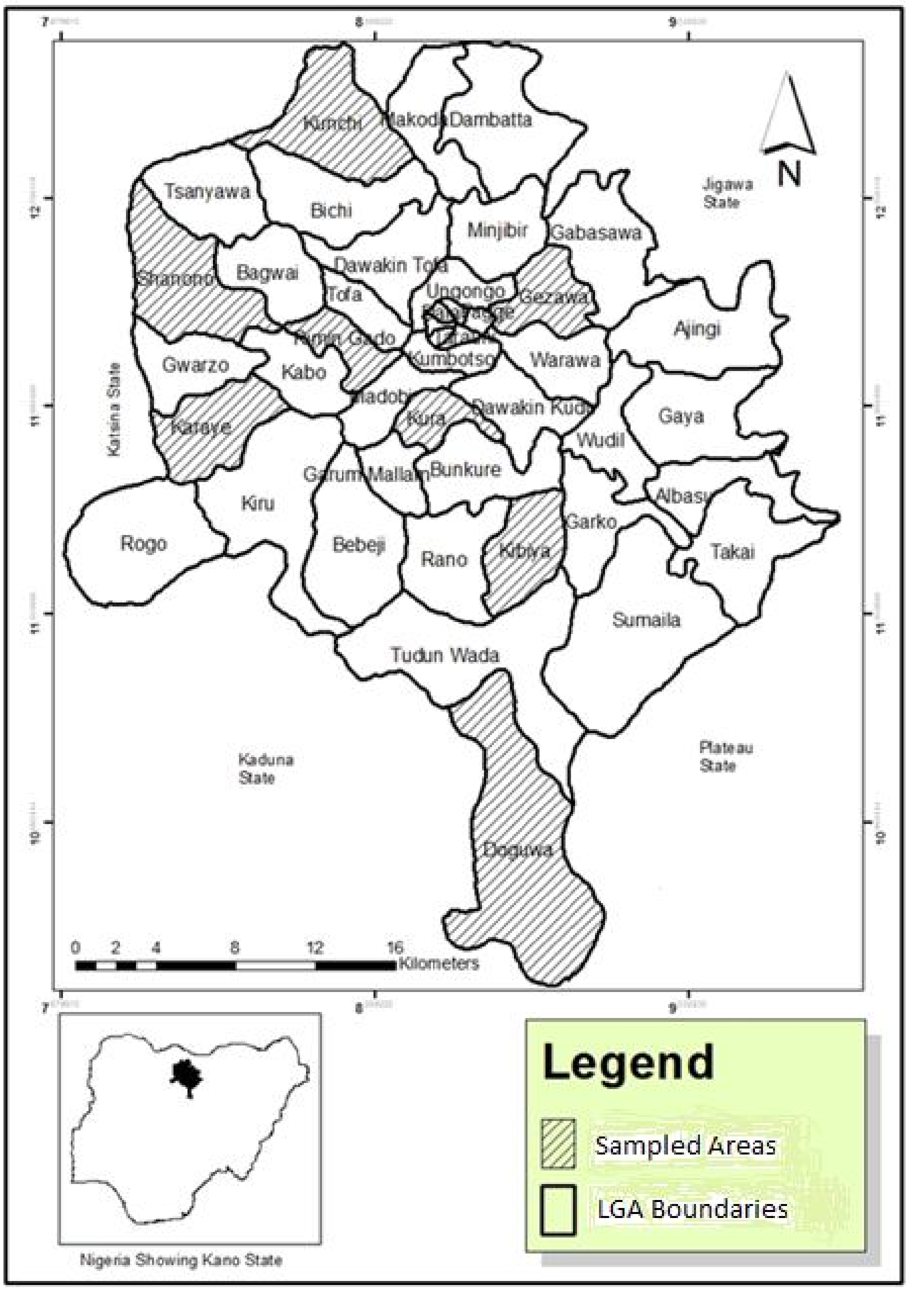
1964). Sara and Charles (1988) pointed out that the geology underlying parts of Kano State is the basement complex and consisting of variety of metamorphic and igneous rocks ranging in age from Precambrian to Jurassic. The climate of Kano is also described as seasonally arid and in southern Kano rainy season average is about 150 days May to October. Mean annual rainfall in the southern parts is about 1000mm and in the north it is 635mm (Sara and Charles, 1988).

