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Pollution vulnerability and health risk assessment of groundwater around an engineering landfill in Lagos, Nigeria

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A B S T R A C T

Solid wastes disposal, through the use of non-sanitary landfill facility has tremendous health impacts on man and environment, yet without regard to environmental consequences, the use of controlled dumpsite is at best a common practice in underdeveloped countries. The paucity of data on modelling of potential vulnerability of neighboring aquifer to the pollution from Soluos dumpsite (a non-engineering landfill) necessitate the study of the use of a model DRALTC (modified DRASTIC) on the estimation of vulnerability of groundwater to dumpsite pollution and associated health risks. Six hydrogeological factors: Depth to water, net recharge, aquifer media, distance of wells to dumpsite, topography, and clay content, were involved in the modification of the model (DRALTC) which helps in characterizing the hydrogeological setting of the study area and estimation aquifer vulnerability. Sodium adsorption ratio (SAR) and permeability index (PI) were used to analyse the data generated in this study. The health risk indices (HRI) were also estimated for trace metals in the groundwater samples. The pollution vulnerability ranged between (161 and 175) moderate and high groundwater pollution potential. SAR results observed in this study reveal 25% excellent, 20 % good, 10% doubtful and 45% unsuitable. The order HRI observed was Cd > Zn > Cu > Ni > Pb for adult, while Cd > Cu > Ni > Zn >Pb trend was found for children, though the HRI value for all the metals investigated were within the safe limit (HRI < 1.0) suggesting no health risk.

Capsule Summary: This study reveals the groundwater pollution (based on depth to water, net recharge, aquifer media, distance of wells to dumpsite, topography, and clay content) vulnerability ranging between moderate and high potential. Sodium adsorption ratio results observed was 25% excellent, 20% good, 10% doubtful and 45% unsuitable. The Health Risk Index for all the metals investigated was within the safe limit.

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INTRODUCTION

Good and sound management of municipal solid wastes (MSW) is of major environmental interests across the world. Dumpsite (an engineering landfill) pollution has been identified as one of the major threats of groundwater resources (Singh et al., 2008). Osibanjo and Majolagbe (2012), conducted a study on the influence on land use pattern in Lagos, confirming solid wastes as the worst of various sources of pollution threatening the groundwater quality. The amount of municipal solid wastes generated globally is projected to increase to 27 billion tons by the year 2050 (MOE, 2009), out of which Lagos, Nigeria generate 12,370 tons of MSW/day (LAWMA, 2011). Solid wastes are of different origin: industrial (this contains much more toxic pollutants, trace metals and organic Ikem et al., 2002), domestic, Agricultural and street sweep.

Improper method and practice, as well as non challance towards waste disposal, affect quality of life, creating problems in public health and environment (Ravi-kumar, 2009), particularly in developing countries. The inefficient and inadequate law (legislation) guiding disposal methods practiced by relevant agencies is another major setback in the handling of municipal solid wastes (Nema, 2004). The process and facilities involved in the storage, collection, sorting, transportation, treatment and disposal of wastes vary from one nation and regions to another. Cultural awareness and belief, organizational abilities, level of technical knowhow and government wastes management policies are some other factors influencing world of MSW disposal practices.

Historically, dumpsite remains the simplest, the most cost effective and common method of organized wastes disposal around the world (Wikipedia, 2013). In most developing countries of low and medium income, almost 100% of the wastes generated goes to dumpsite (Longe and Balogun,2010), 90% of the MSW from India are disposed unscientifically (TETRI, 1998), more than 75% of solid wastes generated in more than half member states of European Union are sent to dumpsite (EEA,2005) and 138 million tons of 251 million tons of MSW generated in USA was landfilled as well as 82.9% of the wastes were dump sited in Ireland (EHS,2005).

There have been several classifications of dumpsite by various countries based on different parameters such as type of wastes deposits, types of liner used and the construction design of the dumpsite. Dumpsite is however, generally grouped into open dumpsite, controlled dumpsite (an engineering landfill) and Sanitary dumpsite (an engineered landfill). Sanitary dumpsites are highly engineered containment system, where wastes is Isolated from the environment. This environmental friendly landfill system involves full or partial hydrogeological isolation, formal engineering preparation, permanent controls and planned waste emplacements and coverings (Kerry et al., 2007; UN-Habitat, 2010; Majolagbe et al., 2011). However, the best wastes disposal facility still in practice in many developing nations like Nigeria is controlled dumpsite (engineering landfill) which is an intermediate stage between open dump and sanitary dumpsite. The engineering landfill (controlled dumpsite) option does not isolate the immediate environment from impact of pollutant emanating from dumpsite, hence the need to constantly monitor the environment especially the groundwater.

