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MAPPING GROUNDWATER VULNERABILITY TO POTENTIAL CONTAMINATION IN KANO METROPOLIS - NIGERIA

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ABSTRACT

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This work attempted to map the groundwater vulnerability of Kano metropolitan area in Nigeria. The condition of groundwater contamination in Kano is becoming a critical issue with regards to high anthropogenic exploitation coupled with continuous deterioration of its quality which poses a great threat to public health and the ecosystem. This study produced the groundwater vulnerability map for the study area using a DRASTIC model with GIS and remotely sensed data. Data for 7 DRASTIC components (depth to water level, net recharge, aquifer media, soil media, topography, the impact of vadose zone and hydraulic conductivity) were collected, transformed into digital thematic map layers and combined to form the overall DRASTIC index map using GIS. The DRASTIC index values ranged from 53 to 99, suggesting that 100% of metropolitan Kano area is less vulnerable to potential contamination. This will be an important tool for policy makers, researchers and other stakeholders for effective monitoring and management of groundwater resources in Kano.

INTRODUCTION

High exploitation and deterioration of groundwater resources caused by increasing population and anthropogenic activities is receiving great attention worldwide. Apart from the high demand for fresh water resources, the deterioration of quality groundwater resource poses a great threat to public health (Mpenyana-Monyatsi et al., 2012), (Rajasooryar et al., 2013), (Kurwadkar, 2014). Geospatial mapping of groundwater vulnerability is an important tool for effective protection, monitoring, land use management, as well as the public health of communities (Baalousha, 2010). Groundwater (GW) is susceptible to contamination by various sources of pollutants in urban

Kano (Mashi and Alhassan, 2007), (Ali and Young, 2013), (Binns et al., 2003). Ali (2012) stressed that these pollutants should be identified and mapped out in order to achieve an effective GW management.

Geographic Information Systems (GIS) tools are now the latest techniques that have gained tremendous applications in various environmental and water resource studies. Groundwater vulnerability mapping has been carried out in many locations across the globe which has provided an excellent means of representation, logical manipulation, hidden information extraction as well as simulation of various phenomena, some of which had never been possible before.

In statistical methods, relationships between the contaminants and location parameters are determined using statistical procedures; this is also constrained by accuracy and adequacy of water quality observations and spatial variable selection (Resek, 1996). Statistical method is only suitable to locations in which their groundwater contamination is governed by similar factors Babiker et al. (Babiker et al., 2005) and Shirazi (Shirazi et al., 2012). Overlay & index method also called "parameter weighting" method according to GAO (1992) has gotten significant attention by many researchers for it being the most suitable and widely used method for vulnerability assessment of groundwater that overcomes most of the limitations mentioned. The simplest overlay method identifies areas where parameters indicating vulnerability coincides, such as the shallow groundwater and sandy soils. More sophisticated systems assign numerical scores based on several parameters (Evans, 1995).

The overlay & index method has been successfully used by many researchers (Baalousha, 2010), (Ojuri and Bankole, 2013), (Farjad, 2012), (Jamil et al., 2011), (Ishaku et al., 2011), (Rahman, 2008), (Abdel-fattah, 2005), (Breu et al., 2008a), (Gogu et al., 2001), (Al-Adamat et al., 2003), (Rahman, 2008), (Alwathaf and Mansouri, 2011), (Mukherjee et al., 2012), (Haile and Abiye, 2012), (Soper, 2006), (Blackmore, 2006), and (Breu et al., 2008b). Commonly known overlay & index methods includes DRASTIC, SINTACS, GOD, SEEPAGE, and EPIK (Shirazi et al., 2012).

DRASTIC Model

The DRASTIC model was first introduced by Aller et al., (1987), it incorporated the experience and expertise of more than 40 hydrologist and geologist. It became the most popular method for GW vulnerability assessment among other overlay and index methods. The acronym "DRASTIC" refers to 7 hydro-geological elements i.e. (i) Depth to groundwater (D), (ii) Net recharge (R), (iii)

Aquifer media (A) (iv) Soil media (S) (v) Topography (T), (vi) Impact of vadose zone (I) and (vii) Hydraulic conductivity (C). It emanated from a scoring system first introduced by EPA (Environmental Protection Agency, USA) in 1980s.