The stream flow in Kano state is characterised by seasonality, river flow is rising and falling in response to rainfall occurrences and the vegetation is Sudan Savanna type. Olofin (1987) observed that the natural vegetation of the study area is tropical grassland characterised by scattered trees which hardly exceed 20 metres high. The soil of the region is tropical Ferruginous rich in sand, while the zonal soils are also influenced by human manipulation to varying degrees (Olofin,1987).



Source: Department of Geography Bayero University Kano, 2011

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Figure 3.1 The Study Area

Methods of Data Collection

Weighted overlay method of Analytical Hierarchy Process (AHP) nine point scales was used as adopted from Tesfaye (2010) and Sitender (2011). Sixteen villages were selected for groungtruthing from eight local government areas using simple random sampling and lucky dip method was used in the selection as adopted from Krejcie, and Morgan (1970). In which boreholes data was collected then Land sat ETM + 2003 with resolution of 28.5m was used to map out the study area using boreholes data, then GIS. was used to assessed the ground water potential through overlaying factors of the study which include lineament, drainage density, geology, hydrogeology, soil and vegetation which were obtained from the land sat ETM + 2003 and maps.
The parameters of each of the factors were given weight and related to groundwater potential weighted overlay method adopted from Tesfaye (2010) Groundwater potential zones map (GPZM) was obtained through overlaying all the thematic maps, weights were assigned to each according to their relative importance to groundwater. Weights of various parameters in each of the factors were determined and maps were reclassified to compare the factors and groundwater potential zones.

Methods of data Analysis

AHP weighted Linear combination formulae was used for the weighting.

$S = \sum_{wi} X_i \times \prod_{cj}$ -- (1)

Where
S = is the composite suitability score
Wi =weighs assigned to each factor
Cj = constant (Boolean factor)
∑ = sum of weighted factors
∏ = product of constraints (1- suitable, 0- unsuitable)

Kano State map with the rural villages was overlaid over the groundwater potential zones map to assess groundwater condition of each rural village. On GWPZM all the sixteen rural areas were displayed on the map so as to show the zone where they fall. Aerial extent of each groundwater zone was determined using extension of ARCGIS 3D Analyst.

Results and Discussion

The result in Figure 2 indicates that the study area is classified into Very High, High, Moderate, Low and Very Low in terms of groundwater potentials. Table 1 indicates result for the weighted overlay of the six factors of groundwater occurrence in the study area as follows with consistency ratio of 0.04. Lineament density among all factors is having the highest weight of 0.46 or 46% this indicate that it is the most important factor in the study area in terms of groundwater occurrence followed by drainage density with 0.024 or 24%, geology 0.11 or 11%, soil 0.05 or 5% and lastly vegetation recorded the lowest value of weight which indicated that among the six factors. This is in line with findings of Khairul-Anam *et al* (2000), Sitender (2011) and that of Zeinolabedini and Esmaeily (2015).

Table 1 weighting of the all factors

	Lineament	D/D	Geol	Hydrogeology	Lithology	Vegetation	Weight	%
Lineament	**1**	3	5	5	7	**9**	0.46	46
D/ Density	1/3	**1**	3	3	5	7	0.24	24
Geology	1/5	1/3	**1**	1	3	5	**0.11**	11
Hydrogeol.	1/5	1/3	1	**1**	3	1	0.11	11
Lihology	1/7	1/5	1/3	1/3	**1**	1/7	0.05	5
Vegetation	**1/9**	1/7	1/5	1/5	1	**1**	0.03	3
Total %								100%

Consistency ratio-0.04
Source: Data Analysis, 2013

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Result shows that three villages fall within the Very High zone and are Yandadi, Shuwaki from Kano north and Karfi from Kano central. Babawa and Kosawa from Kano central and Tarai from Kano south are classified as High. Areas classified as Moderate are Shuwaki, Alajawa, Dokadawa and Karofin-yashi from Kano north and Turawa from Kano south. Rural areas that fall within a zone classified as Low are Fammar, Zainabi and Tudunkaya from Kano south and Tumbau from Kano central. Riruwai located at the extreme southern part of the study area is classified as zone of Very Low groundwater potential (Figure 2).

