ISSN: 2449 - 0539
BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY VOL 19 NO. 2 MAY 2024 PP. 5-20

AQUIFER VULNERABILITY ASSESSMENT USING DRASTIC AND GIS IN DAMATURU METROPOLIS, YOBE STATE, NIGERIA

Adamu Mu'azu Nuhu[1], Nuraddeen Muhammad Babangida[2]

[1,2]Department of Civil Engineering, Bayero University, PMB 3011 Kano, Nigeria
[1]adamumuazu29@gmail.com [2]Nmbabangida.civ@buk.edu.ng

ABSTRACT

The study employed DRASTIC model and Geographic Information System (GIS) technology to assess the intrinsic groundwater aquifer vulnerability to contamination in Damaturu Metropolis, Nigeria. The DRASTIC index model uses seven (7) environmental parameters; depth to water level, net recharge, aquifer media, soil media, topography, impact on vadose zone and hydraulic conductivity for the assessment of intrinsic aquifer vulnerability. The DRASTIC scores obtained vary from 81 to 153 which was classified into four vulnerability zones i.e. low, moderate, high and very high. The GIS analysis shows that of the total area of Damaturu Metropolis, about 8.5% was classified as "Low Vulnerability", 66% as "moderate vulnerability", 18.8% as "high vulnerability" and 6.7% as "very high vulnerability". The validation of the DRASTIC model was achieved through comparison between the DRASTIC vulnerability index map and nitrate concentrations of 52 borehole water samples in the area and using Pearson's (r) correlation coefficient equation. It was found that $r = 0.7$ which indicates a significantly high correlation between the vulnerability index and nitrate concentration values. Overall, this study produced a very valuable tool for the state agencies responsible for groundwater resource management, environmental protection and planning because it can be very useful in planning and siting activities that generate pollutants (e.g., sanitary landfill, soak away, automobile workshops and petrol station) which pollute the groundwater, in determining where groundwater protection or remediation efforts be directed to, thereby reducing the overall cost of groundwater monitoring in Damaturu metropolis.

Keywords: Groundwater; Contamination, Intrinsic.

1. INTRODUCTION

Groundwater (GW) is an essential component of societies and communities around the globe. Not only is it a vital resource for drinking water, it is also essential for social, recreational and cultural activities. It is the world's most extracted natural resource with withdrawal rates in the estimated range of 982km^3/year (Margat & Van der Gun, 2013). It is mostly used for crop irrigation as well as domestic uses. GW is the most important freshwater resource of the world because it accounts for nearly all usable freshwater (Chapman, 1996). Its contribution to food security and domestic water supplies, and the resulting economic benefits, have been enormous (Jude, 2020). Aquifer, the basic term of hydrology, has many definitions and applications worldwide. A basic definition, probably accepted by most hydrologists is: "a body of a permeable rock that contains water in all its pores and can sustain producing wells" (Mazor, 1995). Groundwater is stored in aquifers, and moves slowly through the geologic formation that overlaid the aquifers. In Nigeria, GW continues to be the main potable and reliable water source for a lot of residents in the rural and urban settlements. The Joint Monitoring Programme for

Water Supply and Sanitation estimated that in 2021, 69.6% of Nigeria's population use groundwater (GW) sources: 75.9% in the rural areas and 61.1% in urban areas (UNICEF/WHO/JMP, 2023). However, this vital resource continuous to face many threats due to natural as well as anthropogenic activities. Contaminants in GW, such as toxic metals, metalloids, pesticides, hydrocarbons and other contaminants are a risk factor for the health of both human populations and for the natural environment (Li et al., 2021).

Although GW has a natural protection against contamination, once its quality is impaired, it proves difficult, costly and sometimes practically impossible to remediate (Ahmed et al., 2017). Therefore, it is of great importance to provide preventive measures against GW contamination so as to preserve optimum GW quality. The degree of protection that the natural environment provides against the percolation of contaminants introduced at the land surface into the GW system varies spatially and it depends on the hydrogeological settings of areas, and this is termed as "GW vulnerability". (Maria, 2018) defined it as relative evaluation of the potential exposure of a GW resource to contamination from various human activities. According to (Focazio, 2002), vulnerability can be specific contaminant (specific vulnerability) or for any contamination in general (intrinsic vulnerability). The investigation of potential for GW contamination or GW vulnerability has been intensively studied with a number of approaches during the past years (Machdar et al., 2018). These approaches for assessing GW vulnerability are grouped into three major categories, a) methods using process-based simulation models; b) statistical methods; c) overlay and index methods.

Process-based simulation methods use the well-known laws of physics, chemistry, geochemistry, and other precise sciences. Usually such models need complex data, which are not easily available (Moraru et al., 2018). Statistical method use statistics to determine associations between the spatial variables and the actual occurrence of pollutants; however, they are usually region specific and not suitable for the transfer to other regions (Babiker et al., 2005). In overlay and index methods, hydrogeological factors/parameters that control movement of pollutants from the surface layer of the soil into the saturated zone are mapped based on the derived data. Each parameter, divided to an interval of significant values, is assigned by a numerical rating based on its growing importance in the vulnerability (Abdelmadjid & Omar, 2013). The main benefit of the overlay and index methods is that some of the factors controlling movement of pollutants can be assessed over large area, which makes them appropriate for regional scale evaluation (Oroji, 2018). The most common overlay and index tools are; DRASTIC (depth to GW, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity) system, GOD (GW occurrence, overall aquifer class, depth to aquifer) system, AVI (aquifer vulnerability index) rating system, SINTACS (water table depth, effective infiltration, unsaturated zone, soil media, aquifer media, hydraulic conductivity and topographic slope) method, and EPIK (epikarst, protective cover, infiltration conditions, karst network development). Out of these methods, the DRASTIC and AVI methods have been widely accepted to meet the needs of most countries globally (Anornu & Kabo-Bah, 2013). Several researchers have reported the decrease in GW quality in parts of Damaturu, Yobe State, Nigeria (El-Ishak 2013; Emeka & Weltime, 2008; Kwaya et al., 2017; Oruonye & Medjor, 2009; Umara et al., 2004; Waziri & Bomoi, 2012). The decrease in GW quality in the study area were mostly attributed to improper siting of septic tanks, pit latrines, and sanitary landfills, poor sanitation and inappropriate land use planning. Despite all these, proper documentations of the spatial variations of GW aquifer vulnerability to contaminations was not conducted in the area. To bridge this gap, this study produces a vulnerability map showing the areas which are susceptible to GW aquifer contamination within Damaturu metropolis.

In order to assess the aquifer pollution vulnerability in the study area, this research was conducted using DRASTIC method. The choice of the model is because of the availability of the required input data and the assumptions of the model and also the hydrogeological setting of the study area.

