Ethiopian Journal of Environmental Studies & Management 11(2): 144 – 159, 2018.
ISSN:1998-0507 doi: https://ejesm.org/doi/v11i2.3
Submitted: December 12, 2017 Accepted: March 27, 2018

SPATIAL CHARACTERIZATION OF GROUNDWATER QUALITY AS INFLUENCED BY WASTE DUMPS IN IBADAN METROPOLIS USING GIS MAPPING

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Abstract
Inefficient management of landfills and dumpsites for waste disposal is a major problem in Nigeria. Leachates and pollutants from these dumpsites have been known to contribute to the pollution of groundwater systems. The extents of pollution however are poorly quantified since the flow of pollutants continues below earth surface. The use of GIS mapping enabled the evaluation of spatial characteristic of pollutants in the groundwater systems. Thirty (30) hand dug well within 10 – 100m were sampled around two poorly managed dumpsites in Ibadan. Twenty-three (23) physico-chemical and heavy metals water quality indicators were analyzed following Standard Methods. The result were subjected toT- test of mean compared with WHO (2005) drinking water standard ($p<0.05$). Using GIS Inverse Distance Weighted Interpolation, the maps of the pollutants were produced and the spatial distribution shown. Elevation, topography and slope were major determinants in the distribution of level of pollutant revealed in the generated maps. Although, pH Cl^-, K^+, Fe, Cr and Pb were not significantly different from the Maximum Allowable Limits (MAL) TSS, TDS, Total Hardness, NO_3^- , SO_4^{2-}, Ca, Mg, Na, Cu, Zn, are all lower while CO_3^{2-}, Mn, Cd, and BOD_5 are higher than MAL. The DO is good since it's averagely higher than minimum required for water drinking. The GIS maps will guide in groundwater prospecting in the area and aid decision on enforcement of environmental standard in siting of residences and groundwater wells.

Key Words: *Groundwater, Leachates, Pollution, GIS maps, Ibadan*

Introduction

Indiscriminate disposal and management of municipal solid wastes contribute to surface and groundwater contamination specifically and environmental pollution in general (Longe and Balogun, 2009; Vodela *et al*., 1997). Kolade (1993) in the work on the impact of indiscriminate waste disposal discovered that 90% of dug wells in Nassarawa-Gwon area of Jos were contaminated with feacal coliforms while unacceptable levels of other physico-chemical water quality indicators were observed in hand dug well being used as drinking water sources in Abeokuta, a major city in south western Nigeria.

Dumping of solid waste or refuse in dumpsites or landfills is one major strategy often employed in towns and cities across Nigeria. However, this common practice of waste disposal in many developing countries is often far from recommended standard (Mull, 2005; Orebiyi *et al*., 2010; Adewale, 2009). Adewuyi and Opasina (2010) reported the negative impacts of uncontrolled disposal of hazardous and non-hazardous waste on open and unsecured dumpsites and non-sanitary landfills. Landfills when improperly designed could become a major source of groundwater pollution due to the production of leachate and its migration through refuse strata and soil profile (Chistensen and Stegmann, 1992). Leachates seep from dumpsites and landfills release pollutants which pose high risk to groundwater quality when poorly managed (Ikem *et al.,* 2002). This becomes more pronounced when the soil is highly porous. There is overwhelming negative impacts of leachates on the environment, groundwater and human health of populations who often depend on groundwater source for their drinking (Sangodoyin, 1993; Taylor and Allen, 2008).

Evaluation of the extent of pollution in groundwater structures such as dug or tube well or bore holes need to take into cognizance the spatial distribution of the pollutants across the soil strata. With the complex variability in soil properties and the landscape characteristics, extents and impacts of leachates and pollutants from dumpsites or landfills could be difficult to estimate. However, the Geographical Information System (GIS) technique can significantly assist in showing spatial variation of geospatial variables. The GIS has been used to estimate characteristics of environmental variables severally in hydrological studies (Oke *et al.* (2013); Hudak *et al.* (1993); Song and Kim (2009)). In these studies, nitrate contamination of urban groundwater, impact of land use type on pollution pattern and contribution of various environmental variables such as land cover type, farming practices, animal density, topography, soil and seasonal precipitation on pollutants levels and spatial distribution of pollutants in groundwater systems have been mapped with the aid of GIS while maps of spatial characteristics of pollutants distribution produced.

With GIS, environmental modeling and tracking of solute and pollutants are also possible in surface or groundwater systems. The GIS with DRASTIC model have been used to model information on cropping, fertilizer application rates, aquifers, and aquifer recharge areas. The studies had resulted in a nitrogen fertilizer pollution potential map of Texas. Also, Atkinson *et al.* (1992) used the DRASTIC model and a GIS system to assess groundwater pollution potential of Texas.

Therefore, the use of GIS techniques can facilitate the understanding of the fate of leachates and pollutants within the soil strata across dumpsite environs. This pollution pattern needs further investigation in Nigeria. The main focus of this work is to use the GIS capabilities to understand the extent and spatial distribution of pollutants around dumpsites in relation to water quality status of open wells used from drinking water in residences around major dumpsites in an urban environment.

Materials and Methods

Study Locations

This study was conducted in Ibadan a major city in Oyo State, South Western Nigeria. The study locations are (Fig. 1):

1. Akanran/Aba-Eku refuse Dumpsite and its environs, which falls within Ona-Ara Local Government Area of Oyo State. It is about 8.14 ha (Awajiogak *et al*., 2014). It is located approximately on longitude 003.989°E and latitude 07.326°N, an elevation range of 147 to 181.
2. Awotan dumpsite is located at Akufo, Ido local government area Apete, Oyo State. Land size of dumpsite is about 11 ha. The dumpsite is located approximately on 3° 51′43″ E longitude 7°26′ 35″ N, on a slight hill facing the residential area (opposite) and downhill in the environment

The dumpsites used to be in the outskirt of the city in a sub-urban environment. The Akanran Aba Eku dumpsite now has a low density sparsely built residential land-use developing around it. Similarly, in the Awotan dumpsite, the western part of the dumpsite is fast developing. Houses in these areas depend on groundwater for their domestic water supply using either open dug well or deep bore hole which is feasible for the elite individual who can afford the high cost.

