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Environmental Implications of the Discharge of Municipal Landfill Leachate into the Densu River and Surrounding Ramsar Wetland in the Accra Metropolis, Ghana

Frank K. Nyame[1*], Jacob Tigme[2], Jacob M. Kutu[1], Thomas K. Armah[1]
[1]Department of Earth Science, University of Ghana, Legon, Ghana
[2]SMD Lefa Gold Mine, Kankan, Guinea
Email: *fnyame@ug.edu.gh

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ABSTRACT

Investigations were conducted over a six-month period on leachate which continuously egresses from a "natural attenuation" landfill site into a fragile ecosystem in the Accra Metropolis, Ghana. Most physico-chemical, oxygen demand parameters and nutrient contents were within permissible limits but Total Dissolved Solids (1124 - 13200 mg/l), conductivity (7960 - 24890 μS/cm), Mn (0.12 - 0.94 mg/l), Ca^{2+} (160 - 356 mg/l) and, more especially chloride contents (1030 - 2967 mg/l) far exceeded respective World Health Organisation (WHO) limits for effluent discharge into the natural environment. Multivariate statistics using Principal Component Analysis (PCA) and Cluster Analysis (CA) suggest significant concentrations of Ca^{2+}, Cl^-, and to a lesser extent Zn, Cd, Mn and PO_4^{2-} relative to the river water samples. Because the landfill was abandoned recently (in 2009), degradation and other breakdown processes of waste material may only have just began, suggesting that the uncontrolled and continuous discharge of chloride and some heavy metal-laden leachate could, in the long-term, substantially impact negatively on the Ramsar Densu wetland and surrounding water bodies, soil and nearby marine ecosystem.

Keywords: Densu Wetland; Ghana; Landfill; Leachate

1. Introduction

Municipal solid waste landfills and the many harzardous materials or contaminant types they contain could reportedly have various adverse effects on environmental compartments including surface and groundwater resources, soils, fauna and flora as well as human health [1-7]. Such landfills often produce leachate, *i.e.* the liquid that usually drains from landfills due to infiltration by water and/or biogeochemical decomposition processes, which serves as an important point source of pollution in many environmental media around the world [8,9]. The constituents in leachate, some of which may be toxic, have often posed serious challenges in terms of cost of treatment, accumulation of metal or species, remediation and, in particular, possible eco-toxicological implications resulting from both short- and long-term exposure or bioaccumulation of leachate constituents.

In Ghana, municipal solid waste from households, commercial establishments and industries in the city with varied composition is commonly disposed of at open mainly un-engineered dump sites or, more frequently, abandoned quarry sites located in the city [10,11]. In the Accra metropolis, for example, such landfill sites receive the over 55% of all solid waste generated that the Metropolitan Assembly (AMA) collects [12]. The Oblogo landfill, one of many in the Accra Metropolis, is situated within an abandoned quarry hosted in well bedded rocks of the Togo Formation [13]. As a result of decomposition of waste, streams of untreated leachate continuously flow from the landfill into the surrounding environment [14]. In spite of the possible hazards presented by the apparently uncontrolled seepage and migration of leachate from many such un-engineered landfills throughout the country, very few studies have been undertaken, neither have effective mechanisms been put in place for leachate control or management. This paper presents data on leachate from the Oblogo landfill which continuously seeps and discharges into soils, river (Densu River), ecologically important Ramsar wetland and nearby marine environment in the Accra Metropolis, Ghana. The

*Corresponding author.

implications of the uncontrolled discharge of some constituents in the leachate are also briefly discussed.

2. Study Area

2.1. Location and Geographic Elements

The study area is located on approximately latitudes 5˚33'26"N and 5˚33'40"N and longitudes 0˚18'45"W and 0˚18'55"W in the Ga District in south-western Accra, Ghana (**Figure 1**). The landfill is situated in an area underlain by the Togo series of rocks which consist of bedded and interbedded sequences of quartzite, phyllite and schist [15]. The site covers an area of approximately 20,000 m^2 on the edge of a ridge about 200 m by road from Oblogo Township and approximately 1 km off the major Accra-Takoradi-Half Assini (Accra-Abidjan) highway.