1.1 Study Area

The study area (Damaturu) is the capital of Yobe State, Nigeria and lies between latitude $11^{0}55'$N to $11^{0}45'$N and longitude $11^{0}56'$E to $11^{0}58'$E (Fig. 1). Damaturu local government area consist of twelve (12) wards in which four (4) wards of (Bindigari/Pawari, Gwange/Njiwaji/waziri Ibrahim, Nayinawa/Nasarawa, and Damaturu central/Maisandari) are in metropolitan area or core metropolis while the remaining eight (8) wards are term as sub-core metropolis (Bizi et al., 2022). Figure 2 shows the map of Damaturu with the wards distribution. Damaturu is located in the semi-arid region of Nigeria with tropical continental climate. The climate is characterized by short wet season (June to August) and long dry season (October to May) with high temperature throughout the year. Damaturu experiences a low rainfall, with the average annual rainfall of about 560mm which accounts for the very low surface water in the region and also the town is not drained by any river (Emeka & Weltime, 2008). As a result of this, GW has become the only reliable drinking water source for the entire residents of Damaturu metropolis, serving 145 water systems (boreholes and artesian wells) for approximately 88,014 people(Abdullahi et al., 2019). The geology of Damaturu is part of the sediments of Chad Basin comprising such rock types as, sands and sandstones, clay/shale intercalations (Dawoud & Raouf, 2009).

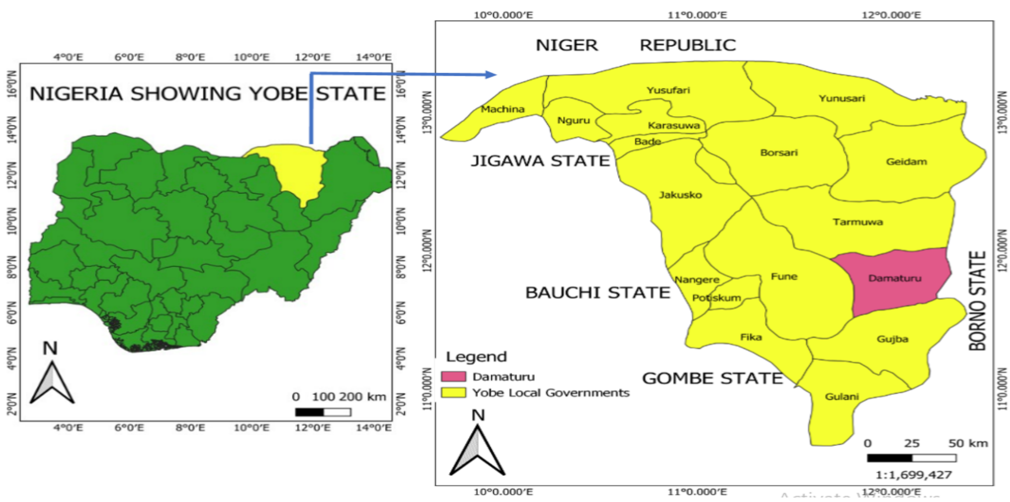

Figure 1: Map of Yobe State showing the study area

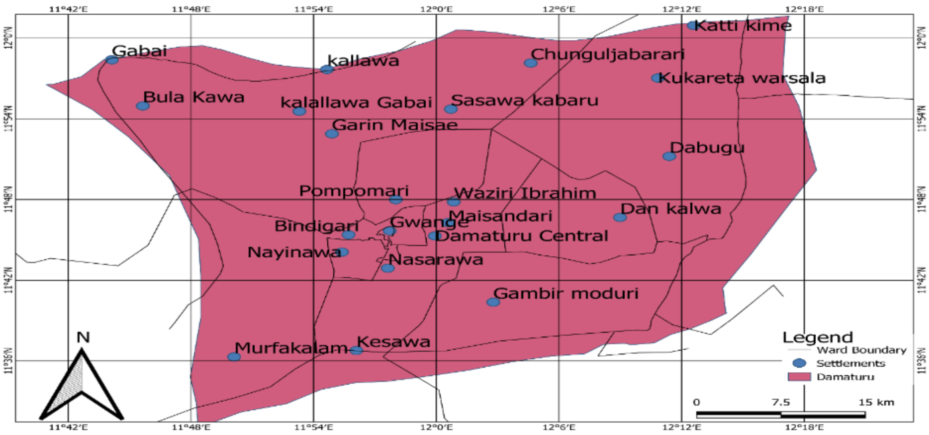

Figure 2: Map of the study area.

2. MATERIALS AND METHOD

2.1. Data collection/Source of Data

This study was based on field survey measurements which was conducted across the study area and coupled with the information that was collected/retrieved from water sector agencies of the State (Yobe State Ministry of Water Resources, Yobe State Water Corporation and Yobe State Rural Water Supply and Sanitation). A total of 50 Borehole Completion Report(BCR)/borehole logs were secured and their coordinates determined in the field using a handheld Global Positioning System(GPS) GARMIN GPSmap etrex 10 model. Over 70% of the BCR was collected from Yobe State Ministry of Water Resources, while the rest from Yobe State Water Corporation and Yobe State Rural Water Supply and Sanitation. GW level measurements were conducted in some areas. The handheld GPS was also used to map some contaminant sources in the study area. Table 1 summarizes the data sources.

2.2. Method

Handheld Global Positioning System(GPS) GARMIN GPSmap etrex 10 model, GIS software QGIS 3.16.4, dip meter, Camera, and Smart 3 Colorimeter were used in this study. The GW aquifer vulnerability assessment model used for this research is the DRASTIC method. Preparation of the seven DRASTIC layers was conducted as prescribed by the authors (Aller et al., 1987) with the exception of net recharge parameter which was modified according to (Piscopo, 2001). Figure 3 shows the methodology process which was applied in this study.

Table 1: Data sources of the DRASTIC parameters

Parameters	Data sources
Depth to water level (as static water level)	BCR/ borehole log, GW level measurement
Recharge	Rainfall data, BCR, DEM
Aquifer media	BCR
Soil	BCR
Topography	Digital Elevation Model (DEM)
Vadose zone	BCR
Conductivity	Pumping test data, literature

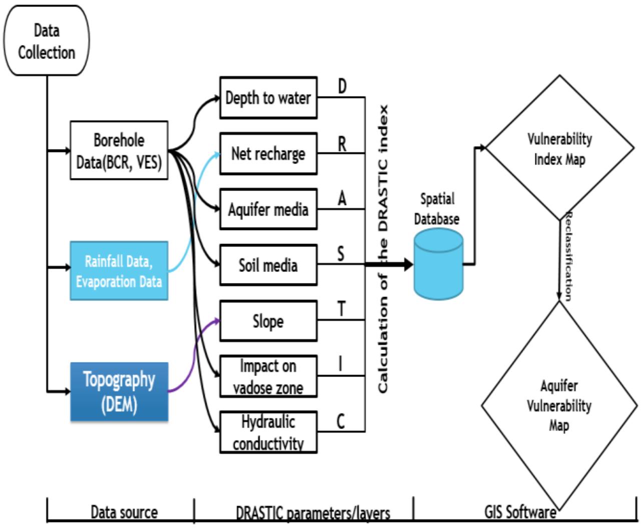

Figure 3: Methodology processes applied.