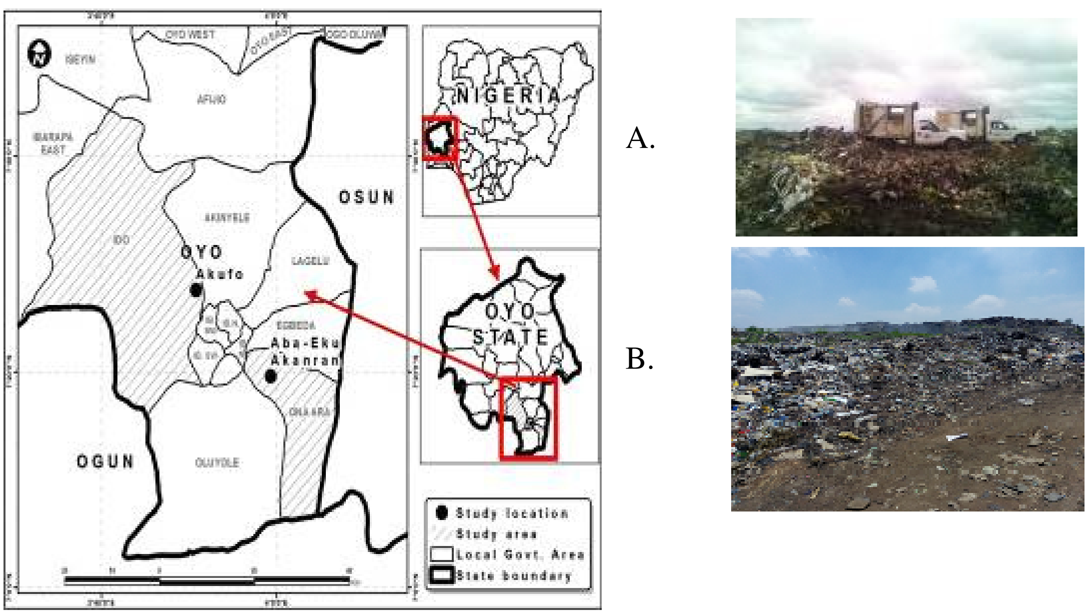

Fig. 1: Map of the Study Locations in (A) Akanran/Aba Eku (B) Akufo Awotan

Land Use Characteristics and Estimated Solid Waste Load

The land use characteristic of the areas where the dumpsites were located was obtained from the records at the Institute of Agricultural Research and Training, Ibadan. Nigeria. This was based on the Remote Sensing and GIS analysis of the location for the year 2015 by the Land Information Network of the Institute. Also, the estimated solid waste loads were retrieved from published work to guide the understanding of waste disposal activities at the sites.

Groundwater Sampling

Thirty (30) hand-dug open wells were sampled within the residential areas around the dumpsites. None of the well is treated. The wells were within 100m around the dumpsites. Sixty (60) water samples were collected from the wells at two (2) samples per well using 1-litre plastic container, (30 white plastic bottle and 30 blue plastic bottles). The blue bottles were rinsed with distilled water. Winkler method was used in DO determination. To the samples in blue bottles (for DO and BOD_5 determination), 10ml of Winkler solution comprising 0.5g/l Manganous Sulphate pentahydrate and Alkaline-iodide-azide solution following the procedure by Bartram *et al.* (1996) was added to each bottle. The procedure preserves the oxygen in order to determine the biological parameters in the samples. Both white and blue bottles were first rinsed three times with groundwater to be sampled prior to filling and the bottles were appropriately labeled.

Laboratory Analysis

Laboratory analysis of physico-chemical water quality parameters followed the APHA (1992) protocols. The pH was determined using the pH meter (Jenway 3510 model). The metals and cations determined include Iron (Fe), Pottasium (K), Calcium (Ca), Cadmium (Cd), Manganese (Mn), Magnesium (Mg), Sodium (Na), Chromium (Cr), Lead (Pb), Copper (Cu), Zinc (Zn).The above metals and cations were analysed after 10mls of concentrated Perchloric acid and 10mls of concentrated Nitric acid (1:1) digestion. The digest was washed in to 100mls volumetric flask and make up with distilled water. The washed sample was then read from Atomic Absorption spectrophotometer (AAS) using their respective lamp and wavelengths.

For the following anions Nitrate (NO_3^-), Bicarbonate (CO_3^-), Sulphate (SO_4^{2-}), Chloride (Cl^-), analysis was done using titrimetric/colourimetric method. Total suspended solid (TSS) was determined using the gravimetric determination and Total Dissolve Solids (TDS) was also analyzed. Total Hardness, Dissolve Oxygen (DO), Biological Oxygen Demand (BOD), were determined using the method American Public Health Association Standard method for the examination of water and waste water (APHA, 2005).

GIS Analysis

The co-ordinate of the locations of each well was taken using Global Positioning System (GPS) Garmin X model. The land-use characteristics within the study areas were obtained from the analysis of Landsat Imagery using the supervised classification techniques (Anderson *et al*., 1971). The landuse systems of the study areas were identified through reconnaissance surveys while the various land types were digitized in ArcGIS software environment using the Google Earth satellite imageries of the localities/areas. The integrated Remote Sensing (landuse) and GIS approach was to predict and overview the spatial distribution of the interference of various geographic and demographic factors with the water quality elements in the study areas. Terrain analysis of a digital elevation model (DEM) is also fundamental to hydrology, since water always flows down a slope. DEMs are very useful for hydrological flow inferences.

This enabled the generation of land-use map for proper identification of basic land features in the study area. Water quality data was imported into the GIS environment and linked with the created Well Shapefiles. The schematic protocol for the GIS analysis is presented in the Fig. 2.

