Assessment of Groundwater Quality Around Open Dumpsites in Suleja Metropolis, North-Central Nigeria Using Water Quality Index and Geospatial Techniques

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Abstract

This research was conceptualized to assess the quality of groundwater around solid waste dumpsites in Suleja and its environs using Water Quality Index (WQI) rating and geospatial techniques. The study area lies between Longitudes 7°08′00″E to 7°14′00″E and Latitudes 9°05′00″N to 9°14′00″N. Geologically, the area is part of the Nigerian Basement Complex which consist regionally of Migmatite-Gneiss complex, low grade Schist Belt and the Older Granites. However, the major rock types in the area investigated are Migmatite, granite gneiss and granites of different compositions. Water samples were collected from Twenty-three (23) different hand-dug wells and boreholes. The samples were analysed for the physico-chemical parameters and heavy metals. Factor Analysis was employed to analyse the information content of the water quality indicators to determine their appropriateness for indexing. The spatial distribution of the WQIs determined using Inverse Distance Weighting (IDW) interpolation procedure. Groundwater samples around the dumpsites had varying degrees of concentrations that either met or failed the NSDWQ regulatory standards. All pH results were within the permissible limits (6.5- 8.5). Conductivity values ranged from 61 to 81µS/cm with the standard limit being 250µS/cm while turbidity and TDS values exceeded the maximum permissible limits (5 mg/L and 500 mg/L respectively). All major ion values for all groundwater samples were within permissible limits of NSDWQ (2015) except chloride contents which were higher than the set permissible limit (3 mg/L) in all the samples analysed. Fe, Pb, Cd, Zn and Ni where detected were mostly above the allowable limits. The computed water quality index at each sampled location range from 36.69 to 608.16, with an average and standard deviation of 129.3 and 181.90, respectively. These results generally indicate that the groundwater resources near the dumpsite are generally not of good quality. The high values obtained in some locations were due to high concentration of Ni and Pb in some of the samples. Water from these locations can be regarded as unfit for consumption and needs to be remediated to prevent further contamination.

Keywords: Municipal Solid Waste, Groundwater contamination, Water Quality, Basement Complex, Heavy metals, Trace elements.

1. Introduction

Large quantities of solid waste are produced daily as a result of human activities (Awaz, 2015). The amount of Municipal Solid Wastes (MSW)generated is increasing rapidly and it is beyond the assimilation capacity of nature (Agrawal, 2011). The lack of efficient management for solid waste disposal leads to pollution of cities and has adverse impacts on human health and the environment

(Yadav and Devi, 2000; Jha *et al.*, 2003). Landfills and open dumps are a common municipal solid waste disposal practice and one of the cheapest methods for organized waste management in many parts of the world (Jhamnani and Singh, 2009; Longe and Balogun, 2010). Waste degradation in MSW landfill is a complex process; once waste is deposited at the landfill (dumpsite) pollution can arise from the migration of both gas and leachate (Al-Khateeb, 2010). In municipal solid waste landfills/dumpsites, both solid and semi-solid wastes are biodegraded anaerobically by microorganisms, producing gas and soluble chemicals that combine with liquid in the waste to form leachate (USEPA, 2009). Leachate production and movement is inevitable in unplanned open land system of waste disposal (Christensen *et al.,* 2001). Their movement, percolation and infiltration into the groundwater system are of major concern.

The nature and properties of the rock, aquifer specific yield and retention and the chemistry of water are governed by the geology (Brassington, 1988; MacDonald *et al.,* 2005). Both natural and anthropogenic activities have some amount of influence on the chemistry and quality of groundwater. Hence, the type and extent of anthropogenic activities on groundwater quality are controlled by the geochemical and physical processes and the hydrological condition present (Sajad *et al*., 1998).

Of primary concern is the quality of groundwater exploited for drinking as well as other domestic uses. This is because consumption of water that is polluted has serious health implication as such World Health Organization has to set safe standards for drinking water. This standard has also been domesticated and the Nigerian Standards for Drinking Water Quality has been published. This concern has attracted overwhelming studies on the quality status of groundwater abstracted from shallow wells (hand dug wells) and deep wells (boreholes) for human consumption in urban areas of Nigeria. Several researches have been undertaken by various researchers to understand the nature and composition of groundwater in urban areas.

In a baseline study on the inorganic and microbial contaminants of health importance in water from boreholes and open wells in Benin City, Erah *et al.,* (2002) found that all of them were contaminated with abnormal levels of lead, chromium, zinc and faecal coliform. They concluded that consumption of water from these wells will have serious implications. In related studies, Alexander (2008) Efe *et al.,* (2008) Al-Hassan and Ujo (2011) found groundwater to be slightly acidic, and calcium, magnesium, chloride and sodium concentrations were within WHO guide limit in Mubi town; hand dug wells located close to dumpsites in Onitsha have higher levels of turbidity, total suspended solids, calcium bicarbonate, electrical conductivity, salinity, acidity, lead. iron and bacteria load; and for Masaka, water from all the wells analysed were polluted with chemical and bacteria, turbidity, dissolved oxygen, nitrates, chromium, total bacteria count, and concluded that water was not safe for drinking.

Jatau *et al.,* (2006) in a preliminary investigation of the quality of surface and groundwater in parts of Kaduna Metropolis, noted groundwater to be slightly acidic, high iron, nitrate and faecal coliform concentrations. This is traced to leachates from wastes and dumpsites. Earlier, Egbulum (2003) used faecal coliform and faecal streptococcus indicator to assess the microbial quality of groundwater from hand dug wells in Mando and Kawo area of Kaduna, found that the wells were all contaminated, and that the bacterial loadings increases from dry season to rainy season between 1998-2002. In Gwagwalada area of Abuja Metropolitan City, Ishaya and Abaje (2009) found that groundwater from the boreholes analysed has turbidity, total dissolved solids, magnesium, total hardness concentrations above the WHO prescribed limit for drinking water in some of the wells. Nitrate was however within WHO guide limit for drinking water.