2.3. Modification of Net Recharge Parameter

Net recharge in DRASTIC is the total quantity of water that has the potential of reaching groundwater. Unfortunately, there was no readily available data on recharge in the study area, as such a formula Eq. (2) proposed by (Piscopo, 2001) was used to determine the net recharge.

$$Recharge\ value = slope\% + Rainfall + soil\ permeability \ldots\ldots (2)$$

In order to get the recharge values for each of the wards, slope (%) was generated by reclassifying the thematic layer of topography which was secured from the Digital Elevation Model of the area. From the slope (%) map (figure 9), almost 80% of the study area falls within the slope range of $2 - 10\%$ and a typical rating factor of 4, as suggested by Piscopo (2001) was adopted. Rainfall data of the study area was extracted from Yobe State rainfall data which was secured/downloaded from the Center for Hydrometeorology and Remote Sensing (CHRS) Data Portal. From the rainfall distribution map in the area (figure 5), it shows that annual Rainfall in the study area ranges between $1058mm$ and $1437mm$. The distribution of rainfall in the whole study area exceeded $850mm$, so a uniform rating factor of 4, as suggested by Piscopo (2021) was adopted. Soil permeability as used in the formula, is a qualitative value given to the three soil types in the area. Sandy soil was rated 5, sandy loam 3 and silty loam 4. The recharge values obtained were used to produce a thematic layer of net recharge using the Inverse Distance Weighting (IDW) interpolation method and reclassified using Raster Analysis function of QGIS 3.16.4 according to the rating as suggested by Piscopo (2001).

2.4. Aquifer Vulnerability Assessment using DRASTIC Model

The DRASTIC model was developed by (Aller et al., 1987) in the united states for environmental protection agency (USEPA). It's one of the most widely used vulnerability assessment methods. The DRASTIC model input thematic layers were rasterized, reclassified according to the model ratings and given appropriate weight in order to integrate them for vulnerability assessment evaluation. The final stage of the vulnerability mapping involves spatial analysis (weighted sum overlay) to combine all the seven hydro-geological parameter thematic layers based on their rates for different classes and corresponding weights. This was achieved via "Raster Calculator" function of QGIS 3.16.4. the DRASTIC index equation (Eq. 1) was inputted, then the model runs and produced the DRASTIC index map of Damaturu Metropolis. The DRASTIC index scores obtained were reclassified (via "Raster Analysis" function of QGIS 3.16.4) into four classes of low, moderate, high and very high vulnerability to contamination as suggested by Aller et al. (1987).

$$\text{DRASTIC}\quad Index = D_wD_r + R_wR_r + A_wA_r + S_wS_r + T_wT_r + I_wI_r + C_wC_r \ldots\ldots (1)$$

Where; D, R, A, S, T, I, and C are the seven parameters and the subscripts r and w are the corresponding rating and weights respectively. Other details on the model can be found in Aller et al (1987).

Depth to water (D) Is the depth from the ground surface to the water table. The depth to water level determines the migration distance that a contaminant will travel before reaching the aquifer (Edet, 2014). The values of the depth to water table (m) for all the boreholes and their coordinates were used to create a rasterized thematic layer of the depth to water level in the study area. Aquifer media (A) refers to the saturated zone material properties, which controls the pollutant attenuation processes (Zenebe et al., 2020). According to Dawoud and Raouf (2009), the study area is overlaid by uniform aquifer media, the sedimentary rock which is comprised of medium to coarse grained sands and shale with intercalation of clayey lenses, this implies DRASTIC rating of between 5 to 9. Soil media (S) represents the uppermost weathered portion of the vadose zone and controls the amount of recharge that can infiltrate downwards (Oke, 2020). According to (Ismaila *et al.*, 2019) and BCR reports, the dominant soil class in the study area is sandy loam soil which covers about 75% of the total area. From the BCR reports, sandy soil and Silty loam were found in some regions. Sandy loam soil which occupies most parts of the study area was rated 5 according to the model. Topography (T) of an area accounts for the change in slope, it determines runoff and infiltrate of rainfall, and the steeper topography is in an area, the greater the possibility of creating surface runoff is, the greater the chance for infiltration is (WU et al., 2018). The Slope (%) map was generated by converting the thematic layer of the DEM of the area from degrees to slope (%). The vadose zone layer (I) controls the passage and attenuation of the contaminated material to the saturated zone and it was evaluated using BCR/Borehole logs from 50 locations within the study area. Hydraulic conductivity (C) is the horizontal flow of water through the aquifer. It indicates the ability of the aquifer to transmit water, hence, determines the rate of flow of contaminant material within the groundwater system (Zenebe et al., 2020). According to (Dawoud & Raouf, 2009), the hydraulic conductivity obtained through pumping test of some boreholes in the study area shows high variability of the parameter which ranges from less than 10m/day to 65m/day, this corresponds to DRASTIC rating value of 1 to 8.

2.4. Validation of the vulnerability index using nitrate concentrations.

In this study, nitrate concentration was selected as the primary contamination parameter to validate the DRASTI

model. Nitrate has been chosen because the study area is characterized by active agriculture, as such fertilizers with nitrogen are frequently used in agricultural areas to increase crop yields. Hence, nitrate can be a good water quality parameter to evaluate DRASTIC index and has been widely used (Jamrah et al., 2008). A total of 52 boreholes in the study area were selected as sampling points for the nitrate analysis.

3. RESULTS AND DISCUSSION

3.1. DRASTIC Vulnerability Parameters

Results of the seven DRASTIC parameter mappings are presented in sequential order according to the ratings and weights of parameters of the DRASTIC model with the modification of Net recharge factor for the study area are presented in Table 2.

Table 2. The rating and weight of DRASTIC Parameters in the study area.

Symbol	Parameter	Weight	Rating	Range
D	Water depth (m)	5	3 2 1	15-22 22.5-30 > 30
R	Net recharge (mm)	4	9 8	$11 - 13$ $9 - 11$
A	Aquifer media	3	5 6 7 8	shale fine medium sand medium sand Coarse grained sand
S	Soil media	2	10 10 9	Sand Sandy loam silty loam
T	Topography (%)	1	10 9 5 3	0-2 2-6 6-12 12-18
I	Impact of vadose zone	5	1 3	Clay Silt
C	Hydraulic conductivity (m/s)	3	1 2 4	4.7×10^{-7} to 4.7×10^{-5} 4.7×10^{-5} to 14.7×10^{-5} 14.7×10^{-5} to 32.9×10^{-5}

3.1.1. Depth to Water Level

From Figure 4, the depth to water table for nearly two-third of the study area was greater than 30m. Areas where the depth to water exceeds 40m include Waziri Ibrahim Housing Estate, Pompomari ward and Maisandari Ward. In some locations around Waziri Ibrahim Housing Estate, groundwater level has reached up to 60m. The fall in water table in the central area (Gwange, Damaturu central, Maisandari, Waziri Ibrahim) could be attributed to the over-abstraction from groundwater aquifers due to the high demand for freshwater as a result of over-population and increase in commercial activities. The water table lowers around the boreholes as water is continuously being abstracted from it. The main source for groundwater aquifer recharge in the region is from infiltration of water during the rainy season but the region experiences low rainfall annually which last for about four months (June to October). Consequently, the aquifers have low recharge rate. Thus, the water table may drop over large area if abstraction rates exceeded the rates of groundwater recharge within the aquifer. Also within the central area, there are paved and built-up areas which promote surface runoff and prevent infiltration. As a result, the runoff is diverted to some areas outside the center area, which causes a decrease in net recharge for the aquifers there. Relatively deep water table have low DRASTIC rating which implies less vulnerability to contamination due to the long time and distance it would take the pollutants to reach the groundwater. Therefore, aquifers in the central area are less vulnerable to contamination because of the deep-depth to water table in the area.

