Hydrological Vulnerability Assessment of Landfill Site Using GIS: A Case Study of Alimosho Landfill Site

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Abstract

Solid wastes are disposed in landfills where it decomposes and produces leachate that can contaminate underlying groundwater. This study investigated the effects of open landfill sites on the underground water quality using the DRASTIC L model based on eight parameters. Water samples were collected using systematic random sampling method from hand-dug wells around the Solous landfill sites in Igando, Alimosho Local Government Area of Lagos State and analysed. A total of thirteen hand-dug wells were sampled at increasing distances from the landfill site and analyzed for heavy metals. A GARMIN GPS was used to record the latitude and longitude of sampling points which were subsequently imported into a GIS environment and parameters integrated to analyse for vulnerability sensitivity. The results showed that out of a total area of 166.657 hectares under study, about 54.013 hectare were found to be within the low vulnerable zone with a DRASTIC index range between 101 - 123, about 52.225 hectares were observed to be in the moderately vulnerable zone with an index ranging between 123 and 135. About 60.417 hectares were located in high vulnerability zone with an index ranging between 135 and 154.The result of the water analysis showed that Zinc had the highest concentration; Chromium was not found present in any of the wells sampled. It is concluded, that the groundwater in the study area has been contaminated. There is therefore the need for adequate and proper planning and strategic management for disposal of waste within the study area.

Keywords: Landfill, leachate, vulnerability mapping, infiltration, dumpsite, GIS, DRASTIC, groundwater, pollution

Introduction

According to (Smith, & Edger, 2006), water is said to be the most abundant environmental resource on planet earth, however, its accessibility is dependent on its quality, quantity and availability. It may be available in various forms and quantity but its usefulness for various purposes is highly dependent on its quality. The human body consists of 70% water while 60-70% of plant cells are made up of water (Smith, & Edger, 2006).

Diseases are likely to spring up through water pollution, especially groundwater contamination, which can rapidly spread beyond human expectation because of its flow mechanism (Afolayan, *et al.,* 2012). Water is one of the major factors that make this planet we live in habitable for humans. Since water forms the major component of plant and animal cells, it is the basis of life and therefore its quality cannot be neglected.

The rapid growth of cities in the developing world in recent times has resulted in increased consumption of resources to meet the growing demands of urban population and industry. This has led to generation of large amounts of municipal solid waste which are collected and disposed in sites designated as landfills. The waste on these landfill sites leaks and this leakage is capable of polluting the underground water. The landfills are made up of a variety of hazardous chemicals, contaminants and non-contaminants, which constitute a threat to groundwater quality (Imoke & Effiong, 2011). When rain drops and infiltrates the soil, harmful substances from these landfills find their way into ground water, thereby polluting the aquifer and making it unhealthy for domestic and other purposes. A release of leachate to underground water poses several risks to human health, destruction to the environment, and increases toxicity in the environment. The toxicity in the environment is affected by the underlying materials of the landfill sites, the hydraulics of the groundwater system and the chemistry of the leachate (Carter and Parker, 2009). The aim of this study to determine hydrological vulnerability assessment of Solous landfill sites in Igando, Alimosho Local Government Area of Lagos State, Nigeria; identify locations of well points that are vulnerable due to the land fill sites and apply DRASTIC L model to analyse hydrological impart of the landfill in the study area.

The DRASTIC model is a method developed by the service of the American Agency of environmental protection USEPA (Aller, *et al.,* 1987) which estimate the potential for pollution and assesses the vertical groundwater vulnerability (Secunda, *et al.,* 1998). This model takes into account most of the hydrological factors that affect and control the flow of groundwater (Muhammad, *et al.,* 2015). The seven index weighing parameters from the word 'DRASTIC' are: D - Depth of water table, R - recharges (net), A - Aquifer media, S - Soil media, T- Topography, I - Impact on vadose zone, C – Conductivity. The eighth parameter is Distance (L) which is the addition that makes the model to be modified to DRASTIC L. In this study, DRASTIC L model was used because it combines the model with distance to landfill site to reflect its peculiarity for the landfill site.