The site lies in the coastal savannah zone and has mean annual rainfall of 800 mm [16]. The rainfall is seasonal with two peaks in June and September. According to Ghana Meteorological Agency, rainfall up to a maximum of about 200 mm can occur in one day and much of that could fall in about one or two hours. The highest mean monthly temperatures occur between March and April. Minimum and maximum daily temperatures range from 22.8˚C to 33.0˚C, respectively. The minimum yearly average is 24.2˚C with maximum yearly average of 31.0˚C. The highest monthly mean temperatures occur in April and the lowest in July. Mean relative humidity is high within a 24-hr period with relative humidity occurring in January and the highest in August.

The dominant vegetation is shrub and grassland. Thin grass and occasional patches of shrub characterise the landfill area. The vegetation grades gradually towards the Densu River into the surrounding wetland close to the coast. The wetland, a designated Ramsar site, is rich in various fish species and rare flora and fauna [17]. Residential buildings occur quite close to the landfill. Stone quarrying, fishing and subsistence farming are some economic activities undertaken by many people in the area. Others also undertake recycling and scavenging activities at or close to the landfill. Leachate from the landfill mainly flows into naturally created sumps where it is stored temporarily before flowing downslope through

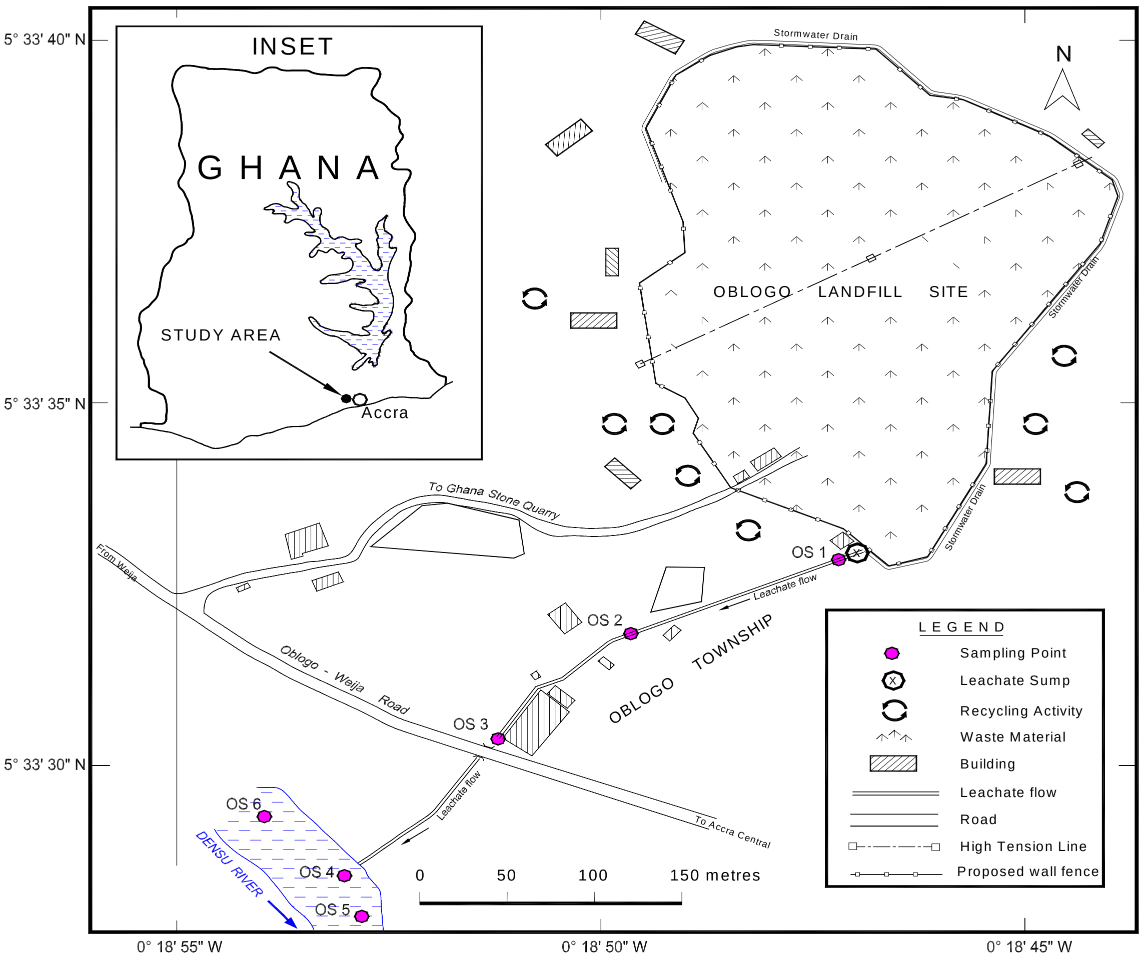

Figure 1. Study area with sampling locations.

Oblogo Township and parts of the wetland to join the Densu River about 250 m from the landfill. The river then flows less than a kilometre through the wetland into the Atlantic Ocean.

3. Methodology

3.1. Field Work

The study involved sampling and analysing leachate and river water along approximately 250 m from the landfill at an interval of about 100 m for six months. The location and description of sampling sites are given in **Table 1**. Sampling was done between January and June, 2004. A hand-held Global Positioning System (GPS) was used to locate sampling points. Samples were taken at varying but designated locations from the landfill site up to where leachate entered the Densu River through the wetland system (**Figure 1**). Samples were collected in the dry (January to March) and rainy (April to June) seasons once every month from six sampling points in accordance with protocols on sampling by APHA [18]. Most samples were collected in plastic