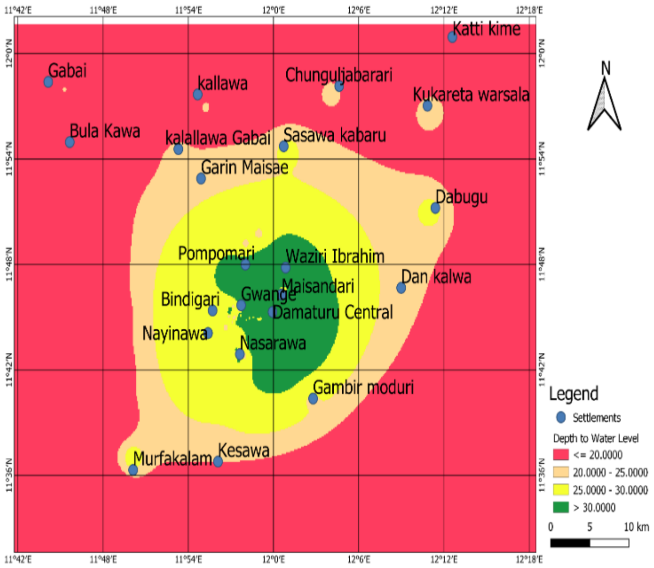

Figure 4: **Thematic layer of Depth to water level**

The regions surrounding the central area (Nayinawa, Bindigari and Nasarawa wards) have shallow depth to water table as compared to the central area. The depth to water table in these areas is between $24m$ to $26m$. The aquifers in the areas have not being tapped excessively, only a handful of boreholes exist, which could be the cause of shallow level depth to water table. Also, due to the absence of drainage systems and paved areas that promote surface runoff in the area, aquifers there receive a high net recharge. According to Aller *et al.* (1987), shallow depth to water table have high rate which implies higher likelihood of contamination because contaminants can reach the groundwater more quickly and over short distances. Therefore, aquifers in these areas are more vulnerable to contamination because of the shallow-depth to water table in the regions. Figure 4 shows the thematic layer of the depth to water table in the study area.

3.1.2. Net Recharge

From the map of distribution of rainfall data in the study area (Figure 5), annual rainfall in the study area ranges between $1058mm$ and $1437mm$.

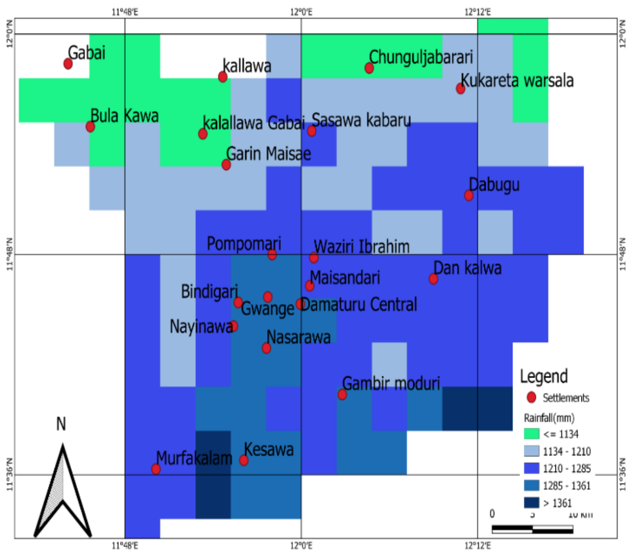

Figure 5: Distribution of rainfall in Damaturu

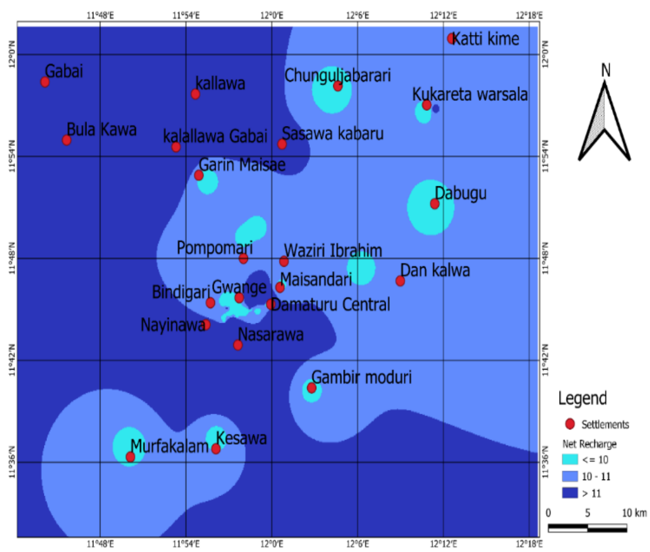

Figure 6: **Thematic layer of Net recharge**

The recharge values obtained are 10, 11, and 12 which implies a rating of 8, 8, and 9 respectively. Figure 6 shows the thematic layer of net recharge in the study area. From the map, the areas of the Northwest and some of the South West of the study area have good recharge rate and as a result are more vulnerable to contamination, however, the Eastern part is less vulnerable to contamination as compared with the other part due to its poor recharge rate.

3.1.3. Aquifer Media

Figure 7 shows the thematic layer of aquifer media in Damaturu. Most parts of the study area are dominated mainly by fine medium grained sand and medium grained sand aquifer media which have a DRASTIC rating value of 6 and 7 respectively.

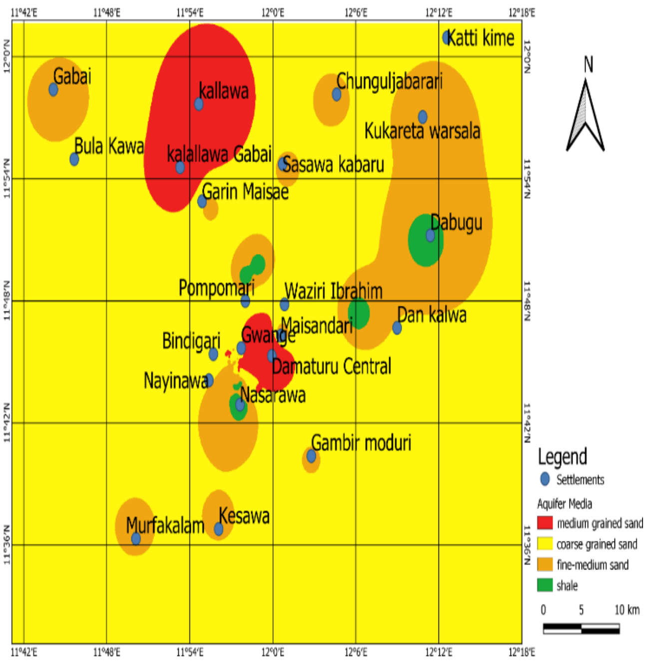

Figure 7: **Thematic layer of Aquifer media**

These are found in Nasarawa, Damaturu central, Gwange, Maisandari and Pompamari wards. Coarse grained sand (rate value of 8) was found in Nayinawa, Bindigari and Waziri Ibrahim Wards. In some locations around Nasarawa and Pompamari wards shale was found, a rating of 5 was adopted. Aquifer media with high rating value have a high rate of permeability. The larger the grain size of an aquifer media, the higher its permeability, the lower its attenuation capacity, and thus, the greater its vulnerability potential. Therefore, areas where the aquifer media is coarse grained sand are more vulnerable to contamination. By contrast, the areas with fine-medium grained sand and shale as aquifer media are less vulnerable to contamination.