Materials and Methods

Study Area

The study area (shown in Figure 1) is located in Lagos, Nigeria. The area is bounded in the North and West by River Owo and IfakoIjaiye, Agege respectively. It is bounded in the East by Ikeja Local Government Area while it is bounded in the South by Oshodi/Isolo, Amuwo-odofin and Ojo local Government Area. The study area, Alimosho Local Government Area is the largest local government in Lagos state within latitudes 6°33’46” N and 6°39’54”N and longitudes 1°41’7” E and 1°48’32” E. It has a total population of 1,362,077, land area of 185 km2 with average density of 713 persons per square kilometre approximately. The study area has a temperature range of 28 0C to 33 0C. It is characterized by swamp forest and coastal plains especially in the riverine and coastal parts. The subsurface geology reveals two basic lithologies; clay and sand deposits. These deposits may be inter-bedded in places with sandy clay or clayey sand and occasionally with vegetable remains and peat (Ayolabi & Peters, 2005).

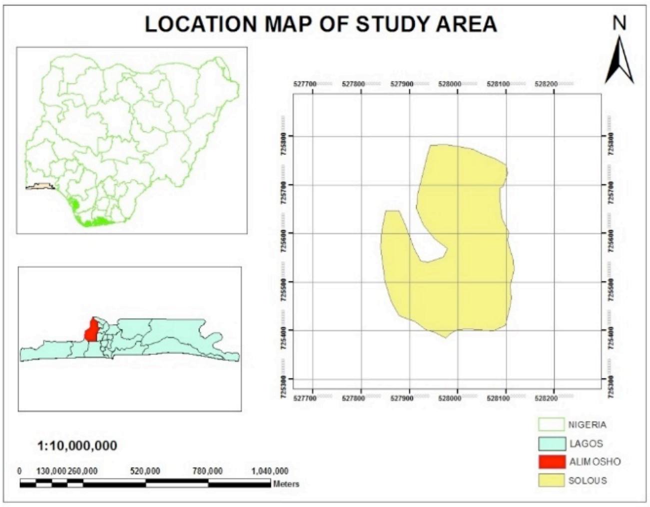

Figure 1: The Study Area

Data Acquisition

A preliminary inspection of Solous landfill site in Igando Local Government to obtain geographical information and similar data prior to a detailed survey was conducted. A GARMIN GPS was used to record the latitude and longitude of sampling points, which were imported into the ArcGIS environment. Topographical data for this research was collected from the Office of Surveyor General of Lagos State. The meteorological data (daily and monthly rainfall) for a period of 2000-2015 were collected from Nigerian Meteorological Agency (NIMET), Lagos State. The various data types used for this study and their respective sources are given in Table 1.

Table 1. Data Used and Sources

Data type	Sources	Output layer
Water level	Water level measurement	Depth to water (D)
Average annual rainfall	Nigerian Meteorological Agency (NIMET)	Net recharge (R)
Geology table	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Aquifer media (A)
Soil table	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Soil media (S)
Topographic data	Office of the Surveyor General of Lagos State.	Topography (T)
Geology table	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Imapact of vadose zone (I)
Hadraulic conductivity	Oluwapelumi O, Bankole T. 2013.J Environ Pro 4, 454-465	Hydraulic conductivity (C)
Distance	ArcGIS measure tools	Distance (D)

Data Processing

Eight parameters were weighted and rated according to their relative susceptibility to the pollutant and relative contribution to the potential contamination. Modified DRASTIC (DRASTIC L) assigns weights and ratings to each of the eight parameters, each is classified into classes on the scale of 1-10, in which one (1) denotes least vulnerable while (ten)10 most vulnerable areas. This rating was further scaled into weights (1-5) based on the importance of the parameter in determining aquifer characteristics. Weight one (1) is least significant and weight five (5) is most significant. The ratings and weights of the eight parameters are shown on Table 2. (Table 2).The coordinate of the entire sample were imported into ArcGIS 10. Interpolation was performed by using inverse distance weight (IDW) to covert the table to raster for effective processing. The area of interest (AOI) was extracted from the boundary shapefile. The extracted raster was reclassified (Table 2) and the rate (R) and weight (W) added for further analysis of other parameters (Figure 2).