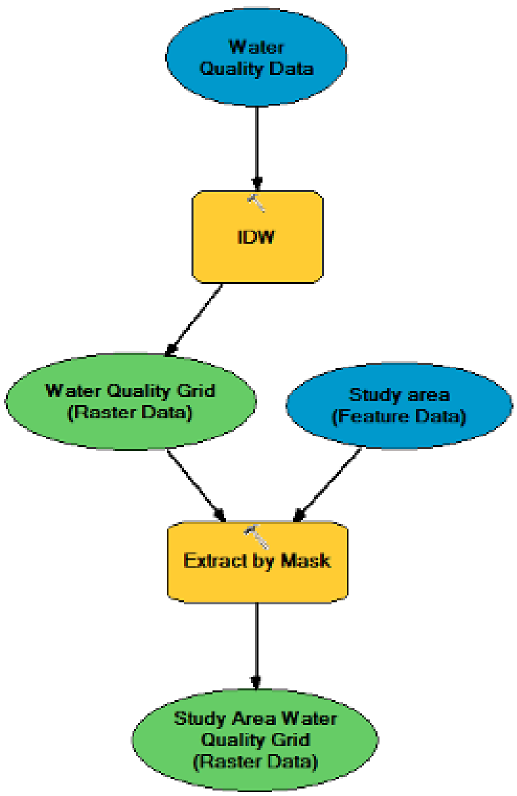

Fig. 2: Flow chart of GIS Analysis for spatial mapping of water quality

The water quality analysis method applied was the effective integration of the GIS-based Inverse Distance Weighted (IDW) Interpolation procedure to estimate the factor values on a grid cell basis across the study areas. As in Figure 1, the measured points (Water Quality Data) were used in the calculation of each interpolated cell (Water Quality Grid). These are cells that fall within the specified study area shape (mask feature data). The IDW was used for river water quality interpolation by Oke *et al*. (2014). All the GIS analyses were conducted using ArcGIS 10x and all the measured points were used in the calculation of each interpolated cells.

Results and Discussions

Land Use characteristics and Estimated Waste Load

The dumpsites in Akanran Aba-Eku (D1) and Awotan Akufo (D2) receive solid wastes from nearly all over the city. Ibadan with population close to 3 million in 2006 (NPC Census, 2006) has per capita waste generation of 0.3kg per day which translate to an estimate of 307,864 tonnes per year. (Badmus *et al*., 2014) The D1 (8.14ha) is an older dumpsites which has being in use for over 30 years whereas the D2 (11.0ha) became active dumpsite in year 2000. Over these years, there have significant changes in the land use pattern around the dumpsites (Figs. 3a and b). Expansion in urbanization was responsible for the increasing housing development around the dumpsites which has been observed to be hazardous to health generally and groundwater quality specifically.Table 1 gives details of the distribution of land use around the study area. The dumpsites have become encompassed by building structures while the groundwater wells are also located around the dumpsites.

Table 1: Land Use characteristics of the Study Location

Landuse Type	Akanran [D1]		Awotan [D2]	
	Area (x 10^4sqm)	%	Area (x 10^4sqm)	%
Built-up area	364125.8	73.7	793363.6	64.4
Dump site	81409.8	16.5	109851.9	8.9
Openland/Swamp	7459.7	1.5	93329.3	7.6
Vegetation	41050.1	8.3	235001.6	19.1

Source: Institute of Agricultural Research and Training, Land Information Network (2012)

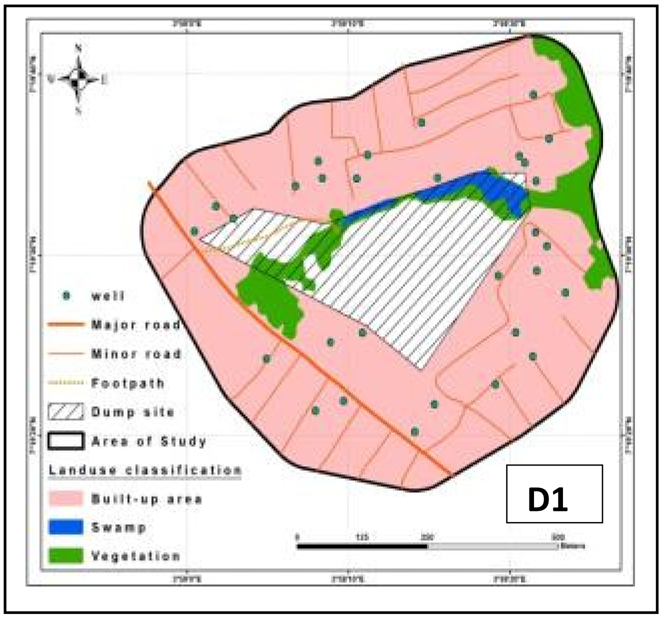

Fig. 3(a): Akanran Aba Eku Dumpsite [D1]

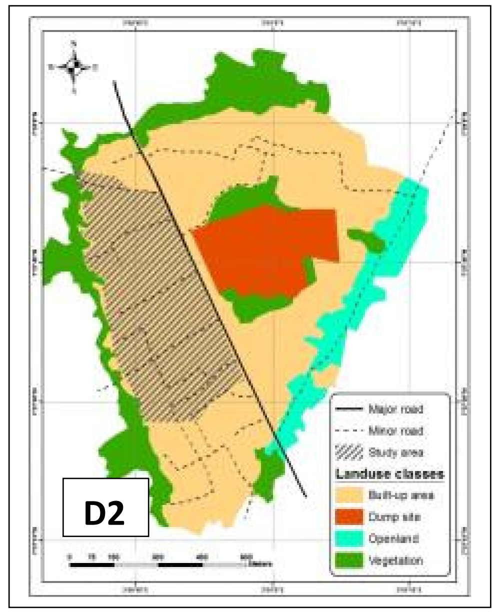

Fig. 3(b): AwotanAkufo dumpsite [D2]

Elevation Characteristics

Fig. 4 is the spatial characteristics of surface elevation of the study areas. The elevation ranged between 108 and 155 mASL in Akanran (D1) while it is between 161 and 222mASL in the Awotan (D2). This shows that D2 is at a higher altitude than D1. The difference between the highest and lowest points within the study areas is 61m and 47m in D2 and D1 respectively. It was observed that whereas the D2 dumpsite slope N-S, the D1 site is more undulating with the major slope W-E while a hill (145 – 146m) exists towards the SW part of the dumpsite. Topography of an area determines the gradient of the land surface. It is a major factor that contributes to the surface and subsurface flow of water and leachates within the environment. The groundwater wells are located obviously at different elevations and this will impact differently on the reception of leachates from the dumpsites.