3.1.4. Soil Media

From figure 8**,** The dominant soil media class in the study area is sandy loam soil which covers about 75% of the total area, followed by sandy soil, and then Silty loam. Sandy loam soil which occupies most parts of the study area was rated 5 according to the model. Sandy soil which can be seen in the northeastern parts of the study area was rated 9. Silty loam soil which was only found in some locations around Nayinawa ward was rated 4.

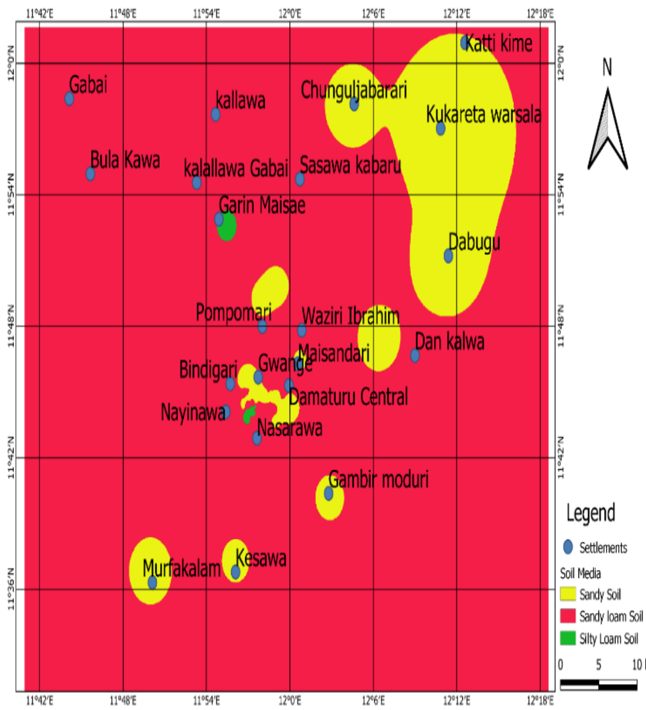

Figure 8: **Thematic layer of Soil media**

Based on the DRASTIC rating, loose/porous soil media have high rates compared to less porous soil media due to their high permeability. The higher the grain sizes, the higher the permeability, thus the DRASTIC rating. And the higher the DRASTIC rating, the more the groundwater vulnerability potential. Therefore, the parts of the study area where the top soil (soil media) is sand have more chance to groundwater contamination as compared with the other parts. Sandy soil was found in some parts of Nasarawa ward, Maisandari, Gwange, Damaturu central and Pompamari ward.

3.1.5. Topography

The slope (%) map of Damaturu (figure 9) shows low variability ranging from 0 to 10.5%. As most parts of the study area have steep slope (slope > 8%) which indicates low DRASTIC rating, therefore, the groundwater potential for pollution in those areas is low because the steeper the slope, the easier it is for contaminants to run-off thereby not allowing more time for the contaminants to percolate down to reach the groundwater.

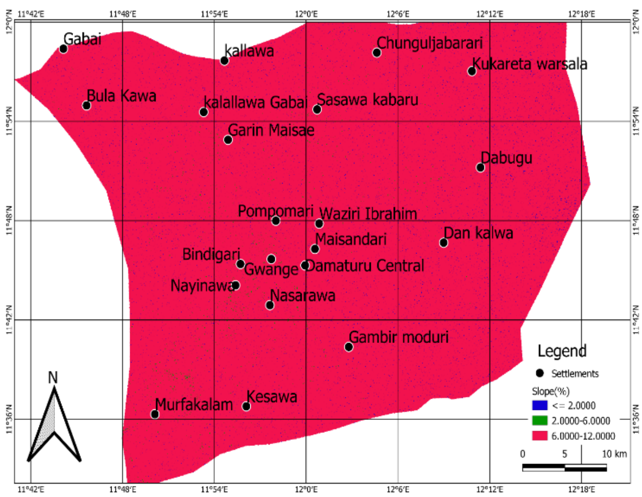

Figure 9: **Thematic layer of Slope (%)**

3.1.6 Impact of Vadose Zone

Figure 10 shows the thematic layer of Impact vadose zone in the study area. From the map, there are two types of vadose zone layers present in the study area i.e. silt(high permeability) and clay(low permeability) which have a theoretical rating of between 2 – 6. A typical rating of 3 was adopted for clay according to the DRASTIC rating, while the rating value of 4 was assigned to silt. According to Aller *et al*. (1987), the more permeable the vadose zone layer is, the more vulnerable the groundwater is to pollution. This suggests that places with silt vadose zone layer have a higher likelihood of having contaminated groundwater than areas with clay vadose zone layer.

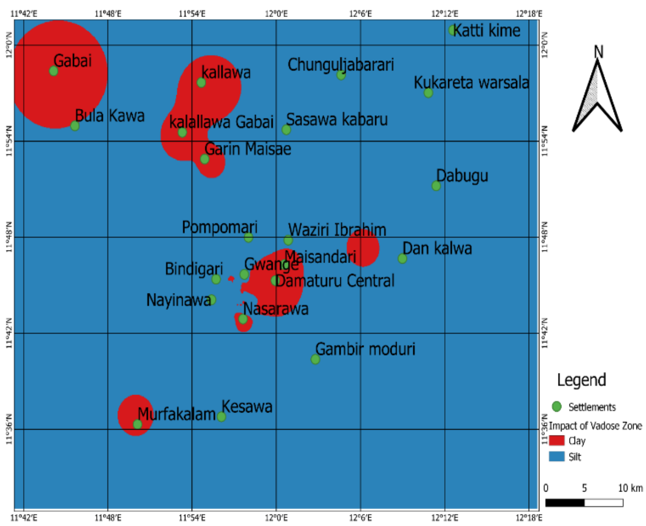

Figure 10: **Thematic layer of Impact vadose zone**

3.1.7. Hydraulic conductivity

From the thematic layer of hydraulic conductivity in the study area (figure 11), it shows that Gwange ward, Damaturu central and some parts of Maisandari ward have the highest hydraulic conductivity range (33m/day to 40m/day). While areas with the lowest hydraulic conductivity range (7m/day to 9m/day, 11.25m/day) are within Nayinawa ward. Areas with moderate hydraulic conductivity range (11.25m/day to 12.5m/day) include Nasarawa ward, Bindigari, Pompamari, Waziri Ibrahim, and some parts of Nayinawa ward. Aquifers overlaid by sandy layers and gravel system with high permeability will have high value of hydraulic conductivity, whereas, those overlaid by thin layers of fine-grained material with low permeability such as clay and silt will have low hydraulic conductivity value.