The model combine maps of influencing contaminant's parameters in the groundwater transport. Each parameter is ranged with possible values denoting the degree to which that parameter may alter the vulnerability of the groundwater in a particular region. For example, shallow water is considered more vulnerable than deeper water, making a basis for ranging certain values for depth to the groundwater parameter.

One of the important features of DRASTIC is that most of the overlaying parameters such as rainfall and depth of the groundwater can be available over large areas, which makes them suitable for assessment in regional scale (Thapinta and Hudak, 2003). However, the subjectivity in assigning numerical values and weights to the descriptive entities and different attributes respectively gives this method some inherent limitations (Babiker et al., 2005).

A number of researchers adopted and modified the DRASTIC method by omitting or introducing a parameter(s) that are not relevant or specific to the local conditions of the area under study (Shirazi et al., 2012).

The DRASTIC method has been considered for this work because of the availability of its parameters as well as its adjustment flexibility.

Method description

General methodological approach for integrating the DRASTIC model procedures is presented in figure 2. From the figure, each phase can be considered as an independent vertical flow process with a horizontal process between the DRASTIC parameters and the GIS application, creating an environment for constant feedback and ease of quality evaluation.

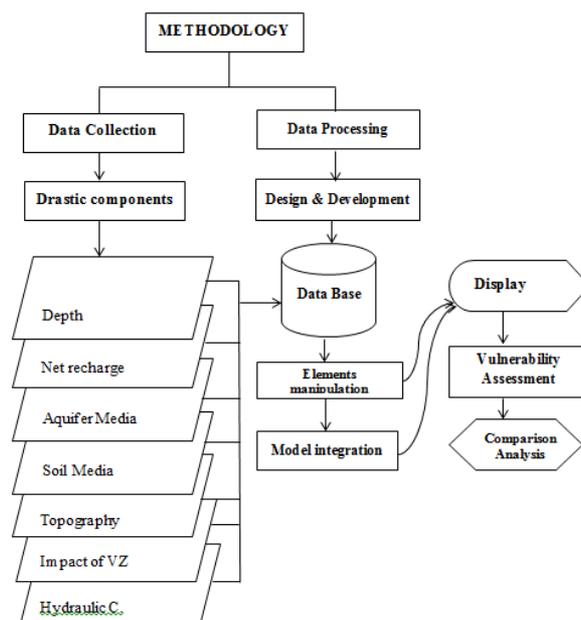


Figure 2. GIS integration approach (modified from (Alwathaf and Mansouri, 2011))

Following steps were carried out:

I. Data collection and compilation of the hydrogeological parameters

The first objective is to develop a database of spatial and non-spatial information for groundwater contamination (GWC) of the study area. Sources and factors contributing to groundwater contamination are vast and numerous, information or data necessary for identification and mapping these sources are numerous. Gathering this information is time intensive and costly. Moreover, availability of published data that relates directly to GWC in Kano is still lacking. Despite the odds, this study focused on the available data related to physicochemical, geological, hydrological and human activities of the area. A data set was collected consisting the location coordinates, depth to the groundwater from ground surface, net recharge, aquifer media, soil media, topography, the impact of the vadose zone and hydraulic conductivity. Table 1 summarized the description of these dataset collection and their sources.

II. GIS processing

All the parameters were carefully prepared and processed using ArcGIS package. UTM zone 32 N coordinate system was generally used and the raster size was 30 by 30 meters for all layers. Logical calculations were conducted with help of raster calculator and all the resulting layers were reclassified and formed the thematic layers of each DRASTIC

parameter representing its contribution the potential vulnerability status of the study area.

III. Weighting, ratings and thematic maps layers

Parameters Weighing and Rating:

A standard have been established for numerical weighing and rating of the DRASTIC parameters(Dee et al., 1973), (Aller et al., 1987).The numerical weights and ratings were based on the Delphi (consensus) technique and they remain relatively constants(Aller et al., 1987). However, based on the nature of the area under study, certain conditions may warrant modification to the standardized 'weights' and the 'rates' values (Shirazi et al., 2012).