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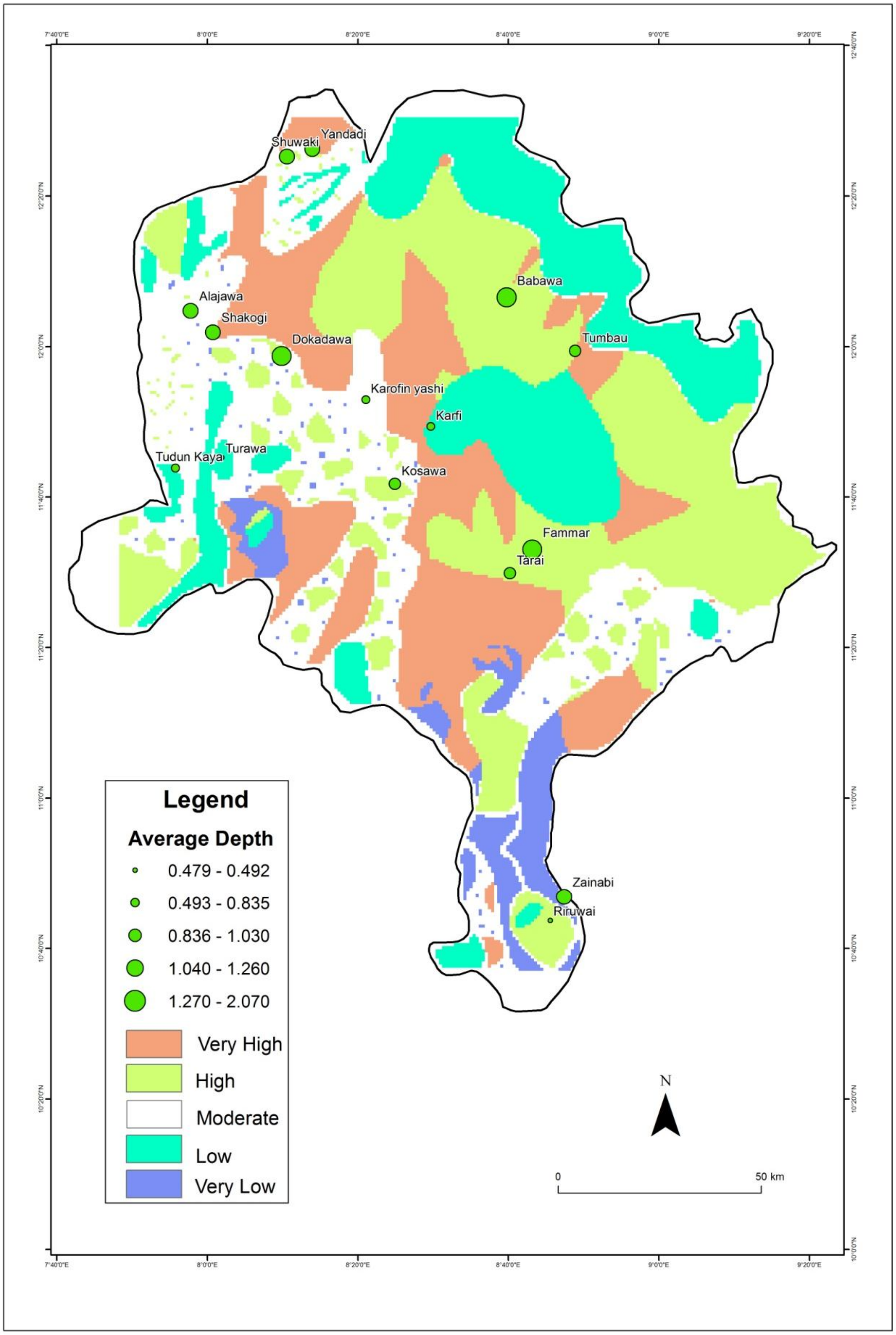

Source: Field Work, 2013
Figure 2 Groundwater potential map

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Lineament line Density weighting