bottles and labelled appropriately. Three samples were taken at each sample point, one in a 1.5-litre plastic bottle for physico-chemical analysis, another in a 100 ml plastic bottle acidified with nitric acid for mainly heavy metal contents and the third in a standard "ox top" bottle for oxygen demand parameters. Sample bottles were first rinsed with leachate or water before carefully dipping individual bottles in flowing leachate and water at the respective sampling points. These precautions were taken to reduce contamination. The collected samples were then kept in an ice chest in the field and later transferred into a refrigerator until analysis was done.

3.2. Analysis of Leachate and Water Samples

Analytical methods used for leachate and water samples varied depending on the parameters of interest. All field and laboratory determinations were done according to standard methods for the examination of waste and waste water [19]. For every sample, physico-chemical, nutrients and oxygen demand parameters were determined. Measurements of physical parameters were taken in situ by the use of a Water Quality Check U-10 instrument. Values of measured parameters were read from the digital display when the Checker U-10 was immersed in the respective samples.

Physico-chemical parameters were determined at the Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR, Ghana). Trace metals Fe, Mn, Zn and Cd were determined with Unicom Atomic Absorption Spectrometer (AAS). Samples were first treated with a mixture of concentrated nitric, sulphuric and perchloric acid in a digest and each sample solution aspirated into a flame and atomized. A light beam was then directed through the flame into a monochromator and onto a detector that measured the amount of light absorbed by the element in the flame. A blank sample (acidified) was also aspirated to set the automatic zero control. At least six standards were used for each element. Various samples were then aspirated individually and the respective concentrations obtained from the digital display. Concentration of sulphate in the samples was determined by the sulphate-turbidimetric method. To 100 ml of the sample, 5 ml of conditioning reagent (barium chloride) was added and stirred for about 60 seconds. The absorbance was read at 420 nm on a spectrometer. Concentration of sulphate was then calculated from standard calibration formula. Phosphate $\left(PO_4^{2-}\right)$ was also determined using the stannous chloride acid method (APHA, 2005).