Idris-Nda *et al.*, (2011) appraised the chemical quality of groundwater quality of Minna metropolis and found heavy metals with high concentrations of magnesium, copper, arsenic and lead. Cation with highest concentration are manganese, sodium and dominant anions HCO_3, CO_2 and NO_3.The groundwater was generally found to be of good quality. In Jemeta area of Yola town, Ishaku and Ezeigbo (2010) analysed the quality of groundwater and found concentrations of chloride, nitrate, total dissolved solids and coliform to far exceed the WHO allowable limit for drinking water and were higher in the wet season. This is traced to anthropogenic activities as household wastes, wastewater find their way into water sources. Relationship show positive correlation for chloride, total dissolved solids, nitrate, sulphate, nitrate and total dissolved solids and sulphate for dry season, while nitrate and sulphate, total dissolved solids and sulphate, chloride and sulphate and chloride and nitrate showed positive correlation for rainy season.

Onwuka *et al.*, (2004) assessed the potability of shallow groundwater using parameters of waste derivable chemical such as nitrate, chloride, sulphate and indicator micro-organism of faecal coliform. Result show 22% of the wells have nitrate above WHO limit, and 8 out of 10 show evidence of faecal coliform derived from sewage contamination. In a related study, Omono *et al.*, (2013) used principal component analysis (PCA) to identify factors controlling groundwater in Achara, Abakpa and Emene residential areas of Enugu town. PCA was able to extract 77.7%, 88.1% and 83.13% of the explained variables for the residential areas. PC 1 reflected weathering of the host rock minerals and constitutes the dominant controlling process of the areas. PC II and PC III of Achara and Abakpa is traced to both weathering/leaching of feldsphatic minerals of host rocks giving rise to alkaline in groundwater and anthropogenic activities. Discriminant analysis of the groundwater quality of the area reveal total dissolved solids, sodium, manganese and chloride as dominant elements. Groundwater in the area is controlled both by geologic and anthropogenic activities.

Few studies have explored the use of water quality indexing techniques to evaluate the phenomenon of municipal solid waste leachates into the groundwater. In addition, there is dearth of literature on the use of geospatial technique in modelling the spatial characteristics of contaminants in the study area. The use of geographical information system (GIS) is of great value in the storage, retrieval, processing and analysis of multifunctional and multidisciplinary data and has greatly simplified assessment of natural resources. In groundwater studies, GIS is commonly used for site suitability analysis, manage site inventory data; estimate groundwater vulnerability to contamination; model groundwater flow, solute transport and leaching; and integrate groundwater quality assessment models with spatial data to create spatial decision support systems. GIS can be a valuable tool in understanding the spatial pattern and migration of contaminants and can help in tracking site treatment and remediation progress (Engel and Navavulur, 1999; Johnson, 2008). This research therefore was conceptualised to assess the groundwater quality around Suleja metropolis open solid waste dumpsites using water quality index rating and geospatial techniques. This is with a view to understanding the level of contamination and spatial pattern quality of groundwater around the site. The efforts should aid water pollution remediating strategies and groundwater resources management of the area.

2. Study area

2.1 Description of the study area

The study area is in Suleja town, part of Abuja Sheet 186 NW and lies between longitudes 7°08′00″E to 7°14′00″E and Latitudes 9°05′00″N to 9°14′00″N (Figure 1). It is accessible through Minna-Suleja road as well as Abuja-Kaduna road. The area covered is accessible through a network of minor paths and tarred roads. The study area is characterised by rugged topography with ridges running from the north to southern portion of the area. They stand up to 600 m about the surrounding country. The area is drained mainly by River Kantoma with smaller stream channels running north south of the area. Some areas are usually swampy during the rainy season and dry during the dry season. Suleja and its environs falls under the middle Nigeria climatic belt which is mainly tropical with an average rainfall in the range of 1100 mm to 1600 mm. (NIMET, 2020). Precipitation is usually high between the months of April and October with double peaks in July and September. Surface water in the area are streams which receive fresh water flows from inland areas. November to March is the dry season with little or no rainfall, which is accompanied by the harsh dry north-easterly harmattan wind. It is often dust-laden and is associated with relatively low humidity and high daily temperature range. The area records its highest temperature of about 34°C during the dry season and drops to about 24°C in the rainy season (NIMET, 2020). Vegetation type is of Guinea Savannah and the area is mostly dominated by shrubs, tall grasses and trees especially along river channels. Soil weathered from rock in Suleja is very rich in humus and favoured production of crops like guinea corn, maize, melon and groundnuts with yam and rice which can all serve as cash crops and food crops.

2.2 Geology of the study area

The exposed lithologic units comprised of biotite and hornblende granite, banded gneiss and migmatites. The banded gneiss exhibit foliations give a dominant general trend of almost N-S and NE-SW. The rocks which are reasonably jointed generally show two joint sets trending NW-SE and NE-SW with the NW-SE being the more prominent. Field evidences show that these rocks are not a homogeneous gneissic body but that certain portions appear granitic in texture. Also, quartzo-feldspathic veins appear on these rock bodies in several directions but most prominently in the horizontal and vertical directions.