The Result in Table 2 indicated that areas with highest lineament density of between 22.5- 28.11 km/km^2 are having weight of 0.48 and 48% weight while areas with lowest lineament density of between 0- 5.5 km/km^2 are having weight of 0.05 and 5% weight. The lineament density is high around Yandadi, Babawa, Kosawa, Karofinyashi, Turawa, and Dokadawa. It can also be seen that most of these areas are areas with Very High to moderate groundwater potential. This is because lineament is an expression of fractures, joints, faults and or other lines of weaknesses usually found on basement crystalline rocks and other hard rock like in this study area. Areas with lower lineament densities coincides with areas of Low to Very groundwater potentials because low lineament density means low infiltration and low groundwater, these areas include Zainabi, Tumbau, Riruwai, Fammar and Tudunkaya. It is supported by findings of Tesfaye (2010) and Alkali *et al* (2011) that low lineament density means low groundwater potential in crystalline basement complex areas.

Table 2 Lineament densities in km/km^2

	22.5-28.11	16.8-22.5	11.2-16.8	5.6-11.2	0-5.6	Weight	Percentage
22.5-28.11	1	3	3	7	7	0.48	48
16.8-22.5	1/3	1	1	5	5	0.22	22
11.2-16.8	1/3	1	1	3	5	0.20	20
5.6-11.2	1/7	1/5	1/3	1	1	0.06	6
0-5.6	1/7	1/5	1/5	1	1	0.05	5
Total %							100%

Consistency ratio: 0.02
Source: Data Analysis, 2013

Drainage Density Weighting

The drainage density weighting result as shown in Table 3 indicated that areas with higher drainage densities are those areas with high groundwater potentials; this can be proved from the weighting where high drainage density is having a higher weight. A drainage density of 97- 121.5Km/Km^2 is having the highest weight of 0.37 or 37% weight while the lowest value of drainage density recorded the lower value of weight in weighted overlay analysis of 0- 24.3km/km^2, this is due to the fact that higher drainage density attract more groundwater in basement complex areas. This is contrary to the findings of Tesfaye (2010) and Sitender (2011) that the higher the drainage density the lower the groundwater potential of an area, that is for a sedimentary environment. In the results areas with high drainage densities and at the same time with High groundwater prospects are Turawa, K/Yashi, Babawa, Yandadi, Kosawa and Tarai while areas with lower drainage densities and low Groundwater potentials are Tumbau, Shuwaki, Riruwai Zainabi, Tudunkaya, Shakogi, Dokadawa and Tarai. It is also observed from the result that the drainage pattern in the study area is most likely structurally controlled.

Table 3 Drainage Density in km/km^2

	97.2-121.5	72.9-97.2	48.6-72.9	24.3-48.6	0-24.3	Weight	Percentage
97.2-121.5	**1**	1	3	3	5	0.37	37
72.9-97.2	1	**1**	1	3	3	0.27	27
48.6-72.9	1/3	1	**1**	1	3	0.17	17
24.3-48.6	1/3	1/3	1	**1**	1	0.11	11
0-24.3	1/5	1/3	1/3	1	**1**	0.08	8
Total %							100%

CR: 0.05
Source: Data Analysis, 2013.

Geology Weighting

The result for weighting of Geology is presented in Table 4. It shows that among the Geologic formations in the study area homblende granite, migmatite, medium biotite and biotite gneiss are having more weight in relation to groundwater potential. The weights are 0.25 or 25%, 0.17 or 17%, 0.16 or 16% respectively. Areas with High to moderate groundwater potential are Karfi, Karofin-Yashi and Kosawa while areas with Low

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groundwater potential are Riruwai, Zainabi and Fammar with low weight of 0.02 or 2%. Those areas are underlain by quartz porphyry and quartzite massive schist which were believed to have originated from younger granites of Jurassic period. This shows that areas with homblende granite, migmatite, medium biotite and biotite gneiss are having more prospects because they can easily develop fractures that can increase infiltration rate The result coincided by that of Alkali *et al* (2011) and Kakwee*t al* (2015) that areas underlain by charnockitic rocks, quartz porphyry and porphritic granites in the study area were found to be of limited groundwater potential due to the presence of higher slopes, low infiltration and low lineament.

