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Assessing the Effects of Aladimma Dumpsite on Soil and Groundwater Using Water Quality Index and Factor Analysis

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Abstract: Waste disposal techniques have created subtle and yet serious environmental pollution and ecological deterioration in many developing countries. Geochemical assessment of the effect of Aladimma dumpsite on the nearby soil and shallow groundwater was undertaken in the present study. A total of twenty soils and thirty groundwater samples were collected during the dry season. The concentration of all the parameters analyzed was higher in soil than in groundwater and these may be attributed to the high affinity between organic matter content of soils and elements. The results indicate the concentrations of the cation to be in the order of Ca > Mg > Na > K in both soil and groundwater while that of anion is in the order of Cl > NO_3 > SO_4 > HCO_3. The heavy metals concentrations vary as follows: Fe > Zn > Cu > Mn > Cr > Pb > As. This may be attributed to high precipitation and subsequent weathering and leaching of metallic objects from the dumpsite into the shallow groundwater table. The application of WQI shows that the groundwater around the dumpsite is poor in quality and the factor analysis revealed five sources of groundwater pollution. Factors 1 and 2 are from natural means while Factors 3, 4 and 5 are from dumpsite and other human activities in the area. Modern sanitary landfills to replace the practice of open dumping and to reduce the reliance on waste incineration were advocated.

Key words: Dumpsite, Evaluation, Soil and Groundwater Quality.

INTRODUCTION

The disposal of waste generated by anthropogenic activities has been an environmental problem in many urban areas in developing countries as they progressively move towards industrialization (Awomeso, *et al.,* 2010). Human activities such as technology, industrialization, agriculture, transportation, education, construction, commerce, nutrition and population are responsible for increase in waste generation in any human society (Olarinoye, *et al.,* 2010). Although solid waste can be an asset when properly managed, it poses the greatest threat to life due to its potential of contaminating terrestrial, aquatic and aerial environments (Bishop, 2000).

Many African countries are dumping ground for technological waste especially used computers and various electronics gadgets from advanced countries. Unfortunately, these products contain hazardous metals like lead, mercury, nickel, cadmium, copper and zinc. The dumping and degradation of damaged parts of these fairly used imported products and similar locally fabricated material could enhance their accumulation in soils and may contaminate surface and groundwater through runoff and infiltration respectively (Amadi, *et al.,* 2010).

Inadequate information, insufficient resources and poor legislation encourage uncontrolled and improper dumping of waste in many state capitals in Nigeria (Oyeku, 2007) and this is unacceptable and far below the minimum standard of using sanitary landfill for waste disposal (Mull, 2005; Adewole, 2009). (Bacud, *et al.,* 1994) linked acidification and nitrification of groundwater to dumpsite while a number of dumpsites have been implicated for bacterial contamination of groundwater (Torres, *et al.,* 1991) and these causes diseases and abnormalities in human (Sia Su, 2008).

The aim of this study is to examine the impact of Aladimma dumpsites on soil and groundwater quality.

MATERIALS AND METHODS

Studied Area Description:

Aladimma open dumpsite is located at the centre of Owerri, the capital of Imo State, Nigeria, between latitudes $5^{o}15^{I}$N to $5^{o}45^{I}$N and longitudes $6^{o}45^{I}$E $7^{o}15^{I}$E (Fig.1). It is sited close to Aladimma mortuary and Aladimma Housing Estate at Owerri. The area has a good tarred road network and is easily accessible. It is an open dumpsite, un-engineered and poorly managed and the activities of birds, rodents and reptiles, and micro-organisms abound.

Climate and Physiography of the Area:

The prevalent climatic condition is marked by two main regimes: the rainy and the dry seasons. The rainy season is from April to October during which the temperature varies from 23^{o}C to 32^{o}C, and this season is associated with the prevalent moisture-laden south-west trade wind from the Atlantic Ocean. The rainy season is also characterized by double maximum rainfall during which the first peak occur in July and the second occurs

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in September with a mean annual rainfall of 2152 mm (Ezeigbo, 1989). The dry season starts in November, when the dry continental north-eastern wind blows from the Mediterranean Sea across the Sahara desert and Samarian desert and down to the southern part of Nigeria. Due to vagaries of weather, the August break sometimes occurs in July or early September. Humidity is usually low and clouds are absent, during the dry season. The area lies within the tropical rain forest belt of Nigeria. The natural vegetation in greater part of the area had been replaced by derived savanna grassland interspersed with oil palm trees (Amadi, 2010).