Biochemical Oxygen Demand (BOD) was determined by diluting portions of the sample and incubating for 5 days at 20˚C. The BOD exerted over the 5 days deter-

Table 1. Location and description of leachate and stream or river water samples relative to landfill site, Accra, Ghana.

Sample No.*	Description of Sample Point	Sample Type**	GPS Location	~Distance (m) from landfill (Reference Pt.)
OS1	Naturally-created leachate sump	Landfill leachate	0˚18'44.8"W 5˚33'33.8"N	5
OS2	Artificial (dug) sump	Landfill leachate	0˚18'49.6"W 5˚33'32.6"N	100
OS3	Natural leachate sump	Landfill leachate	0˚18'52.8"W 5˚33'31.1"N	200
OS4	Leachate confluence with Densu River	River water	0˚18'52.3"W 5˚33'25.8"N	220
OS5	Slightly upstream of leachate confluence with Densu River	River water	0˚18'54.8"W 5˚33'25.1"N	230
OS6	Downstream of leachate confluence with Densu River	River water	0˚18'55.1"W 5˚33'28.1"N	250

*OS1 represents the first leachate sampling point at a sump topographically just below landfill; OS2 sample point along leachate flow path downslope or down gradient of OS1; OS3 is located along leachate flow path close to a major road linking Oblogo and Weija; OS4 is located in an area where the leachate empties into the Densu River; OS5 and OS6 are located downstream and upstream of OS4, respectively (**Figure 1**). **River water = sample taken from Densu River.

mined as follows:

Calculations

$$BOD_5 = BOD \times S_1 \times S_2$$

where

BOD_5 = BOD recorded on the fifth day from the Oxitop.

S_1 = Dilution factor.

S_2 = Factor dependent on total volume of diluted sample put in Oxitop bottle.

In determining the Chemical Oxygen Demand (COD), the sample was refluxed in concentrated sulphuric acid with a known excess of potassium dichromate ($K_2Cr_2O_7$) for two hours. After digestion, the remaining reduced $K_2Cr_2O_7$ was titrated with ferrous ammonium sulphate to determine the amount of $K_2Cr_2O_7$ consumed and the oxidizable matter calculated in terms of the oxygen equivalent.

Microsoft Excel (version 2007) was used to obtain correlation coefficients between measured physical-chemical and nutrient parameters for leachate and river water. In addition, the data were subjected to multivariate statistical analyses [20,21] involving Principal Component Analysis (PCA) and Cluster Analysis (CA) using SPSS (version 12.0).

4. Results

4.1. Physicochemical Data for Landfill Leachate

Data on parameters from leachate samples taken during the study are presented in **Table 2(a)**. pH values of leachate range from 6.6 close to the landfill (~5 m) in January to 7.9 (mean 7.4) in Aprilat a distance of 200 m from the landfill. Throughout the sampling period as well as outwards from the landfill, the pH of leachate thus remained fairly uniform. Temperature values also range from a minimum of 27.8˚C in April at distance 5 m to a maximum of 35.3˚C in January at the same sampling site, *i.e.* 5 m from the landfill. Even though minor differences occur up to about 100 m from the landfill, the values in general suggest not much change in temperature of leachate with respect to sampling period or distance from the landfill site. The lowest and highest conductivity values of 7960 and 24,890 μS/cm were obtained in leachate taken respectively in March (distance 5 m) and June (distance 100 m) from the landfill. Range of values for total dissolved solids (TDS), salinity and turbidity of leachate were as follows; TDS 1124 mg/l in April at about 100 m from the landfill to 13,200 mg/l also in April at about 100 m from the landfill; salinity 0.18% in June at 200 m from landfill to 2.02% in April at 5 m from landfill; turbidity 3.1 NTU in June at 200 m to 60.1 NTU in April at 100 m (**Table 2(a)**).