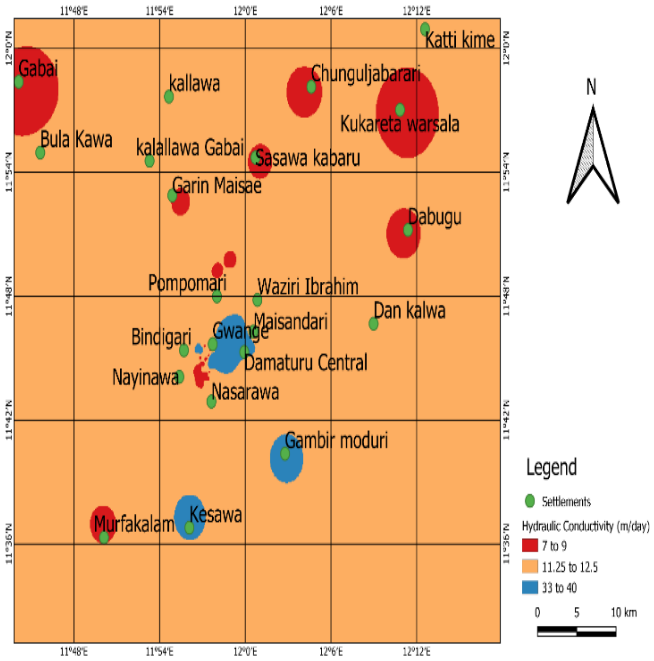

Figure 11: **Thematic layer of Hydraulic conductivity**

3.2. DRASTIC Index Vulnerability Mapping

The DRASTIC scores obtained from the model vary from 81 to 153. On the vulnerability index map (figure 12), the highest index class $(137.97 - 153.00)$ appears as a region that is encircled around Nasarawa ward. While the majority of the study area is classified within the lowest index class $(81 - 122.9489)$, this include Damaturu central, Pompamari, Maisandari, Waziri Ibrahim, and Gwange wards. Only Bindigari and Nayinawa wards fall within the moderate index class $(122.9489 - 137.9745)$. The vulnerability map (Figure 13) shows that of the total area $128.6Km^2$ of Damaturu metropolis, an area of about $10.94Km^2(8.5\%)$ lies in the "Low vulnerability" zone with DRASTIC index ranging between $81 - 99$. About $84.88Km^2(66\%)$ is located in the "Moderate vulnerability" zone with DRASTIC index range of between $99 - 117$. Table 3 shows the DRASTIC vulnerability classes and their areal coverage.

The results suggested that approximately two-third of Damaturu Metropolis is at moderate risk in terms of groundwater pollution potential. Moderate vulnerability areas can be seen in the north eastern part around Waziri Ibrahim Housing Estate, Damaturu Central and Maisandari Ward, in the northwest around Pompomari and Gwange Ward where the physical factors like deep water table and impermeable vadose zone media/layer are very well reducing the chances of getting the groundwater polluted. Low vulnerability areas occupied very small portion within the central parts of Damaturu central and Gwange wards. High groundwater vulnerability areas occupied most of the south-western parts of the study area where the physical factors like low depth to water table and high net recharge are increasing the likelihood of having contaminated groundwater. The "high vulnerability" class covers a large part of Damaturu metropolis, it surrounds the entire Bindigari and Nayinawa ward. Very high vulnerability class occupies very small portion of the study area; it can be seen on the map as an encircled area around Nasarawa ward.

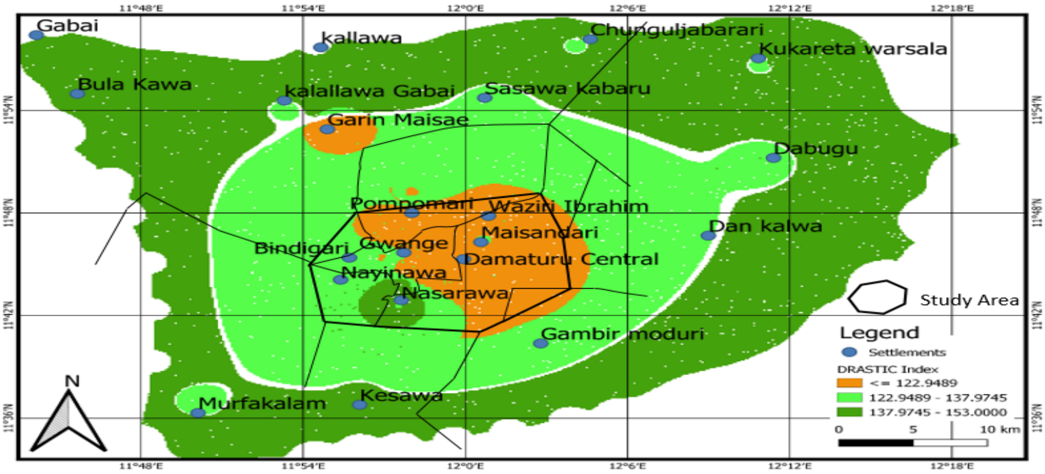

Figure 12: Classified DRASTIC Vulnerability Map of Damaturu Metropolis Based on Total DRASTIC Scores

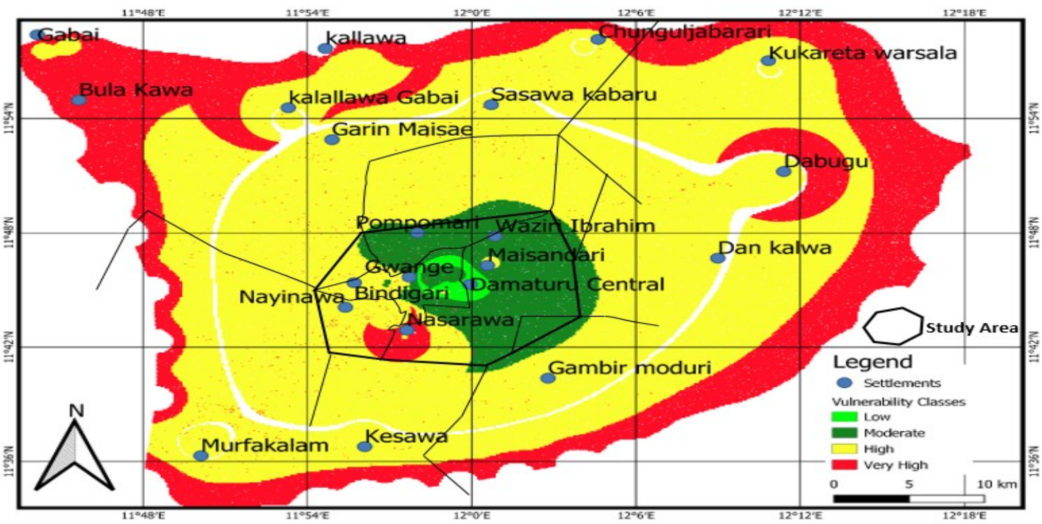

Figure 13: Classified DRASTIC Vulnerability Map of Damaturu Metropolis

Table 3: **DRASTIC vulnerability classes and their areal coverage**

DRASTIC index	Vulnerability Class	Area (Km^2)	Area (%)
81 – 99	Low	10.94	8.5
99 – 117	Moderate	84.88	66.0
117 – 135	High	24.12	18.8
135 – 153	Very High	8.66	6.7
Total		128.6	100

3.3. Validation using Nitrate Concentrations

The Nitrate (NO_3^-) concentration values fluctuate from one borehole to another between 0.8mg/l and 8mg/l, and are classified into four levels $0-2mg/l$, $2-4mg/l$, $4-6mg/l$, $6-8mg/l$ as shown in figure 14.