Various techniques have been extensively used in groundwater quality assessment and monitoring. These techniques include: modeling (Magnus *et al.,* 2011), geophysical method (Adepelumi *et al.,* 2008; Adegbola *et al.,* 2012), and the use of water quality indices (Srinivas and Nageswararao, 2013). However, the application of computer based approach (modeling) is now gaining popularity among researchers (Ojuri and Bankole, 2013).The modelling options have provided solutions to some of the limitation in the aforementioned techniques. This study is therefore designed to use a model (modified DRASTIC model) to evaluate potential groundwater vulnerability to pollution from Solous dumpsite in Lagos, Nigeria and the associated health risk.

MATERIAL AND METHODS

Description of study area

The Solous dumpsite is a controlled dumpsite (engineering landfill) situated within the longitude 3^{o}26 E to 3^{o}25 E and latitude 6^{o}56N to 6^{o}57 N in Igando, Alimosho Local Government Area of Lagos state (Figure 1.0). It started operations in the year 1991 with a projected lifespan of between 5 and 6 years. However, it has been serving for more than twenty (20) years. It is dubbed as Solous 1, as three other relatively newer and smaller refuse dumpsites have been opened very close to the old one (Solous 1). It receives about 4000 tons of waste per day and covers an area of about 5 hectares of land with a waste depth of about 9 m and has reached over 70% of its full capacity (Aboyade, 2004). The dumpsite is surrounded by residential areas, an abattoir and a small fast shrinking Oba stream, located about 2.5 km east ward of the dumpsite.

Sampling, chemical and microbiological analyses

Forty (40) water samples were collected from twenty different wells around Solous dumpsite
bimonthly, for two consecutive years and analysed for various physicochemical parameters using
standard procedures. Ten (10) groundwater samples were also collected for microbiogical analysis following standard procedures.

Chemical analyses

The pH (pH meter, pHep HANNA HI 98107), electrical conductivity (Mettler Toledo) and temperature (thermometer, 0 - 100 ^{o}C) of the water samples were