For this study, the standard weighing and rating tables were used since it has shown many satisfactory results in different locations that having similar characteristics (Alwathaf, 2011). Each of the parameters (a DRASTIC factor) has been assigned a weight relatively ranging from 1 to 5 (Table 2). the highest weight of 5 being assigned to the most significant factor; and weight of 1 to the least significant factor. Pollution potential (vulnerability) is rated using a range value from 1 to 10 denoting low to high level pollution potentials respectively, which shows the level of contribution by each parameter. Thus the terms weight, range and rating have been defined as follows:

Table 1. Summary of data collected

Parameters	Data Collected	Strategy Used	Source
1. Depth to groundwater table	Physometric depth	Download and Processing of the study area's Digital Elevation Model (DEM)	ASTER GDEM DATA available at http://gdem.ersdac.jspacesystems.or.jp/search.jsp "ASTER GDEM is a product of METI and NASA"
2. Net recharge	hydrological data		(Emmanuel et al., 2011)
3. Aquifer media	Geological	Literature search and	KNARDA 1989 in (Emmanuel et al., 2011) and (FAO, 1964)
4. Soil media	Data,	Personal communications	
5. Topography	Topographic		
6. Impact of vadose zone	and Soil maps		
7. Hydraulic conductivity	data		

Weights: A relative value ranging from 1 to 5

Range: A division of values for each DRASTIC parameter.

Rating: A relative value in terms of range with respect to pollution potential. Values range from 1 to 10

W = Weight

The DRASTIC index is an aggregated result delineating areas that are susceptible to groundwater contamination. Higher DRASTIC index indicates higher susceptibility or vulnerability and vice versa.

Table 2. Description of DRASTIC parameters and their assigned weight factors

Factors	Description	Relative Weights
Depth to water level	This denotes the vertical distance from the ground water surface to the water table; the less the distance the more the chances of pollutants to reach the ground water	5
Net recharge	It is the quantity of water that penetrates over a unit area of land that consequently replenishes the groundwater, hence the more the recharge the higher the susceptibility of contamination	4
Aquifer media	It signifies the potential attenuation media characteristics of the aquifer material; the more permeable, weaker the attenuation capacity of aquifer media	3
Soil media	It is the topmost soil cover and weathered portion of the ground; it dictates the movement of the contaminants from the surface, the higher the holding capacity the longer the travel time	2
Topography	It refers to gradient or slope; the steeper the angle of inclination, the greater the runoff flow and the less the recharge ability of the aquifer and vice versa	1
Impact of vadose zone	It is the texture of the soil medium vadose zone between the water table and the unsaturated soil cover	5
Hydraulic conductivity	It is the capability in which formation conductivity aquifer transmits water; the higher the conductivity the more vulnerable the aquifer is	3

Source: Modified from Aller et al. (Aller et al., 1987) and Hamza (Hamza et al., 2014)

The numerical values of ratings and weights for all parameters were plugged into an equation to yield a DRASTIC index (Eq. 1)(Aller et al., 1987)which determined the pollution potential.

$$DI = DrDw + RrRw + ArAw + SrSw + TrTw + Irlw + CrCw \dots\dots\dots Eq.1$$

Where DI = Drastic Index,

- r = Rating, w= Weight,
- D= Depth to groundwater
- R=Net recharge,
- A=Aquifer media
- S=Soil media,
- T=Topography
- I=Impact of vadose zone
- C=Hydraulic conductivity

RESULTS AND DISCUSSION

Depth to water table

Figure 3 shows numerical ratings for the depth to water table input layer with total DRASTIC weight of 40 (Table 3). It denotes the impact of vertical distance from the ground surface to the water table; the less the distance the more

the chances of pollutants to reach the groundwater then the greater the rate value. The results indicated that 59.1% of the whole study area’s depth range between 42-61 feet. The area was determined by multiplying the number of pixel covering the area by 30m since all the spatial accuracy of the maps used were 30m.