Table 2. Ratings and Weights of Eight DRASTIC L Parameters

Drastic L Parameter	Range	Ratings	Drastic L Weight
Depth to water (m)	0 - 2 2 - 10 10 - 20 20 - 40 40 - 60 >60	10 8 6 4 2 1	5
Net recharge (mm/yr)	800 - 900 901 - 1000 1001 - 1100 1101 – 1200 1210 – 1300 1301 – 1400 1401 – 1500 1501 – 1600 1601 – 1700	1 2 3 4 5 6 7 8 9	4
Aquifer media	Sandy clay Silty sand & sand Sand, gravel and sandy clay Sand Sandy gravel Gravel	1 2 4 6 8 9	3
Soil media	Clayey loam soil Clayey soil Silty clay loam soil Silty loam Sandy clay loam soil Sandy clay soil Sandy loam soil Cliffs	2 3 4 5 6 7 8 9	2
Topography	1 – 2 % 2 – 6 % 6 – 12 % 12 – 18 %	10 9 5 1	1
Impact of vadose zone	Confined aquifer Sandy clay and sand Sand	1 5 6	5
Hydraulic conductivity	$1 \times 10^{-6} - 5 \times 10^{-5}$ $5 \times 10^{-5} - 2 \times 10^{-4}$ $2 \times 10^{-4} - 4 \times 10^{-4}$ $4 \times 10^{-4} - 5 \times 10^{-4}$ $5 \times 10^{-6} - 1 \times 10^{-3}$	1 2 4 6 8	3

Distance from landfill site (m)	350 – 500	1	4
	500 – 600	2	
	600 – 700	3	
	700 – 800	4	
	800 – 900	5	
	900 – 1000	6	
	1000 – 1100	7	
	1100 – 1250	8	
	1250 – 1350	9	
	1350 – 1450	10	

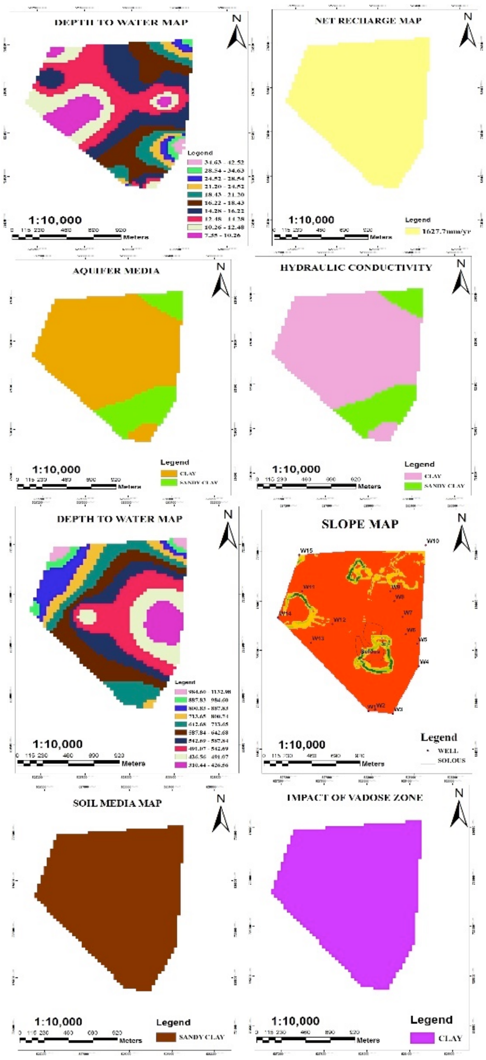

Figure 2. Map showing all the Eight Vulnerability Index

Final Vulnerability Map

The DRASTIC vulnerability index (DVI) was calculated by linear addition of the weights and rating of each factor of vulnerability using the command lookup in ArcGIS raster calculator. The ArcGIS raster calculator is given by the following formula:

$$DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw+LrLw \qquad (1)$$

Dr=depth rating
Dw=depth weight
Rr=net recharge rating
Rw=net recharge weight
r=aquifer rating
Aw=aquifer weight
Sr=soil rating
Sw=soil weight
Tr=topography rating
Tw=topography weight
Ir=impact of vadose zone rating
Iw=impact of vadose zone weight
Cr=hydraulic conductivity rating
Cw=hydraulic conductivity weight
Lr=distance rating
Lw=distance rating

The final vulnerability map was then produced by adding all the factors of vulnerability together in equation (1). Figure 3 shows the vulnerability map.

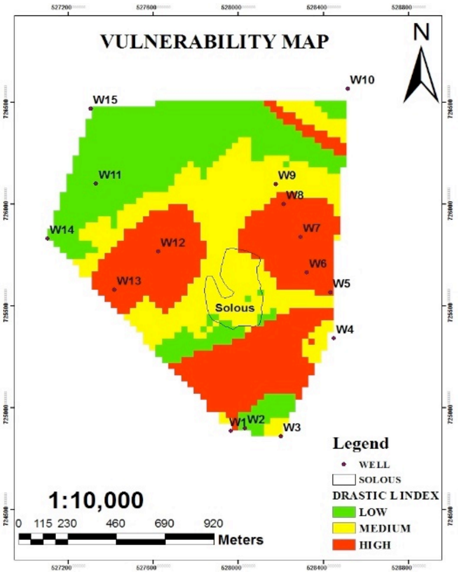

Figure 3. Vulnerability Map

The DRASTIC index values indicates that a range between 101 and 123 is considered to have low vulnerability, while a range between 123 and 135 indicates moderate vulnerability. An area is considered to be highly vulnerable if its range falls between 135-154 indexes.

Data Sensitivity Analysis

The sensitivity analysis is performed to clear the doubt of the argument of certain scientists who believe that groundwater vulnerability can be worked out without using all the parameters of DRASTIC L model. Some others have also in their opinion said the rating and weight are subjective and there is reason to doubt the accuracy of the DRASTIC L model.

In the first instance the rated parameters of the model have been examined for interdependence and variability as a high degree of interdependence of the parameters may lead to the risk of misadjustment (Babiker, *et al.,* 2005; Rosen, 1994).

There are two sensitivity analyses tests.

The first test identifies the sensitivity of vulnerability map by removing one or more layer maps and is worked out using the following equation:

S=100*((V/N-V^'/n)/v) (2)

where S is the sensitivity measure, V and V^'are the unperturbed and the perturbed vulnerability indices respectively, and N and n are the number of data layers used to compute V and V^'. The unperturbed vulnerability index is the actual index obtained by using all seven parameters and the perturbed vulnerability index was computed using a lower number of parameters. The second sensitivity analysis test is the single parameter sensitivity test, carried out to assess the influence of each of the seven parameters of the model on the vulnerability measure. In this analysis, real or ‘‘effective’’ weight of each parameter was compared with its assigned or ‘‘theoretical’’ weight. The effective weight of a parameter in a sub-area was calculated by using the following equation:

W=(PrPw/V)*100 (3)

Where W refers to the “effective” weight of each parameter, Pr and Pw are the rating values and the weight for each parameter. V is the overall vulnerability index.