Migmatite is one the most widespread lithology within the study area. It outcrops as low-lying flat terrains. It is dark coloured and massive with streaks of felsic bands that reflect anatexis and are usually covered in parts by a thin sheet of vegetation occurring within the joints on the outcrop. This rock group is believed to have formed circa 2.5 Ga (Rahaman, 1988; Rahaman, *et al.*, 1983) while migmatization of these paleo-Proterozoic rocks occurred Circa 600 Ma (Pan-African orogeny) during the oblique collision of the Nigerian mobile belt with the West African Craton and thus followed by anatectic doming and wrench faulting. Field observations reveal different grades of mixing. In some areas, the weak lineation is displayed as irregularly convoluted bands, ptygmatitic folds as well as isoclinal to tightly closed folding.

The last class of rocks are the granitic rocks. These granite bodies show a variation in the height of the outcrops which range from steep hills to low lying massive stock with gentle elevations, with textures ranging from fine to coarse. These rocks are dark grey and outcrop mainly as high, extensive whalebacks. They form the highest elevation in the area. They are chiefly made up of feldspars, quartz, biotite and hornblende.

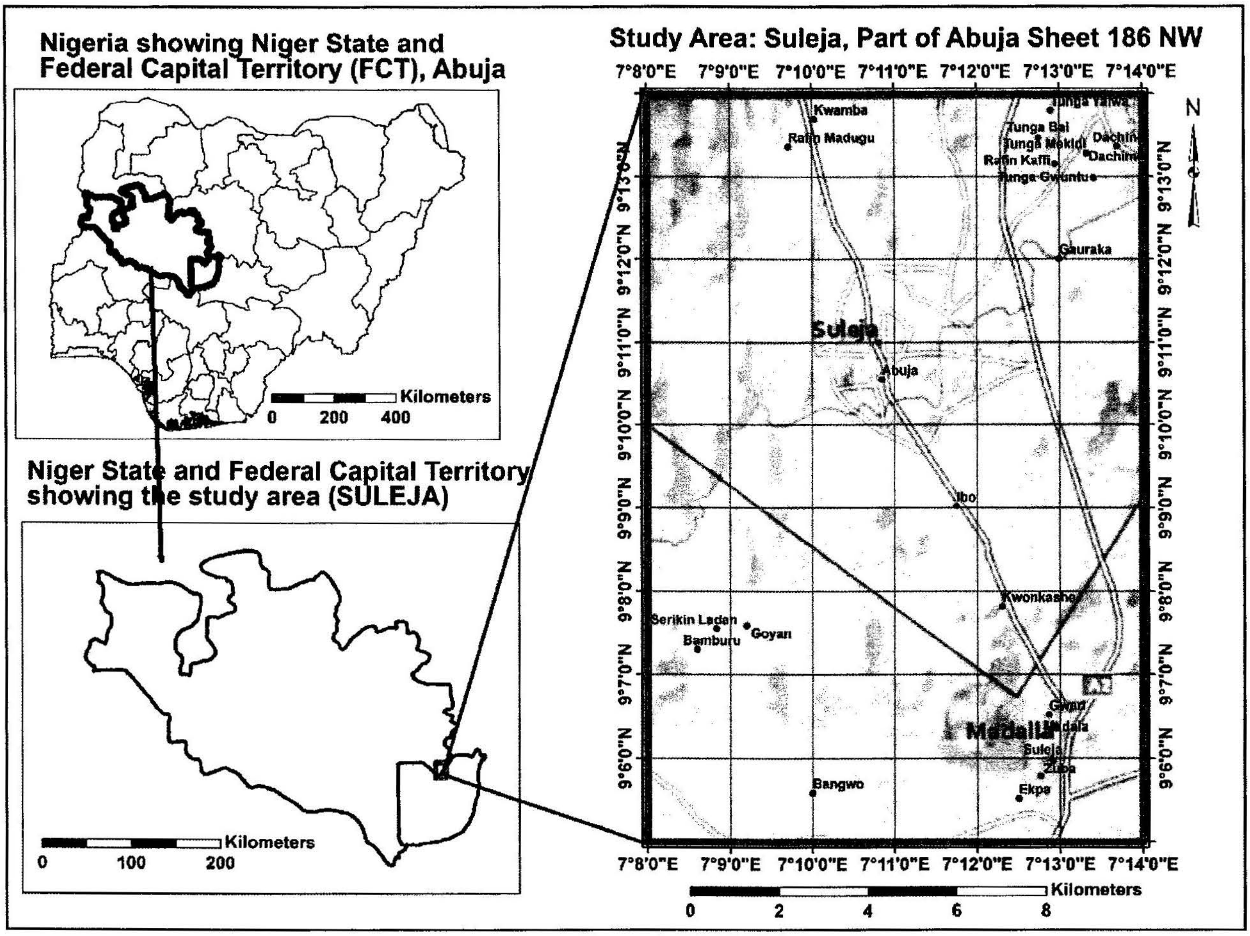

Figure 1: Location of the study area

2.3 Hydrogeology of the study area

From the measurement taken across the study area, it was observed that the average depth of wells is about 4 m with some wells having depth as low as 2 m and some as deep as 7 m and the major source of the recharge is through the regolith. It was observed that water availability or productivity of the well is mostly determined by the elevation of the site where it was dug relative to the elevation of the adjacent areas. Some wells were discovered to have very low dug depths since they were located around the foot of a slope and this allow the groundwater from adjacent points of higher altitude to recharge the point. This shows that the structural control of the geology in the area has good relationship over groundwater availability. The yields of the various wells were not determined. However, interactions with the users of the wells confirm that most of the wells are seasonal. Some produce throughout the season but these are heavily dependent upon the demand for the resource. It can be inferred that the areas having the best groundwater yield are those composed of migmatites and gneisses with good geological structures as against the ones underlain by granitic rocks.