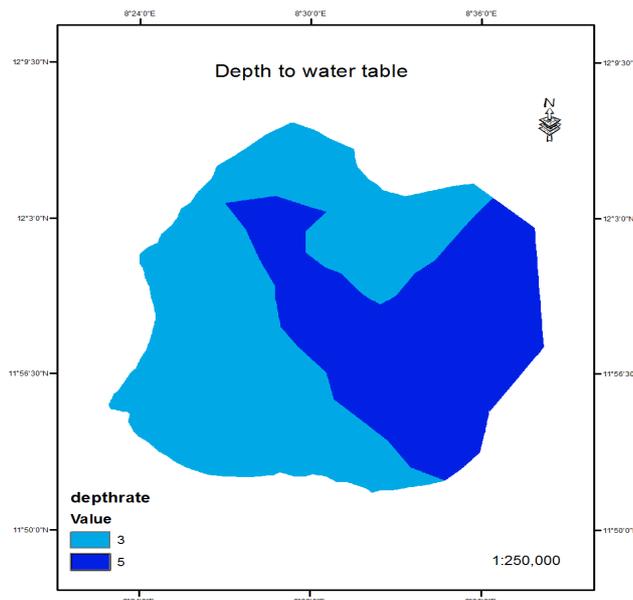


Figure 3. Depth to water table input layer

Table 3. Depth to water table input layer attribute

DRASTIC Parameter	Range	R	W	RW	Pixel Count	Area	
						m ²	%
Depth to water table (ft)	0-42	3	5	15	252819	227537	40.9
	42-61	5		25	364587	328128	59.1
Total				40	617406	555665	100

R=Rating, W=Weight, TWD=Total DRASTIC weight=(RW)

Net Recharge:

For areas with negligible overland flow due to sandy soil and or flat topography, the mean annual net groundwater recharge can be determined using equation 2.

$$R \approx P - ET \dots\dots\dots \text{Eq.2}$$

where R denote the net recharge, P the mean annual precipitation and ET donotes the evapotranspiration (Shirazi et al., 2012).

Value for net recharge can be negative in areas where Evapotranspiration (ET) exceeds precipitation, typically in shallow groundwater areas(Shirazi et al., 2012).Negative Rmeans borrowing water for ET from the groundwater dueto deficit of precipitation in a given location. This is the typical case of Kanometropotan area, while the mean rainfall per year amount to 885.5mm , ET accounts to 1771.8mm (KUST, 2008). Therefore the net recharge for the study are was calculated as (-887.4mm per annum) using equation 2and the Kano climate data reported in (KUST, 2008).

Since the area has a negative net-recharge, it implies that the net-recharge has no significant impact on the pollution potential of the study area. It was therefore been excluded among the 7 parameters of the DRASTIC model. This is in line with Shirazi's recommendations for modification of DRASTIC parameters to suite local conditions(Shirazi et al., 2012).

Aquifer Media

Figure 4 depicts the layer of aquifer media. The layer yields a total DRASTIC weight value of 48 as shown in Table 4.

The metamorphic suits are having the highest weight value of 12. However, it covered only 7.3% of the total area. The granite (older, pink and undifferentiated types) has a lower value of 9 and covered 21.8% of the whole area. This indicates that the aquifer media of the study area are generally medium to fine grained and suggest strong resistance to intrinsic pollution vulnerability.

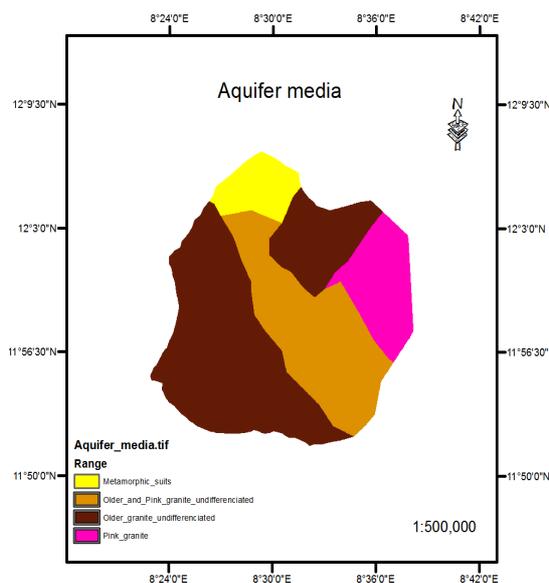


Figure 4. Aquifer media layer

Table 4. Aquifer media attribute

Range	R	W	TDW	Pixel count	Area	
					m ²	%
M	4		12	45174	40656.6	7.3
OG	3	3	9	74069	66662.1	12.0
UOG	3		9	245523	220971	39.7
PG	3		9	79082	71173.8	12.8
O&PG.U	3		9	173888	156499	28.1
Total			48	617736	555962	100.0

R=Rating, W= Weight TWD=Total DRASTRIC weight = (TxW), M= Metamorphic suits OG=Oldergranite, UOG= Undifferentiated Older granite, PG= Pink Granite, O&PG.U= Older and pink granite undifferentiated.

Soil media

Figure 5 and Table 5 shows the resulting layer and attributes respectively, for the impact of soil media for drastic index.