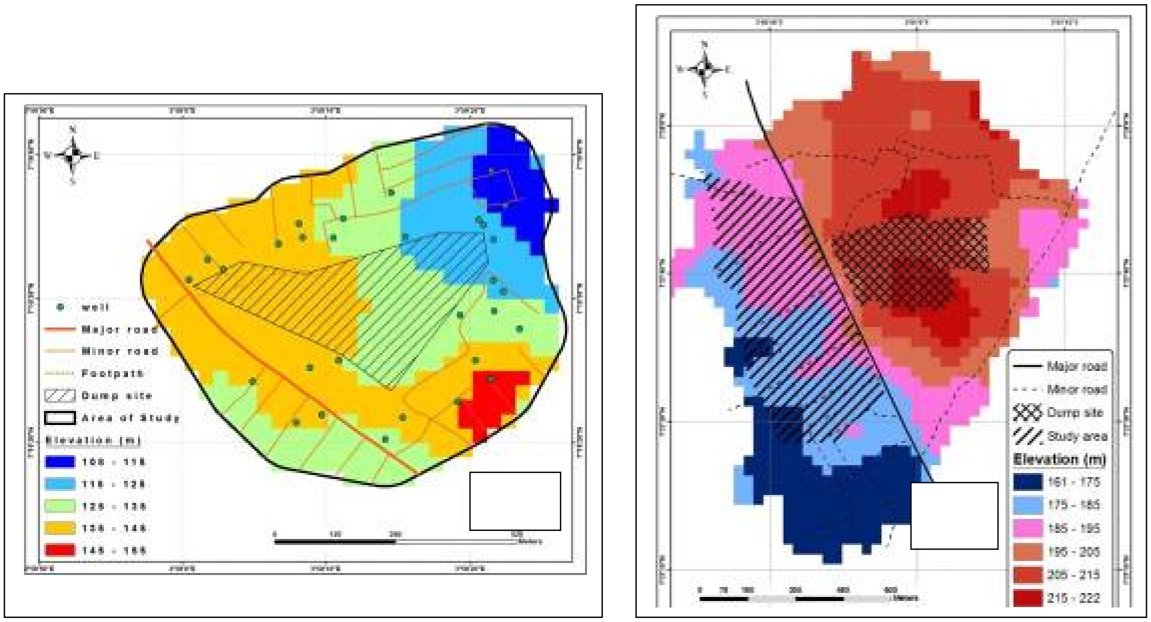

Fig. 4: Elevation Characteristics of Akanran and Awotan study areas

Levels of Pollutant across the groundwater systems in the dumpsites environs

Table 2 reveals the average levels of investigated water quality parameters. The comparison of the pollutant recorded from the analysis of groundwater from the D1 and D2 show that the mean level of pH (6.68), Chloride (317.0 mg/l), Potassium (15.3 mg/l), Iron (0.40 mg/l), Cr (0.04 mg/l) and Pb (0.02 mg/l) are not significantly difference from the level expected in drinking water. Whereas, TSS, TDS, Total Hardness, Nitrate, Sulphate, Calcium, Magnesium, Cu, and Zn, are significantly lower than the maximum guide value, Bicarbonate, Mn, BOD_5 and DO are significantly higher ($p<0.05$). In the case of BOD_5, the high level is not acceptable in drinking water because it is an indication of level of organic load in the water. The average level of 28.7 mg/l which is approximately 10 times higher than the guideline of 3.0 mg/l (UNEP, 1996) is dangerous. However, the high level of DO which is averagely 7.75 mg/l is acceptable. The minimum value of 2.0 was exceeded in the groundwater systems of the two dumpsites.

It was also observed that the low level of Cu and Zn and Cd as well as the insignificant level of Fe, Cr and Pb as compare to the guide value is within the acceptable range. It shows that the levels of heavy metals from the groundwater are still reasonably tolerable. This although is with the exception of Cd which is significantly higher (0.03mg/l). This is different from the level of Cd and Pd observed in similar dumpsite environment in Ibadan from the investigation of Awajiogak *et al*. (2012). With high level of DO and low level of Nitrate, Sulphate, Calcium, Magnesium and Total hardness, the water quality has been within a tolerable level for drinking.

Table 2: Levels of water quality parameters in the groundwater system within the dumpsite environs

Parameters Unit (mg/l)	AKANRAN GROUNDWATR SYSTEM (D1)		AWOTAN GROUNDWATER SYSTEM (D2)			Standards Guidelines	
	Lowest value	Highest value	Lowest value	Highest value	Mean*	WHO** (MAL)	NDWQ***
pH	6.50	6.90	6.48	6.85	6.68ns	6.5-8.5	6.5-8.5
TSS	0.12	0.74	0.01	0.60	0.37↓	25	25
TDS	0.05	0.56	0.01	0.47	0.27↓	500	500
Total hardness	4.8	8.2	3.30	6.40	5.67↓	270	250
Nitrate(NO_3^-)	0.1	0.23	0.1	0.14	0.14↓	50	50
Bicarbonate (HCO_3)	216.6	612.9	266	604	424↑	250	250
Chloride	142.2	461.3	197.0	467.4	317.0ns	250	250
Sulphate(SO_4)	12.7	17.4	11.81	15.8	14.4↓	250	250
Calcium	3.4	5.5	3.58	4.56	4.26↓	75	75
Magnesium	1.36	2.69	0.07	0.51	1.15↓	50	50
Potassium	10.4	21.4	10.2	19.3	15.3ns	10	10
Sodium	20.6	37.9	11.3	32.4	25.6↓	50	50
Manganese	0.12	1.24	0.07	0.51	0.46↑	0.2	0.2
Iron	0.10	0.90	0.07	0.54	0.40ns	0.3	0.3
Copper	0.06	0.86	0.02	0.42	0.34↓	1	1.0
Zinc	0.04	0.91	0.02	0.70	0.42↓	3	3.0
Cadmium	0.01	0.09	0.01	0.02	0.03↑	0.003	0.001
Chromium	0.001	0.009	0.001	0.0047	0.04ns	0.05	0.05
Lead	0.01	0.05	0.01	0.01	0.02ns	0.01	0.01
BOD	21.7	41.1	18.6	33.3	28.7↑	3.0****	
DO	6.6	9.4	6.4	8.6	7.75↑	2.0	2.0
Acidity	0.002	0.017	0.05	0.24			