3. Materials and methods

3.1 Field and analytical procedures

Systematic sampling as described by Lee and Jones (1983), Chilton (1992) and Ahmed (2000) was adopted for the sampling of hand-dug wells and boreholes. The representative water samples were collected using transparent containers. Prior to the time of sample collection, the container and its cap were rinsed repeatedly with the sample to be collected (Barcelona *et al.*, 1985) and thereafter labelled with paper tape before filling to a capacity of about ¾ of the volume container to minimise deoxygenating processes. The water samples were preserved on the field by using cooler filled with ice blocks before moving them to the laboratory for analysis.

In an attempt of ensuring representative sample reflect and maintain the quality of water being examined, the following measures were put in place, which include:

i. The containers and cap were rinsed repeatedly with the sample to be collected as describe by Barcelona *et al.* (1985).
ii. During sample fillings, the containers were held at the base to avoid contaminations and filling to the brim was avoided to enhance circulation of oxygen in the container
iii. Samples designated for trace element analysis were acidified using nitric acid so as to retard biological action and absorption processes which may alter the natural conditions of the water (Wilson and Steve, 1998; Lottermoser *et al.*, 1999; Schreiber *et al.*, 2000).
iv. Cooling systems were provided for the samples on the field to help maintain natural conditions of the water.

Water Temperature, electrical conductivity (EC) and pH were measured in situ with portable digital meter and pen type pH meter (AZ-8864), respectively. Twenty-three (23) samples comprising fifteen from hand-dug wells and eight from boreholes were collected (Figure 3).The samples were labelled and stored chilled enroute the laboratory where the physicochemical constituents were analysed. The geographic locations of the sample points were determined using a hand-held GPS (Garmin GPS map 78S). The water samples were analysed for physical parameters, appearance, total dissolved solid (TDS)and turbidity.

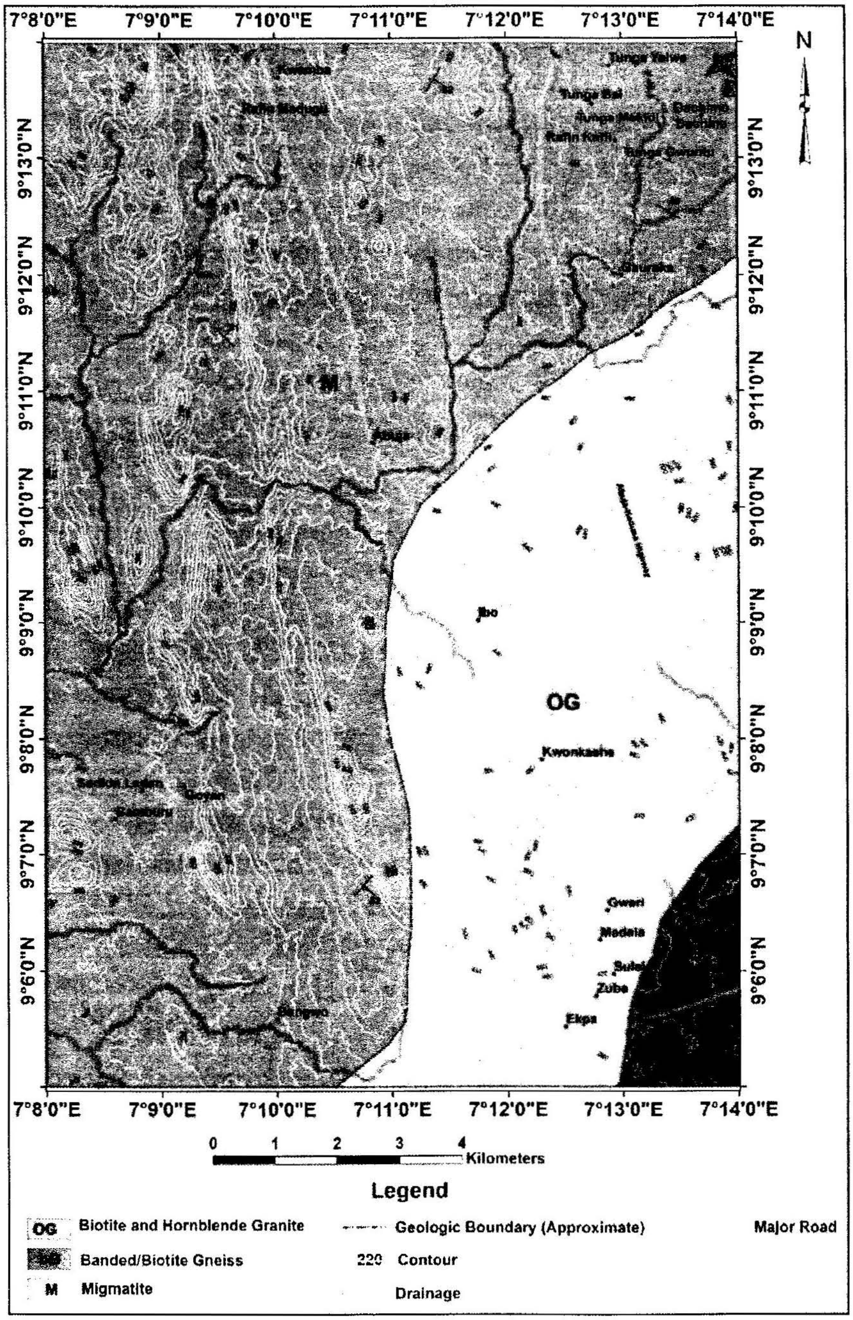

Figure 2: Geologic map of Suleja and its environs

The general chemical parameters include total alkalinity, total hardness and electrolytic conductivity. The major ions analysed include: chloride (Cl^-), nitrates (NO_3^-), sulphate(SO_4^-), magnesium (Mg_2^+), sodium (Na^+), Hydrogen sulphide (H_2S),and the heavy metals analysed include; zinc (Zn),iron (Fe), nickel (Ni), cadmium (Cd), chromium (Cr) and lead (Pb). Oxygen parameter includes; dissolved oxygen (DO). TDS determined using a hand-held meter and turbidity was analysed using spectrophotometric method. Total alkalinity was analysed using acid-base titrimetric methods, total hardness, chloride and dissolved oxygen were also analysed with titrimetric method. Phosphate and nitrate were analysed using colorimetric method. Cations and heavy metals were analysed using spectrophotometric method except for sodium and potassium that were analysed with atomic flame emission photometry. Sampling and analytical techniques followed the suggestions by American Public Health Association (APHA, 1998).