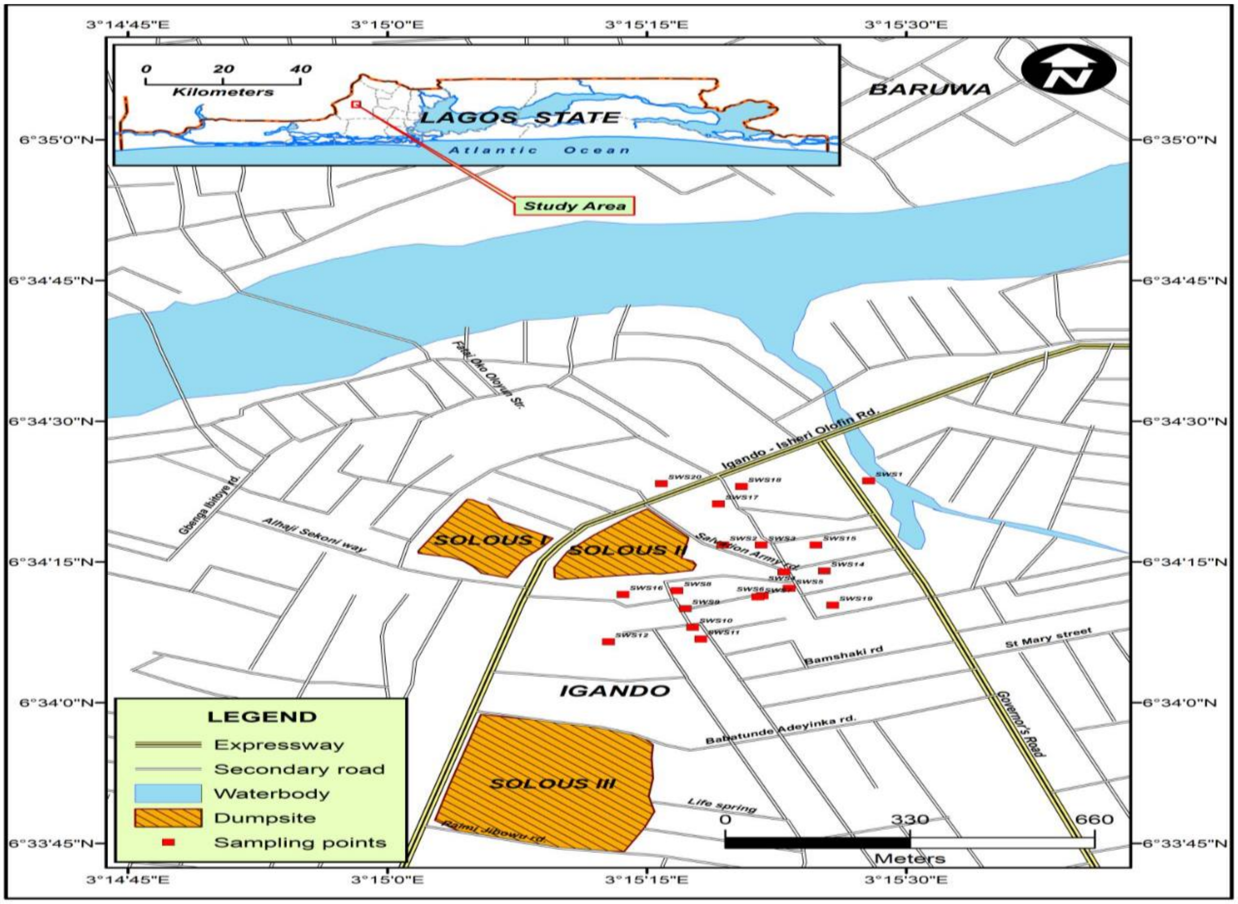

Fig. 1: Sampling locations around Solous dumpsite Igando, Lagos

determined in-situ. Alkalinity, acidity, Total hardness, Total suspended solids (TSS), total dissolved solids (TDS), total solids (TS), chloride, sulphate, phosphate and nitrate were determined using American Public Health Association methods (APHA,2005). Na^+ and K^+ were estimated with flame photometer, and other trace metals analysis was carried out employing Flame Atomic Absorption Spectrophotometry (Buck scientific 210VGP model).

Microbiological analysis

Microbiological quality of groundwater samples was also investigated using standard plate count (SPC), and coliform count using most probable number (MPN) analyses (ISO, 2004). For standard plate count (SPC), 1.0 ml of water sample was added unto solidified nutrient agar. The inoculated plates were incubated at 37 °C for 48 hours after which discrete bacteria colonies were counted. For coliform count, 50.0 ml of water sample was added into 1 tube containing double strength medium, 10.0 ml into 5 tubes containing single strength medium, 10.0 ml of water sample was added into 5 tubes containing single strength medium and 0.1 ml of water sample was added into 5 tubes containing single strength medium. All these tubes had inverted Durham tubes in them and these were incubated at 37 °C for 48 hours. After 48 hours, the broth tubes were examined for gas formation and colour change. Positive tubes showed gas formation in the inverted Durham tubes and colour change in the medium was from pink to yellow. Presumptive coliform count was obtained by making a reference to the Mac Grandy probability table (Gillet et al., 2009).

A drop of culture from the tube showing positive presumptive test was streaked on EMB agar plates and incubated at 37 °C for 24 hours. The plates were observed for growth. The appearance of nucleated colonies within 24 hours indicated a positive test. Isolated colonies from the EMB agar plates were transferred into lactose fermentation broth streaked unto agar slant and then incubated at 37°C for 48 hours. Each sample was analyzed in duplicate.

The use of borehole exploitation logs and soil survey reports

Various sources of data were used of in the course of this study as captured by Ojuri and Bankole (2013). These sources include borehole log from Trevi Foundations Nigeria limited, T.A.E Engineering limited and the Lagos Water Corporation (LWC). Data on geology, topography and

Table 1: Relative weight of the chemical parameters

Chemical parameters	WHO standards	Weight	Relative weight (Wi)
pH	6.5 – 8.5	4	0.1818
Total hardness	300	2	0.0909
Ca	75	2	0.0909
Mg	30		0.0909
Cl	250	3	0.1363
Total dissolved solids	500	4	0.1818
Nitrate	10	5	0.2272

The calculated WQI values are classified into four types as shown in Table 2.

soil features of Lagos state were obtained from the reconnaissance soil survey of Nigeria (FDALR, 1995), while the climatic data were obtained from British Broadcasting Corporation (BBC, 2011).