Sand range of soil covered 36.3 percent of the soil cover which yielded a drastic weight of 18 out of the 56. The lateritic-clay range of the soil has yielded the highest total drastic weight of

20 though only covered 25.4% of the area. The loamy-sand range of soil covers 15.3% of the total area and yields a TDW of 14. TDW of 4 been the lowest among the four soil types is covered by silty-clay type of soil present in the area. This indicates the highest resistance to potential seepage of contaminants in silty-clay range of soil.

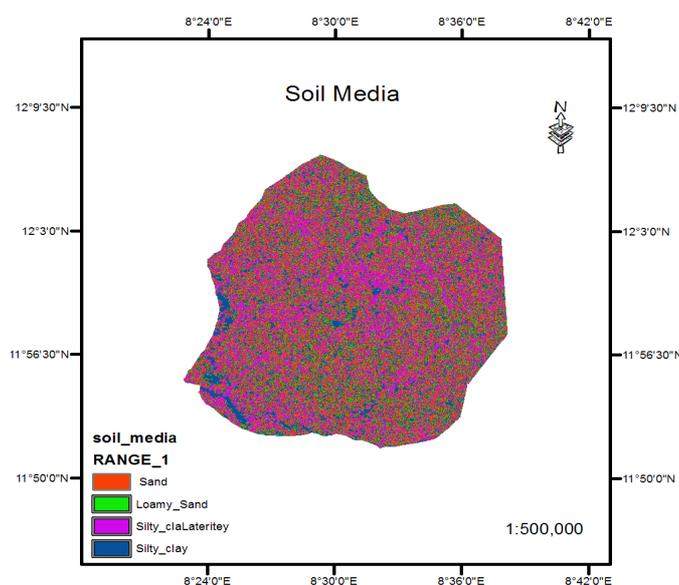


Figure 5. Soil media layer

Table 5. Soil media layer attributes

Range	R	W	TW	Pixel Count	Area	
					m ²	%
SC	2		4	142173	127955.7	23.0
LS	7		14	94787	85308.3	15.3
S	9	2	18	224126	201713.4	36.3
L	10		20	156608	140947.2	25.4
Total			56	617694	555925	100.0

R=Rating, W=Weight, TWD=Total DRASTRIC weight=(TxW), SC=Silty clay LS= Loamy sand, S=Sand, L= Laterite.

Topography

Figure 6 and Table 6 show the layer and attributes for impact of topography respectively. Topography is a controlling factor for pollutant's runoff or infiltration. As shown in Table 6, a TDW of 10 at locations having a slope of 0-2 percent indicates the highest potential for pollutant's infiltration, this covered 30% of the study area; followed

by a slope range of 2-6% covering 35% of the area with a TDW of 9. This implies that the study area is generally having a lower slope and is relatively flat. The total TDW of 28 indicate that the vulnerability contribution of the topography layer have 28% contribution out of the total aggregate contrgibutions of the remaining factors.

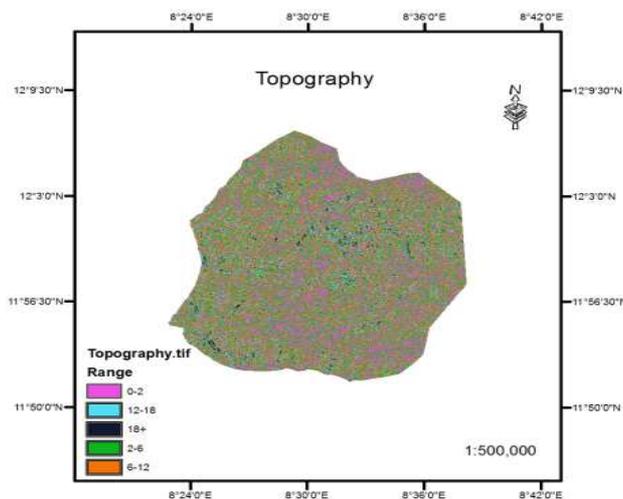


Figure 6. Topography layer

Table 6. Topography layer attributes

Range	R	W	TDW	Pixel Count	Area	
					m ²	%
0-2	10	1	10	184733	166259.7	29.9
2-6	9		9	214304	192873.6	34.7
6-12	5		5	140305	126274.5	22.7
12-18	3		3	63503	57152.7	10.3
18+	1		1	14849	13364.1	2.4
Total			28	617694	555924.6	100.0

R=Rating, W=Weight, TWD=Total DRASTRIC weight=(TxW)