Table 4 Geological formations weighting

	H	M	IG	MG	BG	GG	FGB	MB	Q	QM	Weight	%
H	**1**	1	5	5	7	7	9	9	1	1	0.25	25
M	1	**1**	1	3	3	5	7	9	1	1	0.17	17
IG	1/5	1	**1**	3	5	7	9	9	1	1	0.16	16
MB	1/5	1/3	1/3	**1**	1	3	5	7	1	1	0.08	8
BG	1/7	1/3	1/5	1	**1**	3	5	7	1	1	0.08	8
GG	1/7	1/5	1/7	1/3	1/3	**1**	3	5	1	1	0.08	8
FGB	1/9	1/7	1/9	1/5	1/5	1/3	**1**	3	1	1	0.08	8
MB	1/9	1/9	1/9	1/7	1/7	1/5	1/3	**1**	1	1	0.05	5
Q	1	1	1	1	1	1	1	1	**1**	1	0.03	3
QM	1	1	1	1	1	1	1	1	1	**1**	0.02	2
Total %												100%

Consistency ratio= 0.08
Source: Data Analysis, 2013

KEY
H- Homblend Granite
M- Migmatite
IG- Ignimbrite
MG- Medium biotite gneiss
BG- Biotite Granite
GG- Granite Gneiss
FGB- Fined Grained biotite Granite
MB- Medium Biotite Granite
Q- Quartz Porphyry
QM- Quartzite massive Chist

Hyrogeology Weighting

It can be seen from Table 4 that areas characterized with pink white granite, metamorphic coarse, coarse pink black granite and quaternary formations are classified as areas associated with Very High to High groundwater potential. These areas have higher weight of 0.32 or 32%, 0.18 or 18%, 0.16 or 16%, 0.11 or 11% respectively and low values of water table that ranges from 402m to 666m. Such areas comprises of Karofinyashi, Yandadi, Babawa and Karfi. Areas associated with younger granite with weight of 0.02 or 2%, black and white granite with weight 0.03 or 3%, metamorphic suits with weight 0.05 or 5% and Dior granite 0.05 or 5 these are areas with low groundwater potentials. This is because younger granites very hard impermeable with less fractures and consequently have low infiltration. Such areas include Riruwai Zainabi and their adjoining areas. This is supported by the work of Sitender (2011) that sand silt and clay formation have highest weight of 6, coarse to fine alluvial sand 4, quartzite phyllite and slate 3 and Quartzite- Chist is the least with a weight of 1.

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Table 5 Hyrogeological formations Weighting

	PWG	MC	CPBG	QF	QZ	DG	MS	BWG	YG	Weight	%
PWG	1	3	5	5	7	7	9	9	1	0.32	32
MC	1/3	1	1	3	5	7	7	7	1	0.18	18
CPBG	1/5	1	1	3	5	5	5	7	1	0.16	16
QF	1/5	1/3	1/3	1	3	5	7	9	1	0.11	11
QZ	1/7	1/5	1/5	1/3	1	1	3	5	1	0.08	8
DG	1/7	1/7	1/5	1/5	1	1	3	5	1	0.05	5
MS	1/9	1/7	1/5	1/7	1/3	1/3	1	3	1	0.05	5
BWG	1/9	1/7	1/7	1/9	1/5	1/5	1/3	1	1	0.03	3
YG	1	1	1	1	1	1	1	1	1	0.02	2
Total %											100%

Consistency ratio= 0.07
Source: Data Analysis, 2013

Key
PWB- Pink white granite
MC- Metamorphic course
CPBG- Coarse pink black granite
QF- Quaternary formation
QZ- Quazite**DG**- Dior granite
MS- Metamorphic suit
BWG- Black and white granite
YG- Younger granites

Soil weighting
The result shows that soil is one of the important factors in groundwater identification. Areas with hydromorphic soils and ferruginous tropical soils are more important in terms of groundwater potential because they have higher weights of 0.41 or 41% and 0.38 or 38% such areas include Shakogi, Alajawa, Yandadi, Karfi, Babawa, K/yashi and Turawa. Areas dominated with lithosols are areas with moderate groundwater potential with a weight of 0.15 or 15% while areas associated with brown and reddish brown, these areas include Riruwai, Zainabi, Tudunkaya and Fammar soils are classified as areas of low groundwater potential with a weight of 0.06 or 6% (Table 6). This is because brown and reddish brown soils and clay have low infiltration. It is in line with findings of Oluwatola *et al* (2013) sandy soil is having weight of 3 followed by loam with 2 and clay with 1 in terms of groundwater potential.