Descriptive statistical analysis of data showing mean, range, standard deviation and standard error mean were carried out using Graph Pad Prism (version 5.00). Correlations coeficiency was performed employing Pearson correlation coefficient. Multivariate analyses were carried out using software package for Social Science (SPSS) window.

The degree by which some of the groundwater parameters exceed their respective WHO allowable limit is expressed in a term known as exceedance level. It is a unitless concept, expressed mathematically in Eq. 1.

$$\text{Exceedance level} = \frac{\text{Concentration of a quality parameter}}{\text{WHO acceptable limit}} \quad (1)$$

The following other international water quality indices were applied in this study so as to have a wider interpretation of field data generated.

i. Water Quality Index (WQI)

Water quality index (WQI) was calculated using three steps as described by Srinivas and Nageswararao (2013). In the first step, each of the parameters was assigned a weight (w_i) according to its relative importance in the overall quality of the water for drinking purpose. In the second step, the relative weight was calculated from the Eq. 2.

$$W_i = \frac{wi}{\sum_{i=1}^{n} wi} \quad (2)$$

Where W_i is the relative weight, wi is the weight of each parameter as shown in Table 1.0 and n is the number of parameters. In the third step, a quality rating scale (q_i) for each parameter was assigned by dividing the concentration by the respective standard according to the WHO guidelines and the result multiplied by 100 (Eq. 3).

$$q_i = (C_i - C_o / S_i - C_o) \times 100 \quad (3)$$

Where, Ci is the concentration of each chemical parameter in water sample (mg/L), C_o is the ideal value of the parameter in pure water and Si is the drinking water standard for each chemical parameter in mg/L according to the guidelines of the WHO. For pH, C_o is 7 and $q_i = (C_i - 7)/(S_i - 7) \times 100$. For the remaining parameters, the ideal value is 0. To calculate the WQI, the sub index (SI) was first determined for each parameter, which was used to determine the WQI using the Eqs. 4-5.

$$SI_i = W_i \times q_i \quad (4)$$

$$W_i = \sum_{i=1}^{n} SIi \quad (5)$$

Where, SI_i is the sub index of the i^{th} parameter.

ii. Sodium adsorption ratio (SAR)

SAR is an important parameter for determining the suitability of groundwater. It is a measure of alkali / sodium hazard to plants. SAR is mathematically defined by Subramani (2005) (Eq. 6)

$$SAR = \frac{Na}{[(Ca + Mg) / 2]1/2} \quad (6)$$

Where, all ionic concentrations are expressed in meq/l.

iii. The permeability index (PI)

These values are also used to determine if the groundwater is specifically suitable for irrigation. It is mathematically defined by Elkrail *et al.,* (2004) (Eq. 7).

$$PI = \frac{100 \times [([Na] + [HCO3]1/2)}{[Na] + [Ca] + [Mg]} \quad (7)$$

Where all the ions are expressed in meq/l

iv. DRASTIC model and vulnerability index

DRASTIC is a groundwater quality model for evaluating pollution potential of large areas using the hydrogeologic settings of a region. A hydrogeological setting is defined as a mapable unit with common hydrogeologic characteristics. There are seven hydrogeological parameters factors that made up of the acronym DRASTIC. The DRASTIC parameters influence the fate and transport of water from soil surface to aquifer. The acronym DASTIC stands for D-Depth to water, R- Net Recharge, A- Aquifer media, S- Soil media, T-Topography, I-Impact of vadose zone and C-Hydraulic Conductivity.

A modification was made on the DRASTIC model in this study so as to reflect and accommodate some peculiarities of the dumpsite area. This result in the formation of six hydrogeologic parameter based model, DRALTC. D- Depth to water, R- Net Recharge, A- Aquifer media, L- Distance of well to dumpsite, T- Topography, and C- Clay content. Each factor is then assigned a weight (w)

Table 2: Water quality classification based on water quality index value

WQI	Water quality
< 50	Excellent
50 – 100	Good
100 – 200	Poor
200 – 300	Very poor

based on its relative significance in affecting the pollution potential. The weight is further allotted a rating (r) for different ranges of values. The typical ratings range from 1 - 10 and weights are from 1 – 5 as shown in Table 3.0.