* $p<0.05$; ns = not significant; ↓=significantly low; ↑ = significantly high
WHO (2011) * Nigerian Drinking Water Quality (2007); ****UNEP (1996)
MAL: Maximum Allowable Limits

Spatial Characteristics of pH

The pH variation across the groundwater systems is shown in Fig. 5. The value ranged between 6.5 and 6.9 in the study areas. Tosin *et al.*, (2015) had also observed that pH could be up to 6.1 in other dumpsites in Ibadan environs. The pH was close to neutral showing that the groundwater was near neutral; although, there were not much differences across the two dumpsites in terms of pH. Spatially, variation supports the increasing value of pH from North to South and East West directions of D2 and D1 dumpsites respectively. The dumpsites receive composite of solid wastes including domestic (food wastes, leaves, papers etc), plastics, and electronic wastes among others.

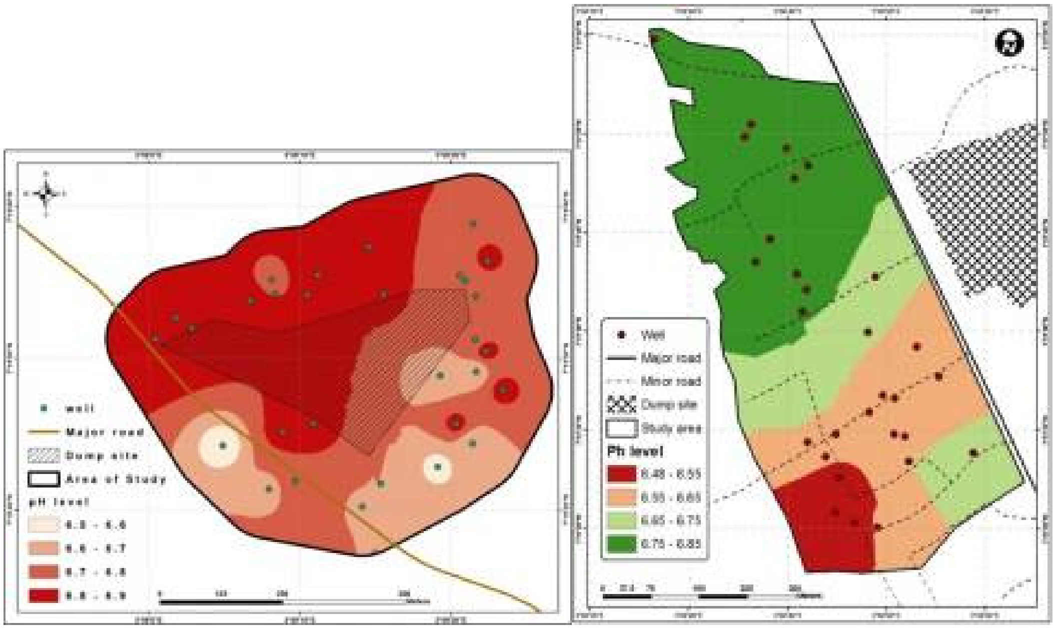

Fig. 5: Spatial variation of pH in the groundwater system of the D1 and D2 respectively

Total Hardness Variation

The observed variation in Total Hardness was different between the dumpsites (Fig. 6). Total Hardness was between 4.8 and 8.2 mg/l in Akanran (D1) while it ranged between 3.3 and 6.4 mg/l in Awotan (D2) dumpsites. The differences may be related to the native soil type of the dumpsites and the SO_4^{2-} and CO_3^{2-} components of the leachates which are products of decaying processes of the organic wastes.

In the D2, it was observed that hardness increases southwards with the lower level of hardness found in the wells within the southern part of the dumpsites. This implies that the flow of leachates within the soil strata tends to improve in quality in relation to water hardness from up to down direction of the dumpsites. However, in the D1, it was observed that the spread of hardness was towards the west along the slope line. Total hardness in groundwater around the dumpsites has direct relationship with topographical pattern. Also, some localized higher monolithic concentration of hardness were observed in the D1 dumpsites which may be as a result of level of hardness causing wastes deposited at such points. As earlier observed the average level of groundwater hardness observed within the D1 environ was higher than what was obtainable in the D2.

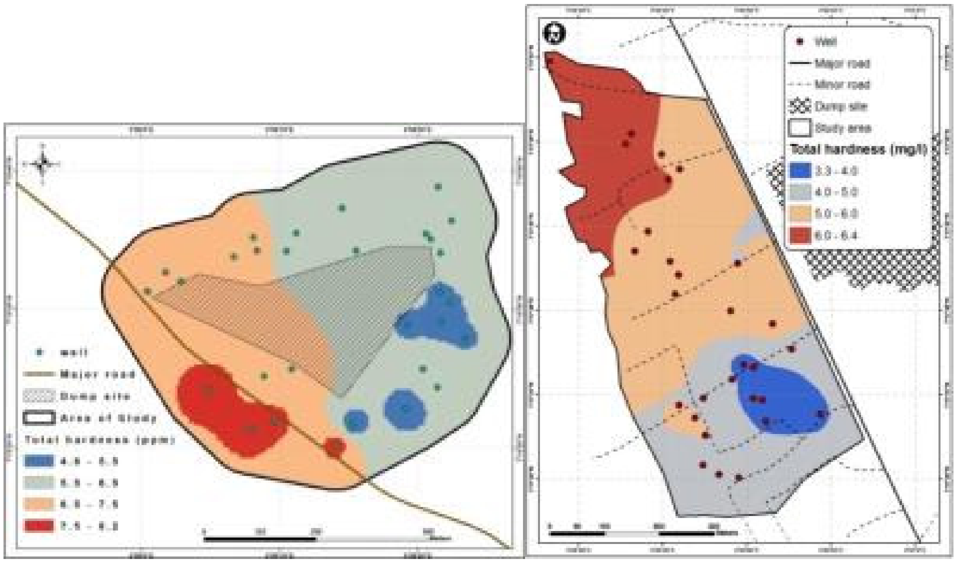

Fig. 6: Spatial variation in Total Hardness of groundwater around Akanran and Awotan dumpsites