Groundwater Test from Wells for Model Check

Wells are hand dug or machine assisted dug holes in the ground to locate the presence of drinking water. These wells are sometimes used directly or as boreholes and connected by pipes to households. Previous studies have shown that wells sometimes contain heavy metals above the accepted standard for drinking water quality (Chowdhury, *et al.,* 2016). The ground water contamination analysis was carried out by taking samples of water from 13 wells in the study area during the month of August 2017. The metals that were analyzed include Lead (Pb), Zinc (Zn), Chromium (Cr) and Copper (Cu). The analysis was carried out to compare the experimental results with the contamination vulnerability index levels as shown by the overall vulnerability map prepared using the DRASTIC L model. The test was performed at the University of Lagos Central Research Laboratory where they were analyzed for metals with Atomic Absorption Spectrometer (AAS). Atomic Absorption Spectrometer is used for the quantitative determination of chemical elements using the absorption of optical radiation (light) by free atoms in the gaseous state. The technique is used for determining the concentration of a particular element (the analyte) in a sample to be analysed (Welz & Sperling 1999). Samples were preserved at 4oC and analysis was carried out within seven days of sample collection. Metal analysis was carried out by taking 50 ml of the water sample into a 250 ml conical flask, 10 ml of aqua regia was added and the mixture was evaporated on a hot plate in the fume cupboard to dryness. The sample was reconstituted with 25 ml of deionized water and filtered with a filter paper and funnel for AAS metal analysis.

The Nigerian Standard for Drinking Water Quality (NSDWQ) was approved by the Council of the Standards Organization of Nigeria in 2007. It specified the upper and lower limits of contaminants known to pose a risk to the wellbeing of individuals. It also provides a comparison of the World Health Organization's standard of water quality with that of the Nigerian Standard for Drinking Water Quality. Minor differences exist between World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). [11].

Result

Vulnerability Result

The results of this study shows that out of the total area of 166.657 hectares, about 54.013 hectares were found to be within the low vulnerable zone with a DRASTIC index range between 101 - 123, about 52.225 hectares were observed to be in the moderately vulnerable zone with a DRASTIC index value ranging between 123 and 135 while about 60.417 hectares were in the high vulnerability zone with a DRASTIC index ranging between 135 and 154.

Statistical Analysis of the Vulnerability Map Result

Statistical analysis was performed on the DRASTIC L index produce for the vulnerability map, the result is stated on Table 3.

Table 3. A Statistical Summary of the DRASTIC L Parameter Maps

	D	R	A	S	T	I	C	L
Min	1	9	1	3	1	1	1	1
Max	10	9	6	3	10	1	6	10
Mean	5.5	9	3.5	3	6.25	1	3.5	5.5
SD	2.87	0	2.5	0	3.6	0	2.5	2.87
CV (100%)	52.18	0	71.42	0	57.6	0	57.6	52.18

Min = Minimum, Max = Maximum, SD = Standard Deviation, CV = Coefficient of Variation

A close observation of the statistical Table 3 shows that the coefficient of variations indicates that a high contribution to the variation of vulnerability index is made by aquifer media (71.42%), then topography and hydraulic conductivity (57.6%), Depth and distance contribution was (52.18%) while net recharge, soil media, impact of vadose zone, had no contribution to the variation of the vulnerability index.

Groundwater Contamination Analysis Result

The purpose of this analysis is to assess the relationship between the ground water vulnerability map and heavy metal concentration in the ground water. A total of thirteen hand-dug wells were sampled at increasing distances from the landfill site and analysed at Central Research Laboratory of the University of Lagos for the presence of heavy metals.