The DRALTC vulnerability Index is then computed through the summation of products of ratings and weights for each factor as follows:

DRALTC Index = DrDw + RrRw + ArAw + LrLw + TrTw + CrCw

Where, Dr = Rating to Depth to water, Dw = Weights assigned to Depth to water, Rr = Ratings for ranges of aquifer recharge, Rw = Weights for ranges of aquifer recharge, Ar = Ratings assigned to aquifer media, Aw = Weights assigned to aquifer media, Lr = Ratings to the distance from well to the dumpsite, Lw = Weights assigned to distance from well to the dumpsite, Tr = Ratings for topography (slope), Tw = Weights for topography, Cr = Ratings for rates clay content, Cw = Weights given to clay content. The vulnerability index of the study area can be classified into four groups : >190, Very High groundwater pollution potential; 160 – 190, High groundwater pollution potential; 101 – 159, Moderate groundwater pollution potential; < 100, Low groundwater pollution potential.

v. Chronic daily intakes (CDIs) of metals and health risk indices (HRI) of metals

The health risks associated with the consumption of heavy metals-in contaminated food were assessed using the Health Risk Index (HRI). The HRI is defined as the ratio of daily intake of metals (DIM) to the reference oral dose (RfD) (Eq. 8).

$$\text{HRI} = \frac{\text{daily intake of metals (DIM)}}{\text{the reference oral dose (RfD.}} \qquad (8)$$

RESULTS AND DISCUSSION

The results of physico chemical analysis of groundwater samples collected around Solous dumpsite are presented in Table 4.0,whle the vulnerability index to the dumpsite pollution is shown in Table 5.0 About twenty percent (20%) of the groundwater samples investigated had pH value within the WHO acceptable limit of pH (6.5 – 8.5) for drinking water. This portends a health risk as consumption of acidic water has been linked to several diseases conditions such as cancers, ulcer and intestinal proliferation (Klaassen et al., 1986). Chloride level of about 20% of the groundwater samples was above 250 mg/L WHO acceptable limit of Cl^- or drinking water, thereby raising doubt on potability of the water samples under investigation. The sources of chloride in groundwater include intrusion of salt water, pollution from dumpsites, effluents discharge from industries and residence as well as the source of aquifer charge.

All other quality parameters determined were majorly within the acceptable range stipulated by World Health Organisation for water except for few sampling locations. This reflect that the water samples analysed are generally of good quality. The concentrations of ten (10) trace metals namely Cu, Ni, Cd, Pb, Fe, Zn, Mg, Na, K and Ca were also determined,. All the toxic metals (Ni, Cd, Pb) were observed below their respective WHO limits. The nutritive metals (Zn, Mg, Na, K and Ca) are required to help in the functioning of animal metabolic system, but when they are existing at extremely high level, they do not contribute to any known hazard in human system. The high level of Iron observed in the groundwater samples analysed around the dumpsite is possibly due to high clay content in the soil around Solous dumpsite. The soil in Lagos, Nigeria has been reported to contain high amount of clay (Osibanjo and Majolagbe, 2012). Iron is useful in human body system but high concentration on Fe, leads to iron toxicity, a situation that that is dangerous to human health (Majolagbe et al., 2013). The degree by which some quality parameters exceed their acceptable limits is expressed as exceedance level. The exceedance levels of some of the parameters are shown in Table 4.0. The order of concentration levels of water quality parameters in relation to the non-uniform increase in exceedance value was Fe > Mg > Cd > Pb > NO_3^- - N.

The correlation coeficiency among trace metals investigated three different classes, strong correlation (r > 0.5): Ni/Cu, Cd/Cu, Na/Cu, Cd/Ni, Mg/Ni and Na/Cd; weak correlation (0.49>r>0.20): Mg/Cu, Na/Ni, Pb/Fe, Fe/Cd, Mg/Cd, K/Na, Na/Ca and Ca/Na. This observation strongly indicates a possible contribution of pollution from the dumpsite. The calculated WQI values ranged from 39.1 to 126 mg /L put the groundwater around Solous dumpsite as excellent- good – poor class using classification shown in Table 2.0. The spatial variations revealed that about 10% of the samples collected around Solus are in excellent grade; 65%, good and 25%, poor. However, some few sampling locations were critical to human health and require measures to mitigate further deterioration.