Impact of the vadose zone

Figure 7 and Table 7 shows the rated layer and attributes for the impact of vadose zone respectively. The Impact of vadose zone layer contributed a TDW of 50, Clayed sand, Old & Pink Granite range of soil material in the vadose zone covered 81% of the study area. The lowest rating of 4 for this vadose zone was justified due to the presence of

alternating layers of clay soil, older & pink granite with medium to fine grained materials. It contributes TDW of 20 as compared with lateritic soil zone that has a higher value of 30. However, lateritic soil covers only 19% of the total area. This shows that the vadoze zone of the study area is dominated by medium to fine grained material, hence the moderate DRASTRIC rating value of 4-6.

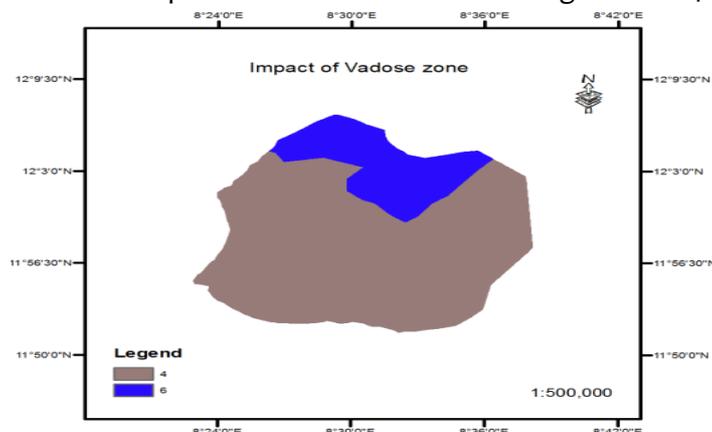


Figure 7. Impact of vadozezone layer

Table 0-5. Impact of vadozezone layer attributes

Range	R	W	TDW	Pixel Count	Area	
					m ²	%
CS/O&P G	4		20	461086	414977.4	80.7
LC		6	30	156608	140947.2	19.3
SC/MO G.						
Total			50	617694	555924.6	100.0

R=Rating, W=Weight, TWD=Total DRASTRIC weight=(TxW), CS= Clayed Sand, O&P G.= Old and Pink Granite, LC= Latritic Clay, SC= Silty Clay, MO G.= Medium grained Granite

Hydraulic Conductivity

The study area is having very low conductivity typically ranging from 0.039 to 0.778 m/d with an average of 0.330 m/d (Emmanuel et al., 2011). Hence a lower numerical rating value of 1 was assigned for the aquifer following

recommendation of(Aller et al., 1987)Figure 8 and Table 8present the thematic layer and attributes for hydraulic conductivity respectively. The TDW was 9 indicating very little contribution to the potential vulnerability.

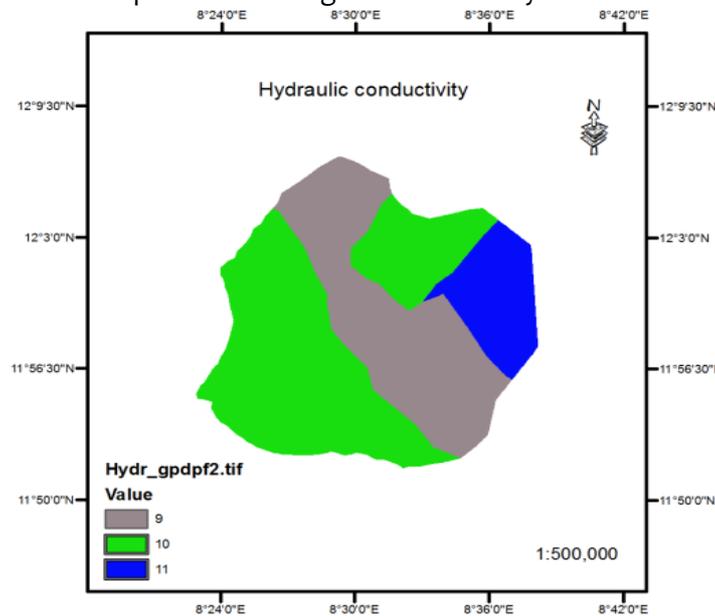


Figure 8. Hydraulic conductivity layer

Table 8. Hydraulic conductivity layer attributes

Range	R	W	TDW	Pixel Count	Area	
					m ²	%
M/O&P.G	1	3		219062	197156	35.5
UOG	1			319592	287633	51.7
PG	1		3	79082	71174	12.8
Total			9	617736	555962	100