Hydrogeology of the Area:

Detailed geological and hydrogeological investigation of the area was undertaken. The study area is outcropped by the Benin Formation which is known as the 'coastal plain-sands' because it consists mainly of sands, sandstone and gravel with clays occurring in lenses (Fig.1). The sands and sandstones are coarse to fine partly unconsolidated with thickness ranging from 0-2100 m (Ezeigbo, 1989). The sediments represent upper deltaic plain deposits. The shales are few and they may represent upper deltaic plain deposit. However, the formation lacks faunal content and this makes it difficult to date, though an Oligocene-Recent age is generally accepted (Uma, 1989). The Benin Formation is composed mainly of high resistant fresh water-bearing continental sands and gravels with clay and shale intercalations (Onyeagocha, 1980). The environment of deposition is partly lagoonal and fluvio-lacustrine/deltaic (Uma and Egboka, 1985). The formation which dips south westward starts as a thin edge layer at its contact with the Ogwashi-Asaba Formation in the northern part of the area, and thickens southwards to about 100 m in Owerri area (Ibe, *et al.,* 1992). The sandy unit which constitutes about 95% of the rock in the area is composed of over 96% of quartz (Onyeagocha, 1980). A marked banding of coarse and fine layers with a large scale cross bedding constitute the major sedimentary structures in the area (Ofoegbu, 1998).

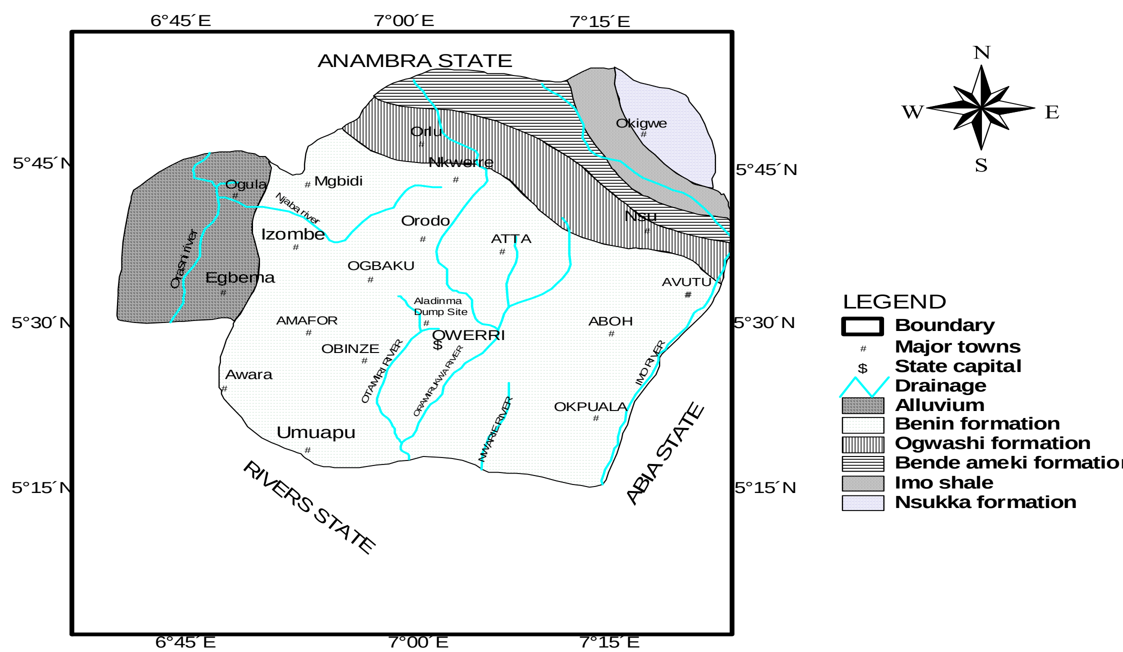

Fig. 1: Geological map of the study area.