The sodium adsorption ratio (SAR) results, observed in this study, reveal 25% excellent, 20 % good, 10% doubtful and 45% unsuitable. SAR has been used extensively to determine the usability of water particularly for irrigation purposes. This imply that almost half of the samples of groundwater collected around the Solous dumpsite cannot agriculture, therefore the need effort to mitigate further influence of the dumpsite on neighboring aquifer. The permeability index (PI) is another tools in determining suitability for irrigation purposes. The PI value

Table 3: Modified DRASTIC (DRALTC) model weight and rating

Factors	Weight	Range	Rating
Depth to water m (D)	5	0 – 5	10
		5 – 15	9
		15 – 30	7
		30 – 50	5
		50 – 75	3
		75 – 100	2
		100+	1
Recharge (Net) (Inches) (R)	4	0 – 2	1
		2 – 4	3
		4 – 7	6
		7 – 10	8
		10 +	9
Aquifer Media (A)	3	Massive Shale 1	2
		Metamorphic	3
		Igneous 2 – 5	4
		Weathered Metamorphic/Igneous 3 – 5	5
		Glacial Till 4 – 6	6
		Bedded Sandstone, Limestone and Shale Sequences 5 – 9	6
		Massive Sandstone 4 - 9	8
		Massive Limestone 4 - 9	8
		Sand and Gravel 4 - 9	9
		Basalt 2 – 10	10
		Karst Limestone 9 - 10	
Distance of well to dumpsite m (L)	4	0 – 50	10
		50 – 100	9
		100 – 200	7
		200 – 500	5
		500 – 750	3
		750 – 1000	2
		1000+	1
Topography (T)	1	1 -2 %	10
		2 – 6%	9
		6 – 12%	5
		12 - 18%	1
Clay content % (C)	4	0 – 10	1
		10 – 20	3
		20 – 40	5
		40 – 55	8
		55 – 75	9
		75+	10

observed in this study was 71.0 % (25 – 74%) designated as class II (Elkrail, 2004). The PI corroborates the SAR that water samples require some treatment before it can be suitable for irrigation purposes.

The final DRALTC index ranged between 161 and 175 for groundwater around Solous dumpsite area. The pollution vulnerability ranged between moderate and high groundwater pollution potential. The observation could be a reflection of steep topography, despite the high (61%) clay composition of soil in the study area which ordinarily acts as sealant, preventing movement of pollutant from dumpsite to the nearby aquifer.

Table 4: Descriptive statistics of physicochemical parameters of groundwater around Soluos dumpsite

Variables		Min	Max (n = 20)	Mean (n = 20)	SD	CV%	SEM	% Exceedance	WHO
pH		4.6	6.9	5.68	0.7	123	0.16	0.76	6.5-8.5
Temp	°C	24.6	26.8	26.2	0.5	1.94	0.11		
Alkalinity	(mg/L)	10.7	36.6	1.23	1.1	86.9	24.4		
Acidity	(mg/L)	6.17	175	62.8	45	73.3	10.1		
TH	(mg/L)	11.9	204	72.6	59	81.5	13.2	0.15	500
EC	(mS/cm)	0.10	2.69	0.53	0.6	119	0.14	0.38	1.4
TDS	(mg/L)	30.7	1535	235	280	122	61.5	0.24	1000
TSS	(mg/L)	9.99	648	693	140	192	30.2	0.07	
TS	(mg/L)	42.1	2174	305	390	132	87.2	0.61	1000
PO_4^{3-}	(mg/L)	0.18	0.94	0.44	0.3	50.9	0.06	0.09	5
SO_4^{2-}	(mg/L)	2.92	228	12.5	6.2	46.6	1.38	0.03	400
NO_3^-	(mg/L)	0.15	3.91	2.48	1.4	76.7	0.31	0.25	10
Cl^-	(mg/L)	17.2	371	147	110	77.3	25.3	0.59	250
Cu	(mg/L)	0.03	0.21	0.09	0.04	40.6	0.01	0.06	250
Ni	(mg/L)	0.01	0.08	0.03	0.02	56.3	0.01	0.02	1.5
Pb	(mg/L)	0.00	0.001	0.001	0.00	0000	000	1.0	0.001
Cd	(mg/L)	0.001	0.02	0.01	0.01	99.6	0.01	2.0	0.003
Fe	(mg/L)	1.24	36.1	13.8	9.0	64.2	2.01	46	0.3
Zn	(mg/L)	0.14	2.37	0.82	0.7	80.3	0.15	0.26	3.0
Mg	(mg/L)	4.11	19.0	14.4	7.0	48.7	1.57	28.8	0.5
Na	(mg/L)	21.1	424	168	130	64.3	29.5	0.84	200
K	(mg/L)	6.29	44.3	20.5	11	54.7	2.55		
Ca	(mg/L)	8.57	178	57.5	47	80	10.6		