Fe concentrations in leachate ranged from 2.05 - 18.0 mg/l at 200 m and 5 m, respectively, from the landfill, the lowest value in April and the highest in January (**Table 2(a)**). Cadmium, Zinc and manganese also varied from 0 - 2.45 mg/l (distance 100 m and 5 m both in January), 0.02 - 0.28 mg/l (distance 100 m in February and 5 m in January) and 0.12 - 0.94 mg/l, respectively.

Both the minimum (0.12 mg/l) and maximum (0.94 mg/l) Mn values were obtained at more than one site (**Table 2(a)**). Calcium and chloride contents ranged from 160 - 356 mg/l (mean 276.7 mg/l) and 1030 - 2967 mg/l (mean 2291 mg/l), respectively, whilst total hardness also ranged from 104 to 1300 mg/l (mean 889.7 mg/l). The highest Ca^{2+} value was obtained in March in leachate sample taken about 5 m from the landfill and the lowest in January about 200 m from the landfill. Chloride in leachate (**Table 2(a)**), on the other hand, registered the highest and lowest values in June, the former nearer the landfill (distance 5 m) and the latter farther away (distance 200 m).

The nutrient contents of leachate, as given by concentrations of PO_4^{2-}-P, SO_4^{2-} and NO_3^--N (**Table 2(a)**), also showed variations with respect to distance from the landfill and sampling period. PO_4^{2-}-P contents ranged from 8.23 mg/l in April at about 200m from the landfill to 30 mg/l in January about 100 m from the landfill. The highest concentrations of SO_4^{2-} (68.3 mg/l) and NO_3^--N (41.52 mg/l) were both obtained in January at site 5 m from the landfill whilst the lowest (*i.e.* SO_4^{2-} 28.6 mg/l and NO_3^--N 1.03 mg/l) were also obtained in June with the SO_4^{2-} at 200 m and NO_3^--N at 100 m from the landfill. The oxygen demand parameters DO, BOD and COD also exhibited variations with respect to sampling site and period but were generally characterised by low values (**Table 2(a)**).

4.2. Physicochemical Data for River (Densu) Water

Table 2(b) gives data from water samples taken from the Densu River into which leachate egresses (see **Figure 1**). Except for Cd and Zn that were generally below detection, the data show perceptible variations with respect to site and period of sampling. pH ranged from 6.6 - 8.1 (mean 7.5), temperature 27.8˚C - 31.2˚C (mean 29.4), conductivity 610 - 1903 μS/cm, TDS 102 - 450 mg/l, salinity 0.01% - 0.13% and turbidity 2.0 - 45.1 NTU. Fe and Mn ranged from 0.12 - 1.23 mg/l and 0.12 - 0.92 mg/l, respectively. Calcium, chloride and total hardness also ranged from 23 - 70 mg/l (mean 36.1 mg/l), 59 - 105 mg/l (mean 81.8 mg/l) and 60 - 140 mg/l (mean 104.7 mg/l), respectively. Other variations were as follows; PO_4^{2-}-P 0.15 - 10 mg/l (mean 2.23 mg/l), SO_4^{2-} 16.1 - 33.8 mg/l (mean 25 mg/l), NO_3^--N (0.23 - 21.02 mg/l (mean 5.6 mg/l), DO 0.26 - 1.64 mg/l (mean 0.94 mg/l), BOD 0.03 - 1.04 mg/l (mean 0.20 mg/l) and COD 0.12 - 1.93 mg/l (mean 0.93 mg/l).

Table 2. (a) Physico-chemical data from landfill leachate from January to June, 2004, Accra, Ghana; (b) Physico-chemical data from River water from January to June, 2004, Accra, Ghana.