Soil and Groundwater Sampling:

A total of twenty soil and thirty groundwater samples were collected from the vicinity of Aladimma dumpsite. All the soil samples were taken from the top 10 cm layer to a depth of over 40 cm (Jose *et al.,* 2005). Sampling tools were washed and dried before the next sample was collected. The collected samples were stored in clean polythene ready for digestion and analysis. Similarly, the groundwater samples were collected from existing private boreholes within the dumpsite area using polythene bottles. The physical parameters such as pH, conductivity and temperature of both soil and groundwater samples were determined on the field using a calibrated pH meter, conductivity meter and mercury thermometer respectively while chemical and bacteriological parameters were analyzed in the laboratory using Atomic absorption spectrophotometer (Perkin Elmer, Model No. 2380) and filter membrane method in accordance with American Public Health Association (APHA, 1995). Prior to sampling, geophysical investigation and sieve analysis had been carried out around the dumpsite to assess the extent of leachate migration into underlying soil/aquifer and to determine the dominant grain-size respectively.

Digestion of Soils for Heavy Metals Analysis Using Microwave Technique:

The accurate measurement of trace metal concentrations is an important goal in environmental monitoring and research, as many of these elements have been identified as potentially hazardous pollutants (CCME, 1999).

The use closed vessel microwave-assisted digestion systems under high temperature and pressure for acid digestion has now become routine as it allows shorter digestion times and good recoveries, even for volatile elements (Valeria, *et al.,* 2003; Hassan , *et al.,* 2007). In addition, it reduces the risk of external contamination and requires smaller quantities of acids, thus enhancing detection limits and the overall accuracy of the analytical method (Valeria, *et al.,* 2003; Hassan, *et al*., 2007). Moreover, they are safer and simpler and provide more controlled and reproducible conditions than hot plate or block digesters (Frank and Arsenault, 1996; Singh, *et al*., 2002).

For the digestion of soil samples, the samples were first dried at room temperature, grounded into powder and sieved with <2 mm sieve and stored in a plastic bag. Then 0.25 g of the sample was added into the reference vessel where 2.5 mL of concentrated HNO_3 and 2.5 mL of HF acids were added according to the USEPA Method 3050B for the analysis of heavy metals (USEPA, 1996). The vessel was then inserted into a carousel and into the microwave unit ready for digestion. The system was then programmed using the Ethos D control terminal equipped with software for 6 minutes of microwave digestion at 300 W power and another 5 minutes of microwave digestion using 500 W power and then left for automatic ventilation for 10 minutes post digestion period. Afterwards, the digested solution was cooled and filtered using Whatman filter paper No.40 and 100 mL distilled water was added to it and stored in a container ready for analysis. Atomic absorption spectrophotometer (Perkin Elmer, Model No. 2380) was used for the sample analysis.

Water Quality Index:

Water Quality Index (WQI) is one of the most effective tools to communicate information on the quality of water to the concerned stakeholders. It has becomes a useful tool for the assessment and management of water resources. WQI is a scale which helps to estimate an overall quality of water based on the values of water quality parameters. It expresses the overall water quality at a certain location and time based on several water quality parameters. The word "Water Quality" is a widely used expression, which has a broad spectrum of meaning depending upon each individual interest of water for an intended use.

The objective of WQI is to turn complex water quality data into information that is understandable and useable by the public. Over the years and even today a decision regarding "quality" of water is made using a series of judgments and can be expressed using several scores of parameters obtained from water analysis in the laboratory. In response to the need for a uniform understandable yardstick of water quality, water scientists worked out to compile all the water quality parameters into what is now known as the Water Quality Index (WQI).

Calculation of WQI:

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method. The quality rating scale for each parameter q_i was calculated by using this expression:

$$q_i = (C_i / S_i) \times 100$$

A quality rating scale (q_i) for each parameter is assigned by dividing its concentration (C_i) in each water sample by its respective standard (S_i) and the result multiplied by 100. Relative weight (W_i) was calculated by a value inversely proportional to the recommended standard (S_i) of the corresponding parameter:

$$W_i = 1/S_i$$

The overall Water Quality Index (WQI) was calculated by aggregating the quality rating (Q_i) with unit weight (W_i) linearly as shown below:

$$WQI = (\Sigma w_i q_i)_{n=1}^{i=n}$$

Where:

q_i: the quality of the ith parameter,

w_i: the unit weight of the ith parameter and.

n: the number of the parameter considered.