Total Dissolved Solids

The pattern of Total Dissolved Solids (TDS) in groundwater system within the study areas are shown in Fig. 7. The level of dissolved solids residue in the water samples within D1 and D2 ranged between 0.05 – 0.56mg/l and 0.01 – 0.47mg/l. The slight difference may be related to the filter property of the soil within the dumpsites. The level of TDS was higher in the location along higher elevation and reduces with elevation. The TDS pattern varies across W-E and N-S in a decreasing pattern. This pattern was similar in the two sites. Thus, wells within lower points were observed to have lower concentration of TDS. This confirms the possibility of improved filtration as flow progresses in the two dimensions, vertically and horizontally.

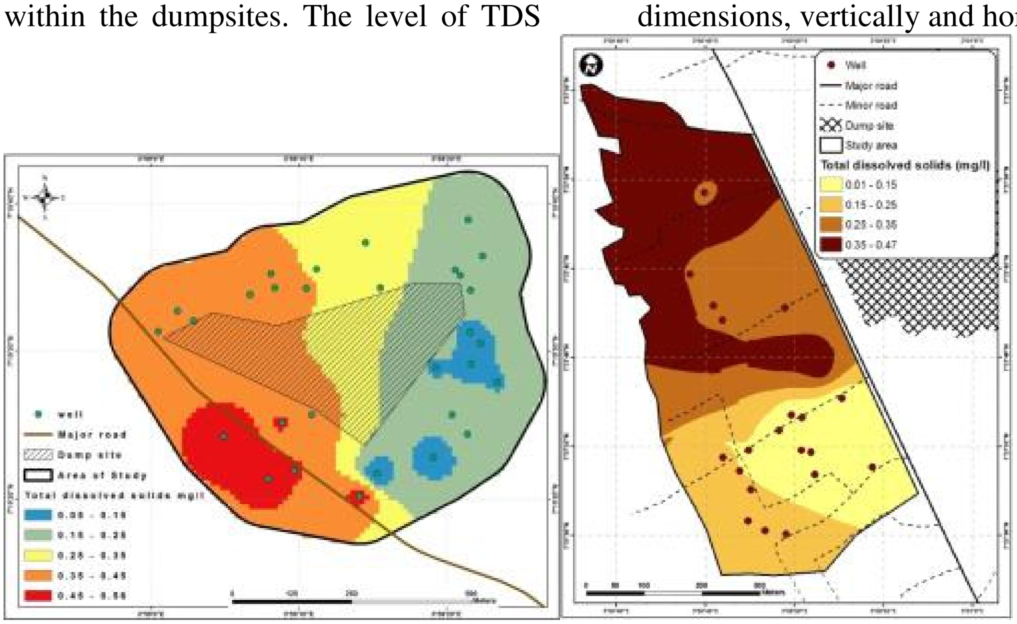

Fig. 7: Spatial variation in Total Dissolve Solid of groundwater around Akanran and Awotan dumpsites

Nitrates

The variation in the NO_3^- levels in the leachates as observed in the groundwater system of the dumpsites areas are shown in Fig. 8. The highest values were observed at the western parts of the study area of D1 (0.15 – 0.23mg/) while the highest in D2 was 0.14mg/l. The variations also follow the W-E and N-S directions in a decreasing order of magnitude which reflect largely the effect of topography distribution of pollutants and leachate migration. The spatial distribution as revealed in Figure 7 shows that sizeable portion towards the SW at the two sites showed the lowest level of Nitrate, 0.1 – 0.13 mg/l at D1 and 0.10 – 0.11 mg/l at D2. The localized differential may be attributed to soil hydrological characteristics relating to variables such as soil texture and infiltration characteristics within the soil interstices.

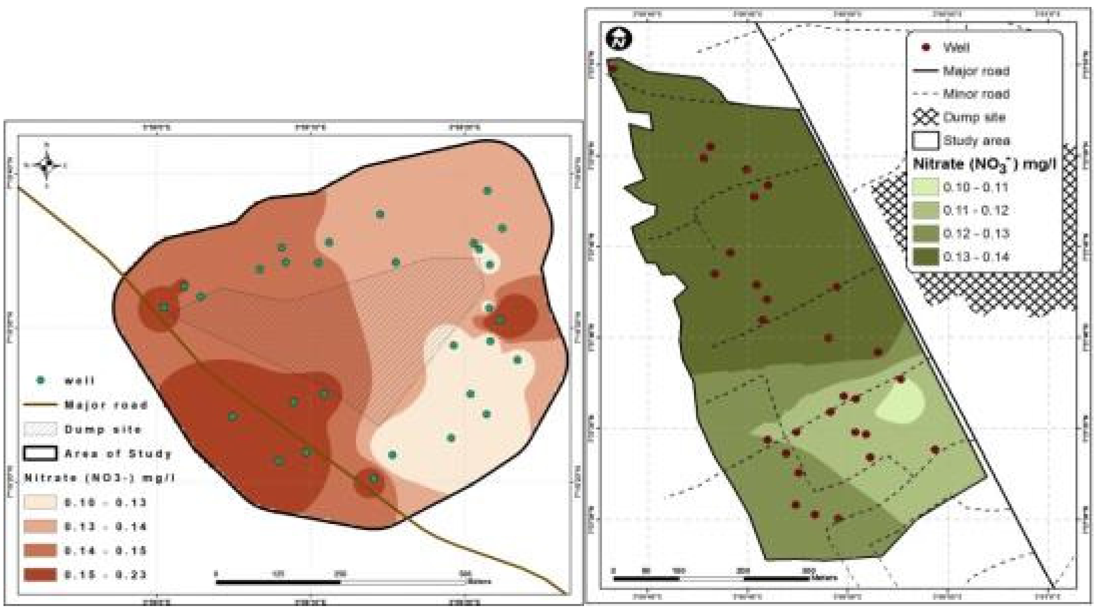

Fig. 8: Spatial variation in Nitrate-Nitrogen of groundwater around Akanran and Awotan dumpsites