Table 4: A Statistical Summary of the Analysis Results

Description	**Wells**	**Cu (mg/L)**	**Pb (mg/L)**	**Zn (mg/L)**	**Cr (mg/L)**
NSDWQ		1.00	0.01	3.0	0.05
WHO		2.00	0.01	NS	0.05
53, Olofin Street	(W1)	0.31	0.001	2.73	ND
4, Adesolarin Street	(W2)	0.13	ND	2.03	ND
23, Oremeji Street, Igando	(W3)	ND	ND	2.53	ND
14, Olorunsogo Street	(W4)	0.46	ND	2.53	ND
8, Kayode Onafinyin	(W5)	ND	ND	3.51	ND
38, Olofin Street	(W6)	0.12	ND	2.47	ND
8, Itoko Avenue	(W7)	0.03	ND	2.62	ND
52, Rafiu Odebiyi	(W8)	0.35	ND	2.71	ND
2, Rafiu Odebiyi	(W9)	0.63	ND	2.54	ND
2, Akandi Salisa	(W10)	0.40	ND	3.39	ND
54, Otunba Bamidele	(W11)	0.12	ND	2.05	ND
6, Alafia Street	(W12)	ND	ND	2.41	ND
Total filling Station	(W13)	0.58	ND	4.45	ND

Note. NSDWQ Values are the maximum permitted levels in the Nigerian Standards for Drinking Water Quality, ND- Not detected, NS- Not supplied. WHO values are the maximum permitted levels in the WHO Drinking Water Quality Guideline.

It can be seen from the result in Table 4 and Figure 4, that the concentration of Copper (Cu) was below the WHO and NSDWQ standard of 3.0 mg/L, However, wells 4, 9, 13 reported a higher concentration when compared to others.

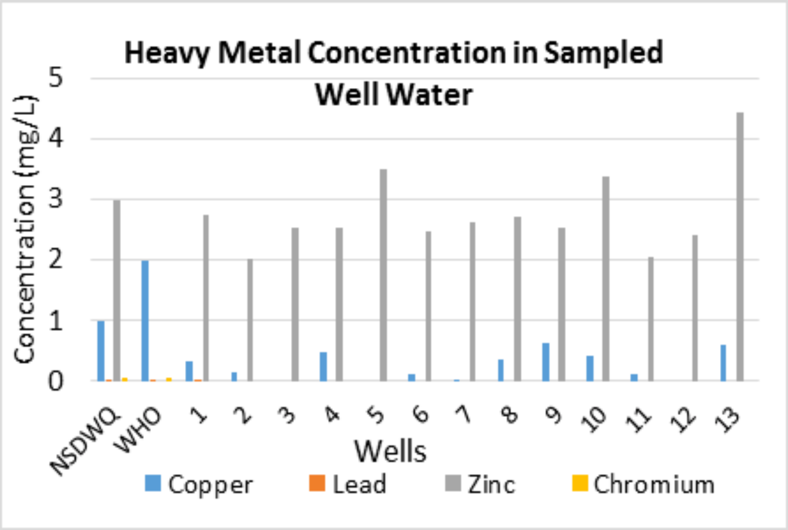

Figure 4. Heavy Metal Concentration in different Wells within the Study Area.

Lead (Pb) is regarded as a heavy metal, which can be poisonous to animals including humans. Lead is usually found in ore together with other metals including silver, copper, zinc and gold. Lead was only detected in well 1 and was not beyond WHO and NSDWQ standard (Table 4).

Zinc (Zn) is an essential mineral with exceptional biologic and public health importance. However, concentrations in humans above the optimum level can be toxic and can result in adverse biological effects. Zn was reported to be above the acceptable limit in well 5, 10, and 13 (Figure 4) of the study area; while others were within the acceptable limit. Chromium was tested for but was not found present in any of the wells sampled (Table 5).