Generally, WQI were discussed for a specific and intended use of water. In this study the WQI for drinking purposes is considered and permissible WQI for the drinking water is taken from the overall WQI given as:

Overall $$WQI = \frac{\sum q_i w_i}{\sum w_i}$$

Factor Analysis:

Factor analysis (FA) is a statistical technique that focuses on data reduction in order to identify a small number of factors that explain most of the variables observed in a much larger number of manifest variables (Abdullah and Aris, 2007; Amadi, *et al*., 2010). It attempts to identify new underlying variables or factors that give a better understanding of the pattern of correlation within a set of observed variables (Praus, 2005). Factor analysis is based more on explaining the covariance structure of the variables than with explaining the variances (Lambarkis, *et al.,* 2004). The purpose of factor analysis is to interpret the structure within the variance-covariance matrix of a multivariate data collection. It uses the extraction of the eigenvalues and eigenvectors from the matrix of correlation or covariance. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset (Prasad and Narayana, 2004; Olobaniyi and Owoyemi, 2006). SPSS-window-16 version was the statistical software used to perform factor analysis on the datasets.

Results:

The statistical summary of the physico-chemical parameters of soil and groundwater samples in the vicinity of the dumpsite are contained in Table 1. The computed WQI values of the groundwater are shown in Table 2 while the global water quality classification is summarized in Tables 3. The results of Varimax rotated factor loading on the data are illustrated in Table 4.

Table 1: Summary of physico-chemical analysis of soil and groundwater from Aladimma dumpsite.

Soil (mg/Kg)			Groundwater (mg/L)		
Parameters	Range	Mean	Parameters	Range	Mean
pH	4.17 – 7.40	5.28	pH	5.32 – 7.10	6.45
EC (µs/cm)	38.00 – 198.00	142.00	EC (µs/cm)	28.60 – 275.20	112.10
TDS	11.30 – 165.80	129.50	TDS	14.08 – 156.55	108.05
Sulfate	12.00 – 148.98	110.42	Sulfate	0.68 – 127.03	55.01
Chloride	0.45 – 355.12	178.22	Chloride	12.09 – 221.08	76.65
Bicarbonate	0.52 – 121.09	56.34	Bicarbonate	0.08 – 60.50	34.11
Nitrate	0.35 – 652.55	336.26	Nitrate	0.16 – 95.02	61.07
TC (cfu/100mL)	2.05 – 240.40	87.94	TC (cfu/100mL)	0.00 – 115.78	53.65
Sodium	18.96 – 490.12	321.08	Sodium	02.75 – 253.56	64.12
Potassium	85.68 – 842.24	456.50	Potassium	7.23 – 118.58	38.01
Magnesium	12.10 – 117.60	89.02	Magnesium	0.98 – 167.03	67.42
Calcium	48.90 – 281.08	98.65	Calcium	4.05 – 184.32	69.84
Manganese	6.98 – 366.64	187.35	Manganese	0.00 – 0.89	0.24
Zinc	68.30 – 290.65	182.38	Zinc	0.02 – 12.08	4.01
Copper	5.20 – 58.57	26.20	Copper	0.00 – 9.04	1.35
Lead	0.28 – 26.46	14.39	Lead	0.00 – 0.06	0.01
Chromium	1.56 – 5.28	3.42	Chromium	0.00 – 0.05	0.01
Iron	26.08 – 264.26	240.15	Iron	0.01 – 16.98	0.98
Arsenic	0.01 – 0.05	0.03	Arsenic	0.00 – 0.03	0.01

EC- Electrical Conductivity; TDS- Total Dissolved Solid; TC-Total Coliform

Table 2: Summary of computed WQI values for the groundwater in the area.