Biochemical Oxygen Demand (BOD)

The distribution of BOD_5 which is an indication of organic load in the groundwater system is shown in Fig. 9. Whereas the level of organic load in samples from Akanran (D1) are relatively higher than the Awotan (D2) groundwater systems, the pattern was seen to decrease along the slope (W-E in D1 and N-S in D2). The level of organic load in the groundwater is too high for drinking water. This shows that groundwater system within the study areas are not fit for drinking with the level of organic load observed. The organic load is significantly higher than the maximum expected ($p<0.05$) (Table 2).

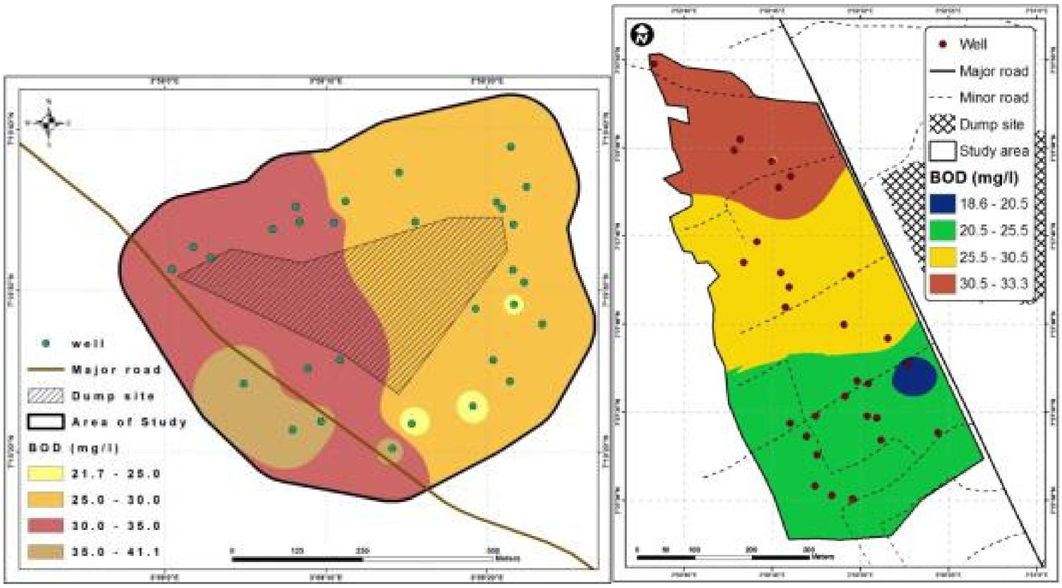

Fig. 9: Spatial variation in $BOD_5$of groundwater around Akanran and Awotan dumpsites

Heavy Metals

The spatial distributions of Fe, Cd and Cu in sampled groundwater system within the D1 and D2 environs are shown in Figs. 10 – 12. The impact of slope and distances from the dumpsites were major on the level of heavy metals in the sampled water as it was characteristics of the other variables investigated. As it was observed (Table 2), the level of Fe and Cr in the groundwater systems of the locations were not significantly different while Cd was higher than the maximum value.

The maps showed that higher concentration were found the East and decreases to the West in D1 following the direction of the land slope. This is also similar to the North – South direction it follows in D2.

Iron

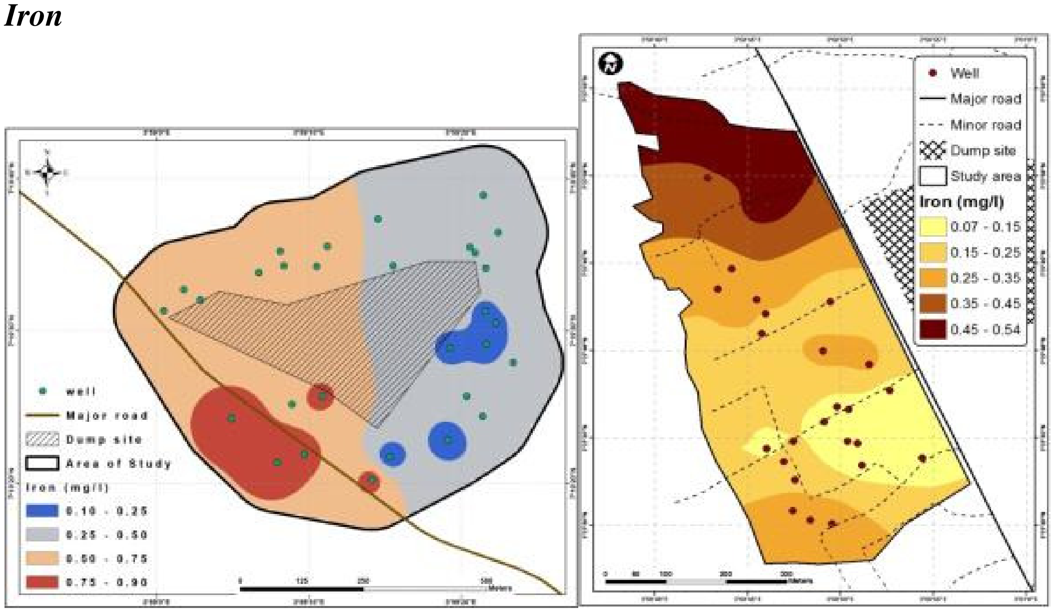

Fig.10: Spatial variation in Fe of groundwater around Akanran and Awotan dumpsites