M/O&P.G = Metamorphic suits/Older &Pink granite undifferentiated

UOG = Undifferentiated Older granite, PG = Pink Granite

DRASTIC Index Result/ Vulnerability map

Figure 9 presents the final vulnerability map of the study area. The DRASTIC index ranges from 52 to 99. This range of index values indicates the degree of intrinsic vulnerability of the Kano metropolitan aquifer to potential contamination of its groundwater. This range falls within the first category of degree of

standardized DRASTIC aquifer vulnerability evaluation criteria and was characterized as low vulnerable. Criteria for the evaluation of vulnerability in the DRASTIC model are shown in Table 9. The result indicates that the study area is generally having a low vulnerability to potential groundwater pollution as determined by the DRASTIC model.

The lower index value may be as a result of the relatively high elevation of the study area (about 400-600m above sea level. Moreover, the area is characterized with negative hydraulic conductivity which also lowers the degree of percolation of contaminants to reach the groundwater; the topography is relatively flat (2-12%); and low rainfall (average of 785mm)(KUST, 2008).

Within the low range of the vulnerability index, the map delineates locations that are more vulnerable compared with other locations. As shown in Figure 9, areas coloured blue having an index range of 81-99 are more susceptible to pollution than the red-coloured locations (ranged 68-81) and the least susceptible ranging from 52-68.

Table 9. Criteria for the evaluation of vulnerability in DRASTIC model (Aller et al., 1987)

Vulnerability degree	Vulnerability Index
Low	1-120
Moderate	121-160
High	161-200
Very high	>200

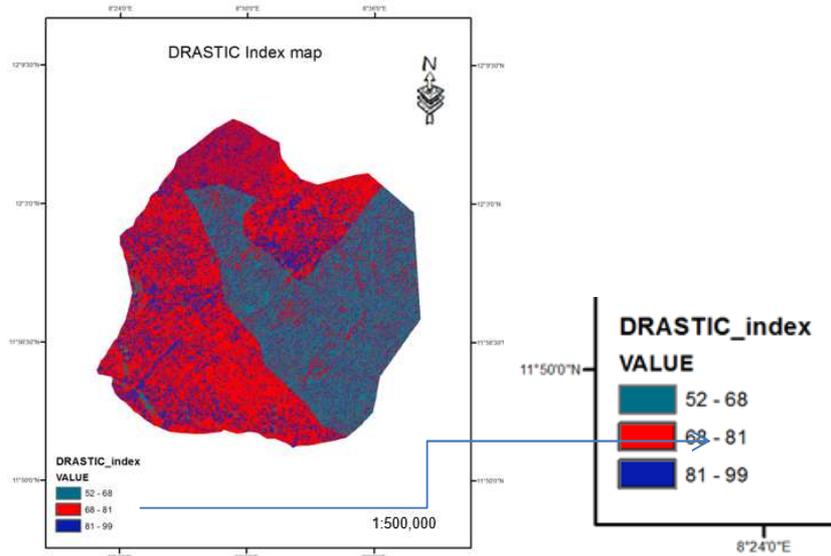


Figure9. Final vulnerability map

CONCLUSION AND RECOMMENDATIONS FOR FUTURE ASSESSMENTS

This work intended to answer the question that “is there significant portions of the Kano metropolitan area that are susceptible or vulnerable to groundwater contamination as identified by the application of available parameters of the DRASTIC model?” A map has been developed using the DRASTIC model and GIS that represent the vulnerability of the groundwater to potential contamination in Kano metropolis. The DRASTIC indexes ranged from 53 to 99, the result suggests that 100% of the metropolitan Kano area is less susceptible

or vulnerable to potential contamination of its groundwater.

Due to the limited scope of this study, a number of recommendations have been drawn for future vulnerability assessments in the study area:

1. Sensitivity analysis of each parameter should be conducted in subsequent studies in order to determine most and least significant factor(s) within the model’s parameters. This can allow to trade off the less important factors and subsequently improve the result’s accuracy.

2. Modification of DRASTIC model is strongly recommended to incorporate the Land use characteristics which will give impact of human activities to the DRASTIC equation. This will also enhance to accuracy of the model to adequately represent the vulnerability of the study area.

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