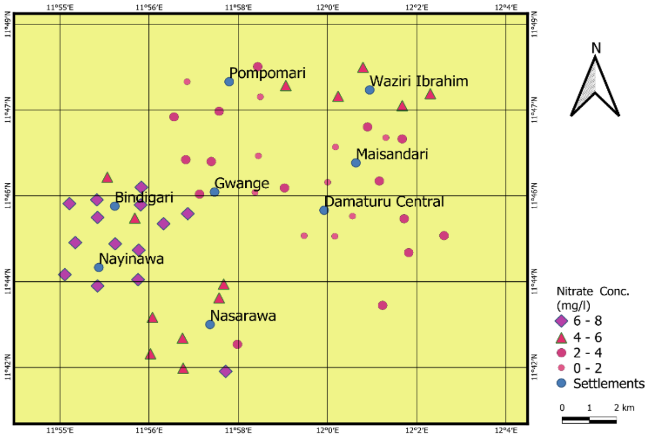

Figure 14: **Spatial distribution of the boreholes With NO_3^- concentration.**

The average NO_3^- concentration in the study area was $4.15mg/l$ with a coefficient of variation of 0.51 and a standard deviation of 2.13. Table 3 shows the mean NO_3^- concentrations for each location/ward in Damaturu Metropolis. Validation technique considers the overlay of the two maps: the DRASTIC vulnerability map (Figure 13) and the map of the spatial distribution of nitrate concentration (figure 14).

Table 3: **Mean nitrate concentrations/ward.**

Location/Ward	Mean NO_3^- concentration (mg/l)
Damaturu Central	1.66
Gwange	2.85
Waziri Ibrahim	5.58
Pompomari	3.05
Maisandari	2.30
Nasarawa	4.38
Nayinawa	7.25
Bindigari	7.07

The resulting map (Figure 15) allows comparison between vulnerability classes and nitrate concentrations, thereby counting the number of nitrate concentration range that falls within a particular DRASTIC vulnerability class. Table 6 shows the nitrate spatial distribution into groundwater with respect to vulnerability classes defined by DRASTIC method. The validation analysis revealed that the correlation coefficient is 70% ($r = 0.7$). This result shows that DRASTIC model is correlated with the actual nitrate concentration of groundwater in Damaturu metropolis.

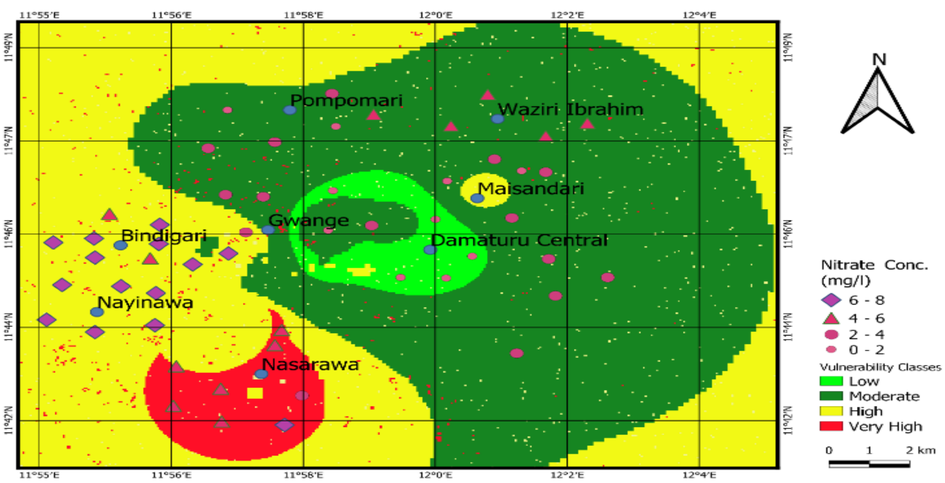

Figure 15: **Comparison between nitrate concentration spatial distribution into groundwater and DRASTIC Vulnerability classes.**

Table 6: **Nitrate Spatial Distribution into Groundwater with respect to Vulnerability Classes Defined by DRASTIC method.**

	Samples Number per Nitrate Content Class (mg/L)				
Vulnerability Classes	$0-2$	$2-4$	$4-6$	$6-8$	Total
Low $(81-99)$	5	0	0	0	5
Moderate $(99-117)$	5	13	5	0	23
High $(117-135)$	0	1	2	13	16
Very high $(135-153)$	0	1	6	1	8
Total	10	15	13	14	52

Pearson's linear correlation equation (Eq. 3) was used to calculate the linear relationship between DRASTIC index and Nitrate concentrations;

$$r_{XY} = r_{uv} = \frac{n\sum fuv-(\sum fu)(\sum fv)}{\sqrt{(n\sum fu^2-(\sum fu)^2)(n\sum fv^2-(\sum fv)^2)}} \quad \ldots\ldots (3),$$

$$r_{uv} = \frac{52\times 49-(31\times 27)}{\sqrt{(52\times 79-31^2)(52\times 53-27^2)}} = 0.7$$

As the value of r = 0.7, so there is a good correlation between the DRASTIC Index and Nitrate concentrations.

4. CONCLUSION

The study assessed the groundwater aquifer vulnerability to pollution by applying DRASTIC model for Damaturu Metropolis, Nigeria. The aquifer vulnerability map of Damaturu demonstrates that 74.5% of areas in Damaturu metropolis are less vulnerable (low and moderate vulnerability) to groundwater contamination and it was highly influenced by the depth to water level map as well as the aquifer media map. The areas are less vulnerable to groundwater contamination. However, this does not rule out the possibility of an actual contamination incidents in the regions. In a situation where there is presence of an actual contaminants sources (hazard) in a low vulnerability area, the area may likely have more potential for groundwater contamination than a highly vulnerable area with no hazards present. The vulnerability index of Nasarawa ward indicates that aquifers in the region are highly susceptible to vulnerability in which, if contaminant load is released on the surface, they can easily reach the aquifer system within a very short period of time.

The validation analysis showed the existence of significant correlation (as Pearson's correlation coefficient $r = 0.7$) between the vulnerability index and nitrate concentration values which indicates that the DRASTIC results obtained are realistic and representative of the actual groundwater vulnerability and the model provides satisfactory results for the intrinsic aquifer vulnerability assessment in the study area. It is recommended to stop the siting and/or expansion of harmful land use practices with high potential of producing groundwater pollution in the areas classified as having "high" and "very high" groundwater vulnerability potential to contamination. If an existing land use with a higher groundwater contamination threat is already present on a highly vulnerable area; more complex control measures should be implemented in order to safeguard the groundwater system. Also, it's important to examine and monitor the water quality of the aquifers in the highly vulnerable areas so as to provide proper protection and management measures.