3.2 Determination of groundwater quality index

Open dumpsites in developing countries usually have a wide range of pollutants emerging from them as a result of the highly varied mix of both domestic and industrial wastes. Acquiring datasets that is comprehensive enough to characterise and ascertain concentration of leachates in the dumpsites are very expensive and time dependent. Therefore, with the sparse data that finance and time will allow one to acquire, Factor Analysis (using Principal component extraction method) in SPSS was employed to analyse the information content of the indicators. The approach was adopted as data reduction tools to distinguish the hydrochemical constituents that best explain the groundwater quality. The factors (Fs) with eigenvalues >1 and those that explained at least 5% of the variability in the water samples were assumed to best represent the variation in the data (Andrews *et al.*,2002; Lobato *et al.*, 2015). These were considered potential members for inclusion into Water Quality Index (WQI) calculation. The components with eigenvalues <1had less variation than an individual variable (Askari and Holden,2014). Varimax rotation was performed on factors to enhance the interpretation of the results (Andrews *et al.*, 2002; Askari and Holden, 2014; Lobato *et al.*, 2015). Highly weighted parameters defined to be those having factor loading of ≥0.50 and whose commonalities were above 0.50 were selected in each factor for the indexing (Chen et al., 2013; Lobato et al., 2015; Swanepoel *et al.*,2014).

Three steps were followed in the calculation of WQI. Firstly, the parameters were assigned weights (Wi) based on their importance to water quality assessment and health implication. The relative weights were based on the communalities between the variables (chemical parameters) derived through Factor analysis. The communalities were calculated as

Equation (5) was used to calculate the sub-index of the ith parameter before the final groundwater quality index was determined with Equation (6). Where SI is the sub-index of the ith parameter, *Wi* is the relative weight and Q*i* is the quality rating and where *i* is the quality parameter.

$$WQI = \left[\frac{\sum_{i=1}^{n} SI_i}{\sum W_i}\right] \qquad (6)$$

Where WQI is the water quality index, SI is the sub-index of the *i*th parameter, and is the weight of the ith parameter.

The water quality indices were categorized into five categories: Excellent (0 - 25), Very good (26 - 50), Good (61 - 75), Poor (76 - 100) and Unsuitable (>100) (Sharma et al., 2014).

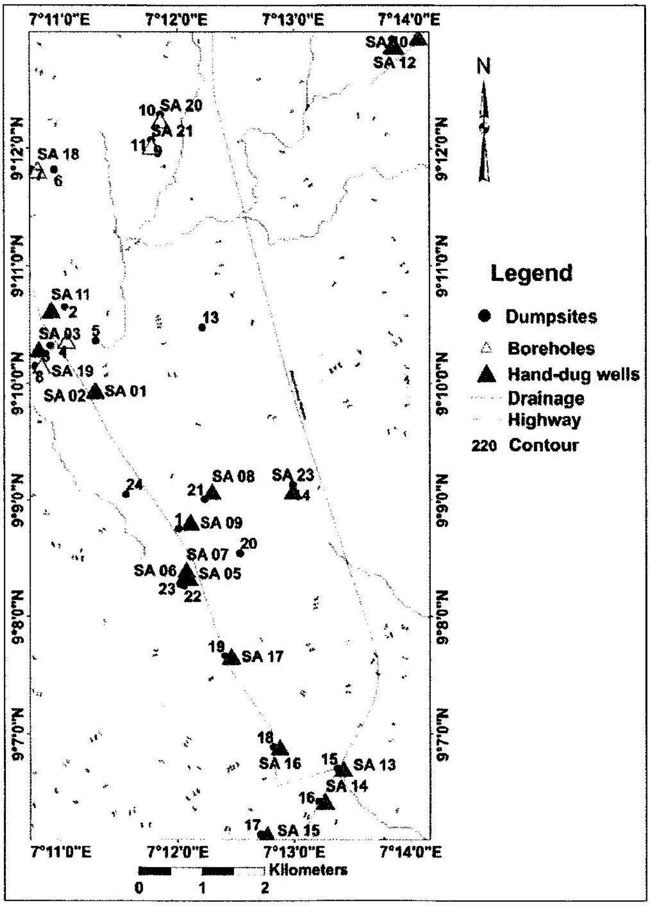

Figure 3: Locations of hand-dug wells boreholes samples in the study area.

3.3 Analysis of the spatial distribution of water quality indices around the dumpsite

Inverse distance weighted (IDW) interpolation explicitly makes the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, hence the name inverse distance weighted (ESRI help file, 2016).

The general equation for the IDW is given as:

$$z_0 = \frac{\sum_{i=1}^{s} z_i \left(\frac{1}{d_i^k}\right)}{\sum_{i=1}^{s} \left(\frac{1}{d_i^k}\right)} \qquad (7)$$

where z_0 is the estimated value at point 0; zi is the z-value at the known point i; di is the distance between points i and 0; s is the number of known points used in the estimation; and k is the power function indicating degree of weight which is often assumed to be two (Dixon and Uddameri, 2016).The IDW interpolation was implemented in ArcGIS 10.5 software environment.