Parameters (mg/L)	C_i	S_i	w_i	q_i	w_i q_i
pH	6.45	6.5-8.5	86.00	0.133	11.438
EC (µs/cm)	112.10	1000.00	11.21	0.001	0.011
TDS	108.05	500.00	21.61	0.002	0.043
Sulfate	55.01	100.00	55.01	0.010	0.550
Chloride	76.65	250.00	30.66	0.004	0.123
Bicarbonate	34.11	100.00	34.11	0.010	0.341
Nitrate	61.07	50.00	122.14	0.020	2.443
TC (cfu/100mL)	53.65	10.00	536.50	0.100	53.650
Sodium	64.12	200.00	32.06	0.005	0.160
Potassium	38.01	150.00	25.34	0.007	0.177
Magnesium	67.42	200.00	33.71	0.005	0.169
Calcium	69.84	200.00	34.92	0.005	0.175
Manganese	0.24	0.20	120.00	5.000	600.000

Zinc	4.01	3.00	133.67	0.333	44.512
Copper	1.35	1.00	135.00	1.000	135.000
Lead	0.01	0.01	100.00	100.000	10000.000
Chromium	0.01	0.005	200.00	200.000	40000.000
Iron	0.98	0.30	326.67	3.333	1088.791
Arsenic	0.01	0.01	100.00	100.000	10000.000

EC- Electrical Conductivity; TDS- Total Dissolved Solid; TC-Total Coliform

Table 3: Water quality classification based on WQI value.

WQI value	Water quality	Water samples (%)
<50	Excellent	21
50-100	Good water	30
100-200	Poor water	25
200-300	Very poor water	15
>300	Unsuitable for drinking	09

Table 4: Factor loading of the dataset after varimax rotation.

Parameters (mg/L)	VF-1	VF-2	VF-3	VF-4	VF-5
pH	-0.198	0.545	0.625	0.432	-0.298
EC (µs/cm)	0.789	0.045	0.422	0.231	0.020
TDS	0.812	0.210	0.245	0.345	0.197
Sulfate	0.105	0.816	0.322	0.141	0.575
Chloride	0.345	0.756	0.236	-0.357	0.153
Bicarbonate	-0.078	0.531	0.119	0.039	-0.208
Nitrate	0.433	0.136	0.213	0.142	0.768
TC (cfu/100mL)	0.038	0.112	0.155	0.138	0.652
Sodium	0.691	-0.208	0.067	-0.301	0.109
Potassium	0.026	0.504	-0.098	0.430	0.242
Magnesium	0.630	0.115	0.179	0.158	0.256
Calcium	0.772	-0.329	0.371	0.142	0.405
Manganese	0.124	0.088	0.268	0.824	-0.349
Zinc	0.238	0.227	0.587	-0.310	0.237
Copper	-0.465	0.320	0.509	0.068	0.208
Lead	0.282	0.354	0.321	0.670	-0.007
Chromium	0.312	0.111	0.24o	0.703	0.050
Iron	0.667	-0.179	0.645	-0.153	0.062
Arsenic	-0.221	0.190	0.083	0.521	-0.180
Eigenvalue	5.302	4.109	3.786	2.281	1.457
Total Variance (%)	25.102	19.861	16.456	13.324	10.705
Cumulative %	25.102	44.963	61.419	74.743	84.448

EC- Electrical Conductivity; TDS- Total Dissolved Solid; TC-Total Coliform

Discussion:

The concentration of all the parameters analyzed are higher in soil than in groundwater and these may be attributed to the high affinity between organic matter content of soils on elements (Bodur and Ergin, 1994; Yisa, 2010). These observed concentrations are highest at the top soil but decreases with increase in depth. These implies that as the parameters are leached probably from the dump, they accumulate at the top soil rich in organic matter and at greater depth where organic matter content decreases, their concentration reduces in correlation with the findings of (Bodur and Ergin, 1994; Lakhan, *et al.,* 2003; Yisa, 2010). The concentration of electrical conductivity (EC) and the total dissolved solid (TDS) falls below the maximum allowable limit for drinking water recommended by Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) but the pH values (6.45) indicate that the water is slightly acidic.

Soil acidification and nitrification can be attributed to the decomposition activities at a dumpsite (Bacud *et al*., 1994). The concentration of major cations (sodium, potassium, magnesium, and calcium) and anions (sulfate, chloride and nitrate) in the groundwater falls within the permissible limits for safe drinking water outlined by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) except nitrate. The high concentration of nitrate in the groundwater may be due to fertilizer application in the nearby farm land or dumping of animal (human) faeces at the dumpsites. Nitrates are very important due to its biological implication but excessive amount of nitrates in water causes eutrophication (retardation in the growth of plants) and methaemoglobemia (infant cyanosis or blue baby syndrome).