The chronic daily intake (CDI) values were found in the order of Zn > Cu > Ni > Cd > Pb for both children and adult in groundwater around Solous dumpsite as shown Table 9.0. CDI values for all the selected metals were found within the oral toxicity reference dose (R_fD) set by United State Environmental Protection Agency (USEPA, 2005) except for cadmium. The order of health risk indices (HRI) observed for the selected heavy metals was Cd > Zn > Cu > Ni > Pb for adult, while Cd > Cu > Ni > Zn >Pb trend was found for children in groundwater around Solous dumpsite. The data revealed that HRI value for all the metals investigated were within the safe limit (HRI < 1.0) suggesting no health risk, if the water is consumed.

Table 5: DRALTC Index computation for groundwater around Solous dumpsite

Factor	Distance			Recharge net			Water depth			Topography			Clay percentage			Aquifer media			pollution vulnerability index
Weight	4			4			5			1			4			3			
	value	Rate	No	Value	Rate	No	value	Rate	No	value	Rate	No	value	Rate	No	Value	Rate	No	
SWS1	157	7	28	1883	9	36	16.2	7	35	1-2%	10	10	63%	9	36	8	3	24	169
SWS2	190	7	28	1883	9	36	15.5	7	35	1-2%	10	10	63%	9	36	8	3	24	169
SWS3	761	2	8	1883	9	36	17.2	7	35	1-2%	10	10	63%	9	36	8	3	24	139
SWS4	871	2	8	1883	9	36	11.6	9	45	1-2%	10	10	63%	9	36	8	3	24	159
SWS5	917	2	8	1883	9	36	17.6	7	35	1-2%	10	10	63%	9	36	8	3	24	149
SWS6	762	3	12	1883	9	36	17.4	7	35	1-2%	10	10	63%	9	36	8	3	24	153
SWS7	1192	1	4	1883	9	36	8.5	9	45	1-2%	10	10	63%	9	36	8	3	24	155
SWS8	210	5	20	1883	9	36	16.7	7	35	1-2%	10	10	63%	9	36	8	3	24	161
SWS9	630	3	12	1883	9	36	10.3	9	45	1-2%	10	10	63%	9	36	8	3	24	169
SWS10	652	3	12	1883	9	36	11.7	9	45	1-2%	10	10	63%	9	36	8	3	24	167
SWS11	642	3	12	1883	9	36	13.4	9	45	1-2%	10	10	63%	9	36	8	3	24	167
SWS12	782	2	8	1883	9	36	11.9	9	45	1-2%	10	10	63%	9	36	8	3	24	163
SWS13	213	7	28	1883	9	36	12.5	9	45	1-2%	10	10	63%	9	36	8	3	24	173
SWS14	761	2	8	1883	9	36	14.4	9	45	1-2%	10	10	63%	9	36	8	3	24	163
SWS15	321	5	20	1883	9	36	16	7	35	1-2%	10	10	63%	9	36	8	3	24	175
SWS16	561	3	12	1883	9	36	16.6	7	35	1-2%	10	10	63%	9	36	8	3	24	155
SWS17	297	5	20	1883	9	36	16.6	7	35	1-2%	10	10	63%	9	36	8	3	24	175
SWS18	457	5	20	1883	9	36	15	9	45	1-2%	10	10	63%	9	36	8	3	24	171
SWS19	579	3	12	1883	9	36	14	9	45	1-2%	10	10	63%	9	36	8	3	24	157
SWS20	575	3	12	1883	9	36	11.7	9	45	1-2%	10	10	63%	9	36	8	3	24	157

Table 6: Correlation coefficient of metals in groundwater around Solous dumpsite

	Cu	Ni	Pb	Cd	Fe	Zn	Mg	Ca	Na	K
Ni	0.604	1.000								
Pb	-0.039	-0.170	1.000							
Cd	0.597	0.519	-0.304	1.000						
Fe	0.183	0.012	0.216	0.227	1.000					
Zn	0.094	-0.201	-0.066	-0.204	-0.262	1.000				
Mg	0.451	0.578	0.066	0.292	-0.302	0.160	1.000			
Ca	-0.375	-0.478	0.075	-0.344	-0.112	0.028	-0.382	1.000		
Na	0.511	0.366	-0.320	0.730	0.054	-0.178	0.383	0.420	1.000	
K	-0.016	0.251	-0.011	-0.142	-0.016	-0.211	-0.077	0.152	0.287	1.000