4. Results and Discussion

4.1. Physico-chemical and heavy metal concentration in groundwater samples

The statistical summary of water quality parameters around the dumpsite are presented in Table 1. The observed variations are due to differences prevailing in the sampling environment and are reflected in the pattern of WQI discussed later in the text. The pH of all groundwater samples in the present study, ranged between 6.5 and 7.3. The minimum value was observed at samples 25, 11 and 15, while the maximum value was observed at samples 8 and 11. All pH results were within the permissible limits (6.5- 8.5). Conductivity values ranged from 61 to 81µS/cm with the standard limit being 250µS/cm. It can be inferred that leachate is not contributing to pH levels in groundwater in and around the study area.

Table 1: Statistical summary of groundwater parameters measured in the study area

Parameters	Mean	Median	SD	Kurtosis	Skewness	Range	Minimum	Maximum
pH	6.87	6.80	0.25	-0.82	0.03	0.80	6.50	7.30
Conductivity (µs/cm)	69.09	69.00	5.66	-0.47	0.58	20.00	61.00	81.00
TDS (mg/L)	484.74	473.00	49.57	-1.12	0.16	168.00	401.00	569.00
Turbidity (mg/L)	6.73	6.80	0.76	-0.72	-0.34	2.50	5.30	7.80
Cl- (mg/L)	21.16	21.41	3.57	-0.15	0.32	14.18	14.13	28.31
NO3- (mg/L)	0.06	0.05	0.04	-0.93	0.32	0.13	0.00	0.13
SO4- (mg/L)	10.23	10.19	1.87	-0.41	0.20	6.99	7.01	14.00
TH (mg/L)	42.00	41.00	5.63	-0.55	0.25	21.00	31.00	52.00
Mg (mg/L)	5.96	6.45	2.26	-1.19	-0.37	6.86	2.29	9.15
Na (mg/L)	53.67	53.81	5.87	0.02	-0.67	22.10	41.09	63.19
H2S (mg/L)	0.01	0.01	0.01	-0.32	0.85	0.03	0.00	0.03
Cr (mg/L)	0.16	0.12	0.17	0.72	1.20	0.57	0.00	0.57
Pb (mg/L)	0.15	0.11	0.16	-1.08	0.60	0.46	0.00	0.46
Ni (mg/L)	0.08	0.00	0.24	20.38	4.42	1.16	0.00	1.16
Zn (mg/L)	0.86	0.69	1.29	11.59	3.32	5.77	0.13	5.90
Fe (mg/L)	1.63	1.17	2.00	19.88	4.33	9.94	0.60	10.54
DO (mg/L)	0.21	0.20	0.10	-0.61	0.58	0.30	0.10	0.40

Conversely, turbidity values and TDS values exceeded the maximum permissible limits. In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases. This is because contaminants like viruses or bacteria can become attached to the suspended solids. The concentration of Total Dissolved Solids (TDS) indicates the nature of water quality and or its salinity. Open dumpsites may lead to increased total dissolved solids concentrations in groundwater. It was therefore concluded that groundwater in several sampling points around the study area are polluted from dumpsite leachates.

All the major ion values at all the groundwater samples were all within their respective permissible limits when compared with the NSDWQ (2015) except chloride contents which were higher than the set permissible limit (3 mg/L) in all the samples analysed. Chloride is not harmful to humans, but high concentration of chloride is not required. Chloride is a conservative contaminant and therefore poses serious threat to groundwater. Excessive chloride concentration increases rate of corrosion of metals in distribution systems especially for deep wells. This can lead to increased concentration of metals in the supply, and this can cause laxative effects and gastro-intestinal irritation in humans (WHO, 2006).

For the heavy metals, concentrations of Fe_2^+ were found to exceed NSDWQ (2015) standards (0.3 mg/L) in all sampled locations. Average concentration of Iron was recorded at 1.63 mg/L(Figure 4). Chromium samples exhibited varied concentrations. In several samples, they were not detected and where detected, few samples were within the recommended standards. For lead, 9 out of the 23 samples were either not detected or were within the recommended limits. Others have concentrations above the NSDWQ (2015) standards (Figure 5). Iron concentrations however do not pose potential health risk as they fall well within the recommended daily dietary allowance (7 mg – 18 mg). It is essential to all organisms and present in haemoglobin system. Water with high iron concentrations may be discoloured and stain washed clothing (Adams, 2001). High concentrations may be attributed to the infiltration from leachate migration from metal scraps dumped in the waste disposal sites.

Major source of lead entering the groundwater from largely connected to the disposal of lead batteries at the sites. Ingesting high concentration of Pb can lead to multiple effects such as hypertension, problems in gastrointestinal systems, kidney disease, encephalopathy, decreased growth, among others (Dooyema *et al.*, 2012; Fewtrell *et al.*, 2004; Pruss-Ustun *et al.*, 2004; Udiba *et al.*, 2012). The zinc levels ranged from 0.132 mg/L to 5.902 mg/L with an average of 0.862. All Zinc concentration levels were within the permissible limits (3.0 mg/L) according to NDWQS (2015) except samples 17 and 19(Figure 6). Sources of zinc in groundwater samples can be attributed to anthropogenic factors of discarding metal scraps at the dumpsites.

4.2. Groundwater quality parameter scores and indices

Table 2 shows the relative weight (Wi) assigned to each parameter which was based on the values of their communalities. Communality estimates reflect the variance of a variable in common with all others together (Yong and Pearce, 2013). Higher communalities were assigned higher weights. H2S had the highest weights, while Cl and Zn, which had the lowest value, had the least assigned weight. The relative weights sum to one. The computed water quality indices at each sampled location are depicted in Table 5. Values range from 36.69 to 608.16, with an average and standard deviation of 129.3 and 181.90, respectively. These results generally indicate that the groundwater near the dumpsite are generally not of good quality.