(a)

Month	Spl. Pt	pH	Temp (˚C)	Cond. ×10^3 (μS/cm)	TDS ×10^3 (mg/l)	Salinity (%)	Turb. (NTU)	Fe (mg/l)	Cd (mg/l)	Zn (mg/l)	Mn (mg/l)	Ca^{2+} (mg/l)	Cl^- (mg/l)	Total Hard (mg/l)	PO_4^{2-}-P (mg/l)	SO_4^{2-} (mg/l)	NO_3^--N (mg/l)	DO (mg/l)	BOD (mg/l)	COD (mg/l)
	OS1	6.61	35.3	21.61	10.80	1.31	41.0	18.00	2.45	0.28	0.12	241	2730	1000	22.80	68.30	41.52	0.63	0.81	1.28
Jan	OS2	7.59	28.3	24.82	7.58	0.88	36.2	14.00	0.00	0.18	0.15	168	1936	800	30.00	63.20	33.03	0.99	0.36	1.23
	OS3	7.68	28.3	23.13	9.01	0.95	31.2	9.78	0.05	0.12	0.14	160	1986	600	17.00	43.10	26.01	0.42	0.76	2.01
	OS1	7.57	32.3	24.28	12.46	1.52	55.0	10.20	1.23	0.07	0.19	348	2878	1200	18.60	63.70	15.23	0.51	0.23	1.32
Feb	OS2	7.61	29.4	15.12	8.97	1.12	48.1	10.10	0.01	0.02	0.35	326	2356	900	17.30	58.50	14.76	0.48	0.31	1.41
	OS3	7.54	28.7	16.83	9.66	0.98	21.1	5.87	0.08	0.09	0.12	189	1782	110	11.30	48.90	12.53	0.47	0.12	1.23
	OS1	7.63	32.7	7.96	10.79	1.51	56.1	8.78	0.98	0.05	0.23	356	2913	1100	18.90	65.10	5.02	0.13	0.21	1.04
Mar	OS2	7.65	29.5	8.23	8.62	1.01	43.0	5.89	0.21	0.06	0.32	342	2798	1000	14.90	56.30	4.89	0.52	0.42	0.43
	OS3	7.58	28.8	18.34	4.22	0.54	23.1	4.98	0.03	0.03	0.28	289	1189	900	11.80	44.00	2.43	0.39	0.81	1.03
	OS1	7.75	27.8	24.43	13.20	2.02	54.9	6.32	0.78	0.04	0.34	287	2889	1200	16.00	59.90	4.25	0.18	0.12	1.06
Apr	OS2	6.98	28.7	20.03	1.12	1.68	60.1	4.32	0.52	0.03	0.94	291	2098	1000	17.00	49.40	9.03	0.38	0.25	0.96
	OS3	7.87	29.6	18.34	9.08	0.64	56.1	2.05	0.43	0.02	0.12	321	1234	800	8.23	42.30	8.05	0.09	0.21	0.86
	OS1	7.65	29.8	24.28	11.22	1.98	48.9	5.32	0.46	0.03	0.72	342	2798	1300	16.50	52.20	3.23	1.02	1.03	1.89
May	OS2	7.36	27.8	21.74	11.88	1.23	50.9	4.82	0.62	0.02	0.45	329	2869	1000	20.00	49.00	9.23	0.48	0.93	1.07
	OS3	6.79	29.4	20.04	11.24	0.56	35.7	3.48	0.64	0.03	0.23	162	2691	104	9.46	32.80	8.24	0.28	0.96	0.89
	OS1	7.21	32.2	23.87	10.90	2.01	52.9	6.98	0.38	0.04	0.23	321	2967	1100	12.10	40.80	3.02	0.92	0.78	1.74
Jun	OS2	7.13	30.1	24.89	12.45	1.02	56.8	6.05	0.64	0.05	0.94	340	2106	1000	10.20	32.70	1.03	1.02	0.34	1.29
	OS3	7.77	28.8	20.65	1.26	0.18	3.1	5.89	0.84	0.07	0.67	169	1030	900	9.34	28.60	9.01	1.03	0.56	0.89
WHO limit		**6.5 - 8.5**	**-**	**-**	**1000**	**-**	**5**	**3**	**0.003**	**3**	**0.50**	**200**	**250**	**500**	**-**	**400**	**10**	**-**	**-**	

(b)