Table 5. Descriptive Statistics of Metal Concentrations in Ground Water Samples

Parameter(mg/l)	**Mean**	**Standard Deviation**
Copper	0.313	0.2087
Lead	0.010	0.000
Zinc	2.766	0.660
Chromium	0.000	0.000

Discussion

In this research study, the DRASTIC L index was used to assess the hydrological vulnerability of landfill site in Alimosho Landfill Site area of Lagos in a GIS environment as also used by other researchers (Zhou, *et al.,* 1999; Afolayan, *et al.,* 2012). It was observed from the results of the statistical analysis that the mean for the recharge was 9. This value was the highest contribution to the vulnerability index, followed by topography with a mean value of 6.25. Depth and distance was 5.5, a moderate contribution to the vulnerability index, while aquifer and hydraulic conductivity contributed 3.5 to the vulnerability index. The lowest contribution was observed by the impact of vadose zone with a value of 1. The coefficient indicates that a high contribution to the variation of vulnerability index is made by aquifer media (71.42%), followed by topography and hydraulic conductivity (57.6%), Depth and distance contribution was (52.18%) while net recharge, soil media, impact of vadose zone, have no contribution to the variations of the vulnerability index. Findings from all these parameters agree with (Alaa & Ayser, 2014).

The area under study has a total coverage of 166.657 hectares out of which, about 54.013 hectares is in the low vulnerable zone with a DRASTIC index range between 101–123; about 52.225 hectares are in the moderately vulnerable zone with a DRASTIC index ranging between 123 and 135. About 60.417 hectares are in the high vulnerability zone with a DRASTIC index ranging between 135 and 154. The resultant vulnerability map was subdivided into three classes in relation to each degree of vulnerability according to the classification, this agrees with (Engel*, et al.,* 1996). It was discovered from the result that about 32.409% of the study area has low degree of vulnerability, while 31.339% of the area has moderate degree of vulnerability. About 36.252% of the study area is reported to be highly vulnerable and this is due to the landfill site.

It was observed that wells 15, 10, 11, 14 and 2 are within the low vulnerable zone while wells 9, 4 and 3 are seen to be within the moderate vulnerable zone. Wells 13, 12, 8, 7, 6, 5 and 1 are reported to be located in the highly vulnerable zone.

Findings from this study have shown that there seems to be some relationship between the location of these wells and the test results of the water analysis. Certain physical parameters like taste, colour and odour can serve as main indicators for assessing the quality of drinking water. It can also serve as indicators of water pollution, without taking into consideration other physical, chemical and biological variables of water. This research tested sampled underground water for presence of heavy metals. The results obtained agree with groundwater chemistry of the neighboring communities of Oregun, Ketu and Ojota, which were reported by (Oyeku & Eludoyin 2010). Copper (Cu) was not found to exceed the WHO and NSDWQ acceptable limit in all sampled wells, Although, wells 4, 9 and l3 had higher concentrations of 0.46 mg/L, 0.63 mg/L, and 0.58 mg/L respectively when compared to other wells.

Lead (Pb) was detected in Well 1 only with a concentration level of 0.001 mg/L and was not beyond WHO and NSDWQ limit, although its location is within the high vulnerable zone of map index result.

Zinc (Zn) was found to be beyond the NSDWQ acceptable limit of 3.0 mg/L in wells 5, 10, and 13. Well 5 (3.51mg/L) and 13 (4.45mg/L) are within the high vulnerable zone of the vulnerability map, however, well 10 (3.39mg/L) is not, rather it is located within the low vulnerable zone, yet the test result reported its concentration to be above the approved NSDWQ standard. Well 13 is located within a gas filling station and this may be reason it accounted for high level of Zn concentration.

Chromium (Cr) was not detected throughout in all the water samples tested in the study area.

Conclusion

This study has shown that landfill sites contaminate ground water and thereby compromise the quality of drinking water from wells in surrounding regions. Also, this study has shown that increasing distance from the landfill do not necessarily reduce the concentration of heavy metals presence in the wells as can be clearly seen in Well 10 which is located within a low vulnerable zone of the vulnerability map. It can be concluded therefore, that not all wells in the study area are within the acceptable WHO and NSDWQ standard for drinking water, hence a careful alternative is recommended.

Acknowledgments

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