Table 7: Sodium adsorption ratio for groundwater around Solous dumpsite

Sample codes	Sodium adsorption ratio (SAR)	Sample codes	Sodium adsorption ratio (SAR)	Sample codes	Sodium adsorption ratio (SAR)
SWS1	15.8	SWS8	16.2	SWS15	27.0
SWS2	30.4	SWS9	43.3	SWS16	2.42
SWS3	5.21	SWS10	64.0	SWS17	26.2
SWS4	5.40	SWS11	56.4	SWS18	12.5
SWS5	53.3	SWS12	89.2	SWS19	19.1
SWS6	24.3	SWS13	59.1	SWS20	15.2
SWS7	5.08	SWS14	6.40		

Table 8: Classification of groundwater for irrigation based on Sodium adsorption ratio

Quality of water	Sodium adsorption ratio (SAR)
Excellent	<10
Good	10 – 18
Doubtful	18 – 26
Unsuitable	>26

The total heterotrophic bacteria in water samples ranged from 1.0 × 105 to 18 × 107 cfu/ml. The heterotrophic bacteria and total coliform bacteria are used extensively as a basis for assessing the microbial quality of drinking water. According to WHO guidelines for drinking water quality, the total heterotrophic bacteria should be <10 cfu/ml at 37°C. In the study, all the water samples exceed the permissible limits of World Health Organization.

The total viable bacteria in all the water samples were found to be too numerable to count (TNC). Excessively high colony numbers of total viable bacteria indicate that the water is highly contaminated with microorganisms and is not suitable for drinking purpose, as consumption leads to various water borne diseases like nausea, vomiting, diarrhoea, gastroenteritis, etc. The most probable number is the most widely used method to determine the microbial quality of water.

CONCLUSIONS

The potential vulnerability of groundwater in the surroundings to the pollution from Solous dumpsite (an engineering landfill) in Lagos, Nigeria was investigated. Physico chemical analyses revealed the groundwater with acidic pH which portend health risk, while microbiological examination showed the groundwater samples to exceed the permissible limits of World Health Organization guidelines total heterotrophic bacteria (<10 cfu /ml at 37°C)

Table 9: Chronic daily intakes (CDIs) ug/ (Kg. day) and Health risk indices (HRI) of heavy metals through water consumption

	Cd		Ni		Pb		Cu		Zn	
	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children
CDI	0.17± 0.05	0.18± 0.05	0.97± 0.29	1.00 ± 0.32	0.02± 0.01	0.03± 0.01	2.5± 0.0	2.8± 0.04	20± 0.67	18± 0.78
HRI	3.33E-4	3.67E-4	4.8E-5	5.4E-5	7.72E-8	3.48E-8	6.7E-5	7.4E-5	6.8E-5	6.1E-7

Table 10: Results of microbiological analyses of water samples around Soluos dumpsite

Sample code	Total Plates count (cfu/ml)	MPN per 100ml	Sample code	Total Plates count (cfu/ml)	MPN per 100ml
SMW1	27	< 1	SMW6	83	3
SMW2	212	6	SMW7	93	6
SMW3	44	< 1	SMW8	9	3
SMW4	97	< 1	SMW9	91	3
SMW5	4	< 1	SMW10	125	2
WHO	100	< 1	WHO	100	< 1

NB: The Completed test result for all the plates with MPN 1 and above showed gram negative with rod shape, confirming coli form

for drinking water. The total viable bacteria in all the water samples were found to be too numerable to count (TNC). Various water quality indices were also used to show variation of quality trends in the water samples collected. WQI values observed ranged from 39.1 to126 mg/L, depicting water samples around Solous dumpsite as excellent – good – poor class. The sodium adsorption ratio (SAR) observed showed 25% of samples having excellent quality, 20% good quality, 10% doubtful and 45% unsuitable for agricultural purposes. The health risk indices (HRI) for the metals investigated revealed the order of Cd > Zn > Cu > Ni > Pb for adult and Cd > Cu > Ni > Zn > Pb for children, though all metals were within the safe limits.

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