Month	Spl. Pt	pH	Temp (˚C)	Cond. ×10^3 (μS/cm)	TDS (mg/l)	Salinity (%)	Turb. (NTU)	Fe (mg/l)	Cd (mg/l)	Zn (mg/l)	Mn (mg/l)	Ca^{2+} (mg/l)	Cl^- (mg/l)	Total Hard (mg/l)	PO_4^{2-}-P (mg/l)	SO_4^{2-} (mg/l)	NO_3^--N (mg/l)	DO (mg/l)	BOD (mg/l)	COD (mg/l)
	OS4	6.56	29.7	610	402	0.02	2.6	0.86	0.01	0.01	0.47	25	75	120	10.00	28.80	10.89	1.64	0.08	1.68
Jan	OS5	7.69	29.9	870	450	0.04	3.0	0.78	0.03	0.02	0.46	26	78	130	8.58	30.10	20.78	1.58	0.05	1.32
	OS6	7.84	30.1	790	305	0.03	2.7	0.87	0.02	0.03	0.51	28	73	140	5.02	29.30	10.41	1.61	0.06	1.93
	OS4	8.13	27.9	830	308	0.13	4.3	0.45	BD	BD	0.15	28	87	109	0.64	33.80	0.35	0.75	0.14	1.49
Feb	OS5	7.89	28.8	740	360	0.09	3.7	0.41	BD	BD	0.13	25	79	108	0.34	27.00	0.41	0.69	0.15	1.85
	OS6	7.97	29.5	630	415	0.08	4.1	0.32	BD	BD	0.18	25	85	108	0.15	27.00	0.95	0.73	0.11	1.34
	OS4	8.02	28.6	670	424	0.05	3.2	0.14	BD	BD	0.18	24	59	109	0.18	23.70	0.56	0.48	0.12	1.06
Mar	OS5	7.98	29.1	710	209	0.08	3.0	0.12	BD	BD	0.16	23	76	107	0.16	28.40	0.82	0.67	0.09	0.98
	OS6	6.99	28.4	740	322	0.07	2.3	0.13	BD	BD	0.12	24	74	108	0.19	29.70	0.68	0.63	0.07	1.06
	OS4	7.94	30.4	850	428	0.01	45.1	0.21	BD	BD	0.34	32	97	120	2.04	25.50	1.08	1.03	0.09	1.23
Apr	OS5	6.89	29.8	980	354	0.03	7.0	0.19	BD	BD	0.18	24	87	110	3.78	30.60	1.05	1.12	0.03	0.84
	OS6	7.58	28.5	780	352	0.02	7.1	0.19	BD	BD	0.92	28	59	100	1.78	29.40	0.96	0.94	0.06	0.67
	OS4	6.97	27.8	1080	122	0.08	4.0	0.12	BD	BD	0.46	62	89	100	1.05	18.90	0.23	0.26	0.03	0.21
May	OS5	7.02	30.4	690	328	0.02	4.7	0.17	BD	BD	0.28	59	97	102	1.89	19.10	0.34	0.96	1.04	0.12
	OS6	7.12	31.2	790	425	0.04	2.7	0.23	BD	BD	0.61	70	76	104	1.29	17.90	1.23	0.85	0.38	0.14
	OS4	6.69	28.4	1903	102	0.05	2.9	1.23	BD	BD	0.21	34	105	80	0.69	16.10	21.02	1.05	0.34	0.28
Jun	OS5	7.56	29.6	1480	403	0.03	2.0	1.02	BD	BD	0.16	42	100	70	1.05	17.20	20.03	1.01	0.45	0.31
	OS6	8.12	31.2	1263	324	0.04	2.7	0.23	BD	BD	0.61	70	76	60	1.29	18.20	8.56	0.85	0.38	0.14
WHO limit		**6.5 - 8.5**	**-**	**-**	**1000**	**-**	**5**	**3**	**0.003**	**3**	**0.50**	**200**	**250**	**500**	**-**	**400**	**10**	**-**	**-**	

BD: below detection. Distances of sample sites from landfill: OS4: 220 m; OS5: 230 m; OS6: 250 m.