The mean concentrations of manganese, iron, copper, chromium and zinc were slightly higher than the permissible limit of (NSDWQ, 2007) thereby signifying possible contamination while the mean concentration of lead, and arsenic are within the maximum permissible limits recommended by Nigerian Standard for Drinking Water Quality (NSDWQ, 2007). Their enrichment in groundwater can be as a result of leachate migration from the dumpsite to the shallow water table via the porous and highly permeable underlying formation (Uma, 1989). Although high concentration of iron had been previously recorded in the area and attributed to the leaching of the iron content of the lateritic soil (Uma, 1989; Amadi, *et al.,* 2010) the enrichment of other metals in the groundwater may be due to leachate from dumpsite to the shallow water table. This process is enhanced by favourable geologic conditions such as permeable sandy lithology, heavy precipitation and shallow water table which may have assisted in the introduction of these pollutants into the groundwater system.

The water quality index (WQI) of all the groundwater samples analyzed was calculated according to the procedure explained above and presented in Table 2 while Table 3 shows the five groups of WQI, ranging from excellent water to water unsuitable for drinking and the distribution of the thirty groundwater samples according to their respective quality group. The computed overall WQI was 150.99 belonging to the poor water quality category. The high value of the WQI obtained may be due to the impact of leachate from the dumpsite on the groundwater as well as infiltration arising from fertilizer application and unlined soak-away within the vicinity.

$$\text{Overall } WQI = \frac{\sum q_i w_i}{\sum w_i} = \frac{61937.58}{410.21} = 150.99$$

Factor analysis was applied to dataset and it generated five significant factors (Eigenvalues >1) which explained 84.45% of the variance in datasets and it suggests five different sources of pollution. The first factor consists of electrical conductivity (EC), total dissolved solid (TDS), magnesium, calcium, sodium and iron which accounts for 25.10% of the total variance (Table 4). Magnesium, calcium, sodium and iron are major cations in water and relatively related to the natural conditions. TDS and the conductivity may be due to their dissolution through natural means in the course of groundwater movement or anthropogenic means via leachate migration from dumpsites and unlined soak-away. Factor 2 explains 19.86% of the total variance and it includes pH, sulfate, chloride, bicarbonate and potassium. Sulfate, chloride and bicarbonate are major anions in water are mainly from natural interference. Seawater intrusion into the shallow aquiferous system in the process of aquifer recharge mechanism as well water-soil-sediment interaction is the possible sources.

Factor 3 is a high loading from pH, zinc, copper and iron and constitutes 16.46% of the total variance (Table 4). High precipitation and relative humidity of the area coupled with porosity and permeability of the underlying lithology (Olobaniyi and Owoyemi, 2006) encourages rapid chemical weathering and infiltration of leachate into the water table. Factor 4 explains 13.32% and comprises of manganese, lead, chromium and arsenic. Leachate of metallic object from dumpsites and their migration through the unconfined highly permeable sandy formation to the water table may be responsible for their enrichment. Factor 5 has the moderate loading with nitrate, sulfate and total-coliform contributing about 10.71%. This is attributed to fertilizer application and animal faeces. Contributors to Factors 1 and 2 are attributed to natural sources while Factors 3, 4 and 5 comes from anthropogenic sources arising from the various human activities in the area.

Conclusion and Recommendation:

The application of WQI suggests that the groundwater around the dumpsite is poor in quality while factor analysis revealed five sources of groundwater pollution. Factors 1 and 2 are from natural means while Factors 3, 4 and 5 are direct effects of dumpsite and other human activities in the area. The concentrations of the elements in the soil falls within the limits recorded for a normal soil. However, there was an anthropogenic enrichment of the soils beneath the dumpsite when compared with those away from it. The study has shown that leachate from the dumpsite is a threat to shallow groundwater sources around the study area. Hence a stop should be put to the dumping of waste at this site. A well coordinated clean-up operation should be undertaken at the dumpsite to curtail the spread of leachate to the surrounding groundwater zones as well as adjoining rivers. The use of trashcan and rubbish drums in residential and working places will improve management of wastes and lead to a cleaner and safer environment. Future boreholes should be drilled to tap from deep aquiferous zone and good sanitary landfill that incorporates leachate collection sump and multiple clay liner system to prevent direct contamination of shallow groundwater system should be constructed to replace the open dumpsite that is been practiced presently.

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