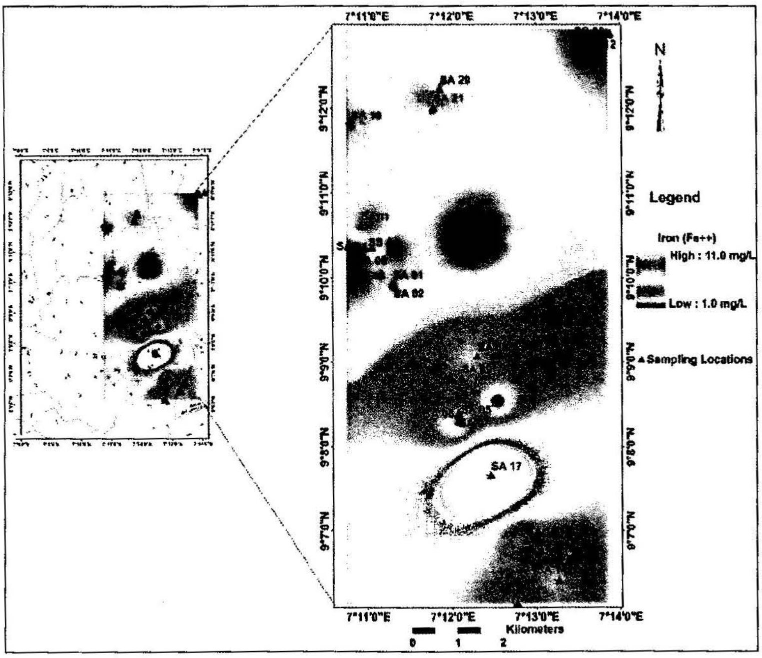

Figure 4: Spatial Distribution of Iron (mg/L) concentration in water samples within sampling locations.

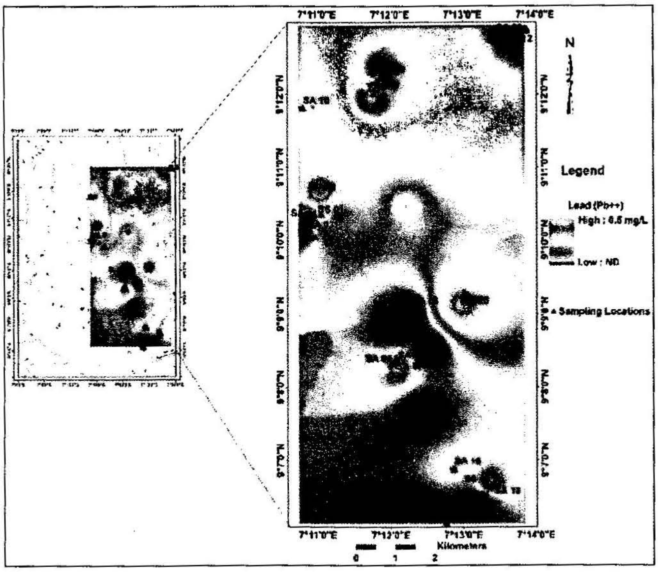

Figure 5: Spatial Distribution ofLead (mg/L) concentration in water samples within sampling locations.

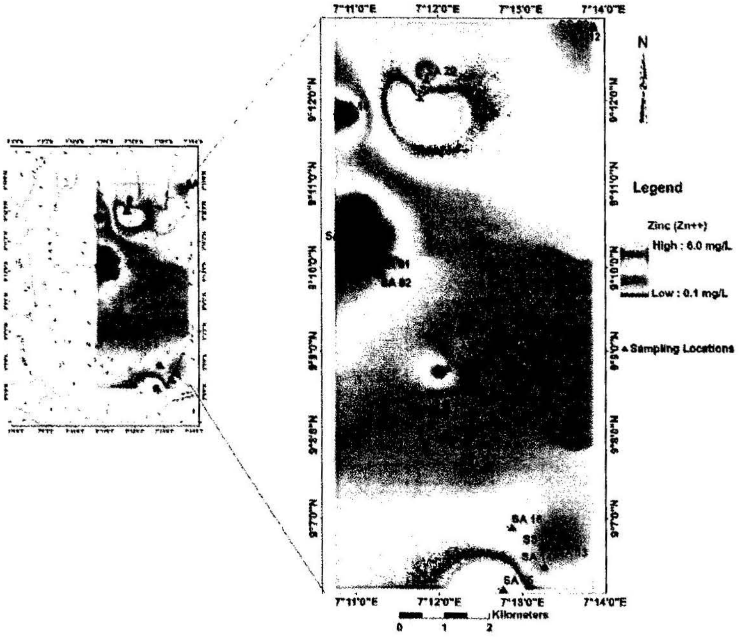

Figure 6: Spatial Distribution of Zinc (mg/L) concentration in water samples within sampling locations.

Table 2: Parameters and their assigned weights.

Parameters	Communalities	Relative weights
pH	.765	0.06
Conductivity	.861	0.07
TDS	.819	0.07
Turbidity	.880	0.07
Cl^-	.536	0.04
NO_3^-	.657	0.05
SO_4^-	.700	0.06
Total hardness	.696	0.05
Mg^{2+}	.772	0.06
Na^+	.823	0.07
H_2S	.913	0.09
Cr	.604	0.05
Pb	.753	0.06
Ni	.688	0.05
Zn	.582	0.04
Fe	.646	0.05
DO	.698	0.06

Extraction Method: Principal Component Analysis.