Cadmium

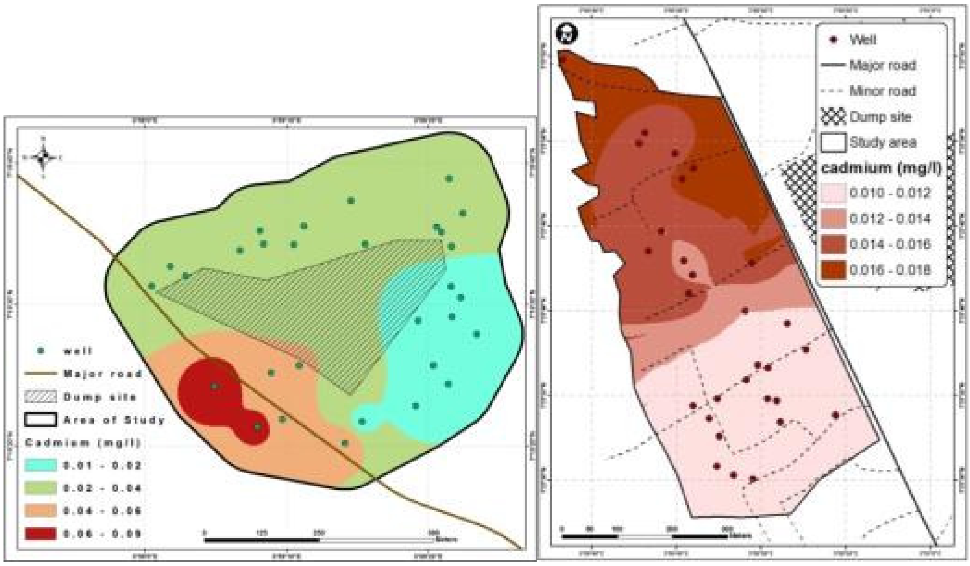

Fig. 11: Spatial variation in Cd of groundwater around Akanran and Awotan dumpsites

Copper

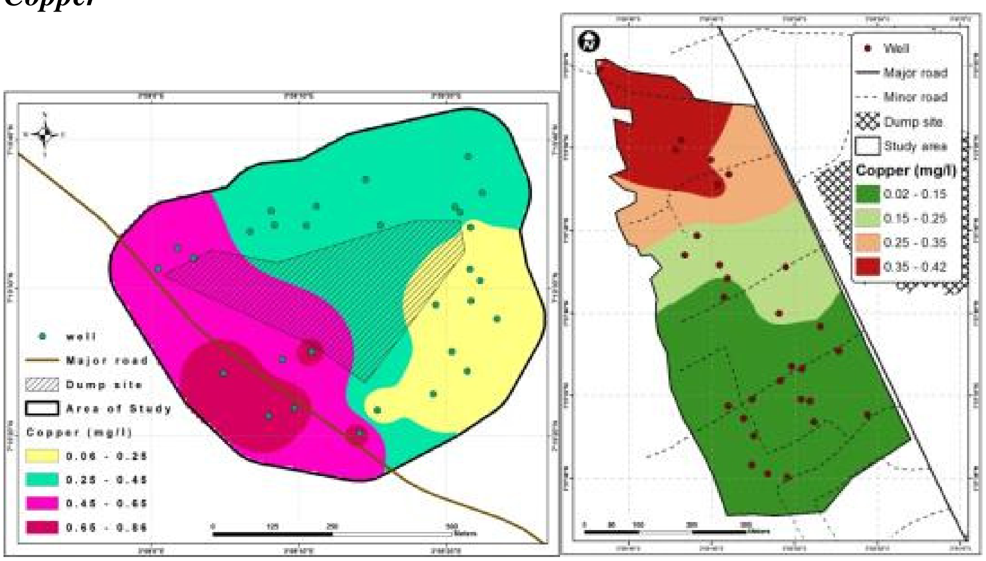

Fig. 12: Spatial variation in Cu of groundwater around Akanran and Awotan dumpsites

GIS Maps: Decision Support Tools

The leachates movement was found to be dependent on the slope characteristic of the dumpsite. Leachate flow in 2D, (laterally and longitudinally) was generally pronounced. The influence of soil characteristics can be seen in the heterogeneity of some of the variables such as nitrate, total dissolve solid, pH and total hardness. This same pattern was observed with the level of heavy metals investigated. The BOD_5 level however followed a N-W pattern in the 2 sites which shows that the movement of organic materials was more influenced by the topography. The spatial analysis using GIS has further strengthened the standard practice that wells should not be dug near contamination sources. The sampled sites were all within between 10

– 50m to the end of the dumpsites and yet the impacts of the leachates from the sites were noticeable in the level of pollutants discovered in the sampled wells. Dumpsites should be dug to a reasonable depth also be properly lined and covered. Moreover, water from the well should be treated before being consumed. Currently, in all the sampled well, there are no further water treatment before domestic use. This potent great danger for inhabitants of these areas. They depend on the shallow wells for domestic use without any form of treatment (Kolade, 1993). These corroborate the work of Sangodoyin (1993) on the danger of siting groundwater well near dumpsites as primary pollutants. Higher levels of pollutants have been observed from rivers draining pollution sources than in groundwater within the same environs (Sangodoyin, 1989). The use of GIS spatial analysis tools has enabled the production of maps to show the distribution of water quality pattern across the groundwater resources around the dumpsites. The parameters will enable the groundwater prospecting experts to be guided in the distances to be observed away from the dumpsite for fairly safe water quality to be ascertained.

The map is a decision support tool for the location of wells. It gives information of what is expected within the study area in terms of the level of investigated pollutants and the quality status of water within the groundwater systems.

Conclusion

Groundwater wells should be dug far away from contamination sources such as dumpsites and dug to a reasonable depth. It should also be properly lined and covered. Moreover, water from these wells should be treated before being consumed. It is highly recommended to use GIS as a tool to communicate tragic water quality situations to stakeholders in risky environments like the study area. Constant water quality monitoring with GIS should be encouraged to effectively analyze the impact of dumpsites on the environment and human health across the state and the nation at large.

Sustainable and healthy waste disposal practices have to be employed urgently in studied areas and in Nigeria at large.

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