Table 6 Soil types weighting

	Hydromorphic soil	Ferruginous tropical soil	Lithosols reddish brown	Brown and reddish brown	Weight	%
Hydromorphic soil	1	1	3	7	0.41	41
Ferruginous tropical soil	1	1	3	5	0.38	38
Lithosols reddish brown	1/3	1/3	1	3	0.15	15
Brown and reddish brown	1/7	1/5	1/3	1	0.06	6
Total %						100%

Consistency ratio= 0.01
Source: Data Analysis, 2013

Vegetation weighting
The result shows that among the major types of vegetation in the study area areas under Sudan savanna >60% is having more influence on groundwater potential and are within Very High to High groundwater potential

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zones with a weight of 0.56 or 56% followed by Sudan savanna 30- 60% with a weight of 0.26 or 26% (Table 7). This is so because density of vegetation increases infiltration rate and groundwater potential. This is supported by the findings of Stinder (2011) that high dense vegetation indicates possibility of acting as major conduits for subsurface movement and for the storage of groundwater particularly in basement complex areas.

These areas include Karfi, K/Yashi, Babawa, Yandadi and Turawa. Shrub savanna and savanna wood land recorded low weight and low groundwater potential with weight of 0.13 or 13% and 0.05 or 5% respectively. These areas include Riruwai, Zainabi and some patches at extreme northern and southern parts of the study area.

Table 7 Vegetation types weighting

4	**SS >60%**	**SS 30-60%**	**Shrubs SV**	**S/ wl**	**Weight**	**Percentage**
SS >60%	**1**	3	5	7	0.56	56
SS 30-60%	1/3	**1**	3	5	0.26	26
Shrubs SV	1/5	1/3	**1**	5	0.13	13
SV WL	1/7	1/5	1/5	**1**	0.05	5
Total %						100%

CR: 0.02

Source: Data Analysis, 2013

Areal Coverage of the Groundwater potential zones

The result indicates that the whole state is categorised into five zones of groundwater potential zones as follows Very High 5,676 km^2 with 27.3%, High 7,400km^2 with 35.7%, Moderate 1,284km^2 with 6.2%, Low 5,375km^2 with 25.9% and Very Low with 1,025km^2 with 4.9%. (Table 8). These show that High Potential zone is having the largest areal coverage and Low potential zone is the least. The result is closer to that of Matthew (2006) that in United State there is principal aquifers of over 300,000km^2, principal aquifers of over 20,000km^2, principal aquifers of less than 20,000km^2 and non-principal aquifers.

Table 8 Percentage Areal Coverage of groundwater potential Zones

S/N	**Groundwater potential zones**	**Areal coverage (km^2)**	**Percentage (%)**
1	Very High	5,676 km^2	27.30%
2	High	7,400 km^2	35.70%
3	Moderate	1,284 km^2	6.20%
4	Low	5,375 km^2	25.90%
5	Very Low	1,025 km^2	4.90%
	Total	20,760 km^2	100%

Source: Data Analysis, 2013

Conclusion and Recommendations

It can be concluded that the study area fall under five groundwater potential zones which are very high, high, moderate, low and very low. The five groundwater potential zones are directly controlled by six factors which are lineament density, drainage density, geology, hydrogeology, soil and vegetation according to their relative importance to groundwater potential. Based on the findings of the research it is concluded that rural areas in Kano sate with high lineament lines density, high drainage density, low slope values, older granite basement complex, alluvial, hydromorphic and ferruginous soils and high percentage of Savanna vegetation are areas with high groundwater potential because they attracted more infiltration and groundwater accumulation. Among the factors lineament density is the most important because in crystalline basement complex areas the greater the fractures the more the infiltration and more groundwater.

In relation to the findings obtained from the research work and conclusion reached the following recommendations are forwarded. Since lineament, Drainage Density, Geology, Hydrogeology, Soil, Vegetation

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and slope are the major factors controlling groundwater occurrence in the study area analysis of these parameters should be supported by more high resolution terrain data like radar images. It is recommended further that areas with very low to low groundwater potential low yielding boreholes are to be the best options to avoid total aquifer drying

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