Figure 7 shows the spatial pattern of the water quality indices. The area is generally characterised by poor drinking water quality. The high values obtained in some locations were due to high concentration of Ni and Pb in some of the samples. The concentration of these water quality indicators was higher than the recommended threshold for drinking by the NSDWQ (2015) standard. Samples with unsuitable WQI rating were mainly from the wells sited in close proximity to the dumpsites which may have suffered from anthropogenic influence. Water from these locations can be regarded as unfit for consumption and needs to be remediated to prevent further contamination. It is imperative that the disposal sites be managed so as to ensure that there is no indiscriminate dumping of refuse. Also, a modern engineered landfill should be constructed in order to forestall further groundwater contamination by leachates.

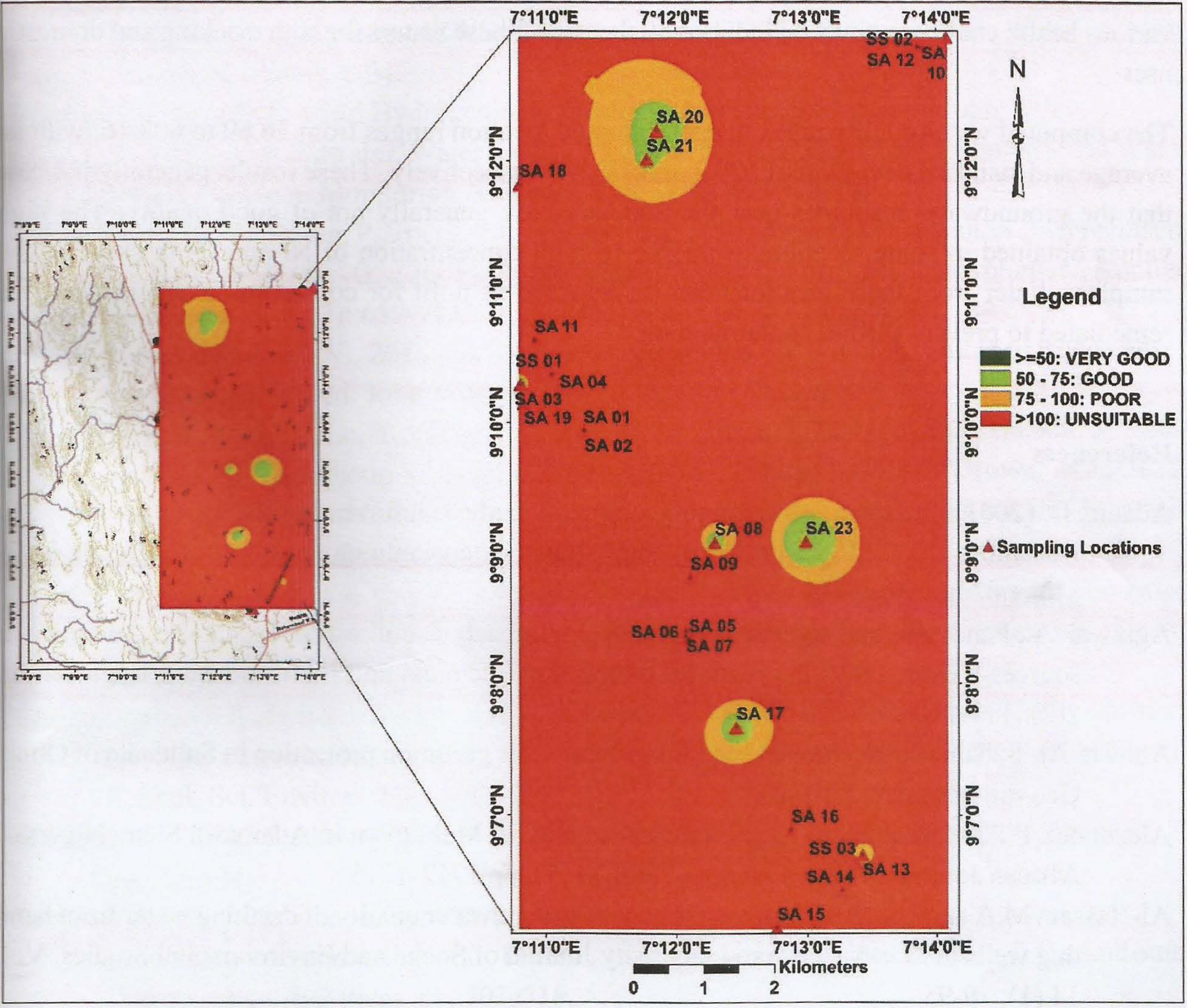

Figure 7: Spatial distribution of Water Quality Index of sampled locations.

7. Conclusion

The study assessed the groundwater quality around open solid waste dumpsite in Suleja metropolis in North-Central Nigeria using water quality index ratings and geospatial techniques. Groundwater samples around the dumpsites had varying degrees of concentrations that either met or failed the NSDWQ (2015) regulatory standards. All pH results were within the permissible limits (6.5- 8.5). Conductivity values ranged from 61 to 81µS/cm with the standard limit being 250µS/cm while turbidity and TDS values exceeded the maximum permissible limits. All the major ion values at all the groundwater samples were all within their respective permissible limits when compared with the NDWQS (2015) except chloride contents which were higher than the set permissible limit (3 mg/L) in all the samples analysed. Fe, Pb, Cd, Zn and Ni where detected and were mostly above the allowable limits. When concentrations of some of these elements exceed the permissible limits, various health challenges may be induced by the use of these waters for both drinking and domestic uses.

The computed water quality index at each sampled location ranges from 36.69 to 608.16, with an average and standard deviation of 129.3 and 181.90, respectively. These results generally indicate that the groundwater resources near the dumpsites are generally not of good quality. The high values obtained in some locations were due to high concentration of Ni and Pb in some of the samples. Water from these locations can be regarded as unfit for consumption and needs to be remediated to prevent further contamination.

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