REFERENCES

Abdelmadjid, B., & Omar, S. (2013). Assessment of groundwater pollution by nitrates using intrinsic vulnerability methods: A case study of the Nil valley groundwater (Jijel, North-East Algeria). *African Journal of Environmental Science and Technology*, *7*(10), 949-960.

Abdullahi, M. A., Mahadi, A. A., & Kyari, M. B. (2019). Geographical Study of Rural Urban Migration in Damaturu. African Scholar Journal of Env. Design and construction, 15(4), 1896-6783.

Ahmed, M. S., Tanko, A. I., Eduvie, M. O., & Ahmed, M. (2017). Assessment of groundwater vulnerability in Kaduna metropolis, northwest Nigeria. *Journal of Geoscience and Environment Protection*, *5*(06), 97-106.

Aller, L., Bennett, T., Lehr, J., Petty, R., & Hackett, G. (1987). DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings. US Environmental Protection Agency. *Washington, DC*, *455*.

Anornu, G., & Kabo-Bah, A. T. (2013). Evaluation of AVI and DRASTIC methods for groundwater vulnerability mapping. *Journal of Environment and Ecology*, *4*(2), 126-135.

Babiker, I. S., Mohamed, M. A., Hiyama, T., & Kato, K. (2005). A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, central Japan. *Science of the Total Environment*, *345*(1-3), 127-140.

Bizi, M. K., Ibrahim, D. M., Usman, A., Musa, G. G., & Mahdi, M. A. (2022). Information a Tool for Social Advocacy Protection Services for Children in Damaturu Metropolis, Yobe State. *Fane-Fane International Multi-Disciplinary Journal*, *6*(2, DEC.), 155-163.

Chapman, D. V. (1996). *Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring*. CRC Press. 609.

Dawoud, M. A., & Raouf, A. R. A. (2009). Groundwater exploration and assessment in rural communities of Yobe State, Northern Nigeria. *Water Resources Management*, *23*, 581-601.

Edet, A. (2014). An aquifer vulnerability assessment of the Benin Formation aquifer, Calabar, southeastern Nigeria, using DRASTIC and GIS approach. *Environmental Earth Sciences*, *71*(4), 1747-1765.

El-Ishak , A., Akinsola, R. O., & Mamman, M. (2013). Determination of quality of portable water in Damaturu Metropolis. *International journal of biological and physical sciences*, *1*, 001-006.

Emeka, D., & Weltime, O. (2008). Trace elements determination in municpal water supply in Damaturu Metropolis, Yobe State, Nigeria. *Bayero Journal of Pure and Applied Sciences*, *1*(1), 58-61.

Focazio, M. J. (2002). *Assessing ground-water vulnerability to contamination: Providing scientifically defensible information for decision makers* (Vol. 1224). US Government Printing Office.

Ismaila, M., Mohammed, B., Lawan, B., Ali, M., Baburo, S., Modu, A., & Ma'aji, A. (2019). Assessment of Micronutrients Status of Damaturu Soils of Yobe State, Nigeria. *Asian Journal of Plant and Soil Sciences*, 1-6.

Jamrah, A., Al-Futaisi, A., Rajmohan, N., & Al-Yaroubi, S. (2008). Assessment of groundwater vulnerability in the coastal region of Oman using DRASTIC index method in GIS environment. *Environmental monitoring and assessment*, *147*, 125-138.

Jude, C. (2020). Groundwater and the discourse of shortage in Sub-Saharan Africa. *Hydrogeology Journal*, *28*(4), 1143-1154.

Kwaya, M. Y., Hassan, H., Umar, J., & Musa, K. (2017). Appraisal of Fluoride Concentration, Distribution and Geogenic Origin in Ground and Surface Water from Semi-Arid Region, Part of Yobe State North-eastern Nigeria. *International Journal of Environmental Chemistry*, *2*(1), 16-21.

Li, P., Karunanidhi, D., Subramani, T., & Srinivasamoorthy, K. (2021). Sources and consequences of groundwater contamination. *Archives of environmental contamination and toxicology*, *80*, 1-10.

Machdar, I., Zulfikar, T., Rinaldi, W., & Alfiansyah, Y. (2018,march). Assessment of groundwater vulnerability using DRASTIC Model and GIS: A case study of two sub-districts in Banda Aceh city, Indonesia. ln IOP Conference Series: Materials Science and Engineering(Vol. 334, No. 1, p. 012032). IOP Publishing.

Margat, J., & Van der Gun, J. (2013). *Groundwater around the world: a geographic synopsis*. Crc Press. 203-240.

Maria, R. (2018, February). Comparative studies of groundwater vulnerability assessment. ln IOP Conference Series: Earth and Environmental Science (Vol. 118, No. 1, p. 012018). IOP Publishing.

Mazor, E. (1995). Aquifer definition: specific (by water properties) or generalized (by stratigraphic or geographic terms), examples from Israel. *IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences*, *232*, 183-194.

Moraru, C., Hannigan, R., Moraru, C., & Hannigan, R. (2018). Overview of groundwater vulnerability assessment methods. *Analysis of Hydrogeochemical Vulnerability*, 1-16.

Oke, S. A. (2020). Regional aquifer vulnerability and pollution sensitivity analysis of drastic application to Dahomey Basin of Nigeria. *International Journal of Environmental Research and Public Health*, *17*(7), 2609-2622.

Oroji, B. (2018). Groundwater vulnerability assessment using GIS-based DRASTIC and GOD in the Asadabad plain. *J. Mater. Environ. Sci*, *9*(6), 1809-1816.

Oruonye, E. D., & Medjor, W. (2009). MICROBIAL ANALYSIS OF MUNICIPAL WATER SUPPLY IN DAMATURU METROPOLIS, YOBE STATE, NIGERIA. *Nigerian journal of microbiology*, *24*(1), 2106-2109.

Piscopo, G. (2001). Groundwater vulnerability map explanatory notes, castlereagh catchment, Parramatta. *Centre for natural resources, NSW department of land and water conservation*, *CNR 2001.017. 95-101*.

Umara, B., Yaji, M., & Fannami, A. (2004). Groundwater contamination in Damaturu, Nigeria. *ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY AND ENVIRONMENT*, *4*, 45-50.

UNICEF/WHO/JMP. (2023). *Progress on household drinking water, sanitation and hygiene 2000–2022.special focus on gender.* New York: United Nations Children's Fund (UNICEF) and World Health Organization (WHO), 2023.https://washdata.org

Waziri, M., & Bomoi, A. (2012). Evaluation of heavy metal levels in sachet water produced in Damaturu, Yobe state, Nigeria. *Bulletin of Pure & Applied Sciences-Geology*, *31*(1and2), 11-16.

Zenebe, G., Hussien, A., Girmay, A., & Hailu, G. (2020). Spatial analysis of groundwater vulnerability to contamination and human activity impact using a modified DRASTIC model in Elalla-Aynalem Catchment, Northern Ethiopia. *Sustainable Water Resources Management*, *6*, 1-16.