4.3. Comparison of Data with WHO and UNEP Values

Compared to WHO [22] and WHO/UNEP [23] values, leachate and river water in the present study appear to have fairly high conductivity and, to some extent, high Mn, Ca and Cl contents. Leachate, however, registered total hardness values above WHO guideline values whereas corresponding river water values were below WHO values (see **Table 2**). Comparatively low values in river water than leachate probably reflect the extent of dilution in the river water compared to the narrower, low volume and channelized leachate.

4.4. Correlation Coefficients

Table 3 gives the correlation coefficients between measured parameters determined in leachate and river water samples. In leachate samples, strong to moderate positive correlations appear to exist mainly between NO_3^--N and Zn (0.96), NO_3^--N and Fe (0.85), NO_3^--N and PO_4^{2-}-P (0.67), Zn and Fe (0.86), Cl^- and each of TDS (0.69), salinity (0.74) and turbidity (0.60) and PO_4^{2-}-P and Fe (0.75). Ca^{2+} also correlates positively with turbidity (0.73) as are Cd and temperature (0.75) and turbidity and salinity (0.69). Similar positive correlations also exist between SO_4^{2-} and each of Fe (0.64) and PO_4^{2-}-P (0.78). Other relationships vary from weak to only slightly positive or negative (**Table 3**). The river water samples also show positive relationships between NO_3^--N and DO (0.61), SO_4^{2-} and COD (0.79), PO_4^{2-}-P and DO (0.85), total hardness and each of SO_4^{2-} (0.69) and COD (0.74), Fe and NO_3^--N (0.89), Fe and DO (0.64) and conductivity and NO_3^--N (0.65). Negative correlations are also shown by the pairs

Table 3. Correlation coefficients between measured parameters in landfill leachate (above) and river water samples (below), Accra, Ghana.

	pH	Temp. (˚C)	Cond. (mS/cm)	TDS (mg/l)	Salinity (%)	Turb. (NTU)	Fe (mg/l)	Cd (mg/l)	Zn (mg/l)	Mn (mg/l)	Ca^{2+} (mg/l)	Cl^- (mg/l)	Total Hard (mg/l)	PO_4^{2-}-P (mg/l)	SO_4^{2-} (mg/l)	NO_3^--N (mg/l)	DO (mg/l)	BOD (mg/l)	COD (mg/l)
pH		–0.45	–0.20	–0.09	–0.11	–0.16	–0.25	–0.52	–0.35	–0.15	0.13	–0.32	0.19	–0.08	0.05	–0.28	–0.10	–0.36	0.00
Temp. (˚C)	0.07		–0.11	0.30	0.29	0.26	0.55	0.75	0.46	–0.24	0.29	0.40	0.29	0.16	0.39	0.30	0.07	0.08	0.15
Cond. (mS/cm)	–0.24	–0.08		0.17	0.20	0.04	0.13	0.13	0.19	0.20	–0.25	–0.02	0.12	0.12	–0.21	0.22	0.47	0.28	0.54
TDS (mg/l)	0.30	0.50	–0.50		0.44	0.49	0.16	0.24	0.03	–0.32	0.32	0.69	0.09	0.12	0.29	–0.01	–0.11	0.05	0.29
Salinity (%)	0.32	*–0.61*	–0.09	–0.34		**0.69**	0.13	0.20	–0.08	0.14	0.53	**0.74**	*0.58*	0.31	0.49	–0.13	0.01	–0.07	0.41
Turb. (NTU)	0.20	0.21	–0.07	0.23	–0.33		–0.05	0.17	–0.26	0.17	0.73	*0.6*	0.51	0.20	0.37	–0.20	–0.26	–0.24	0.07
Fe (mg/l)	–0.22	–0.01	*0.56*	–0.10	–0.16	–0.21		0.47	**0.86**	–0.37	–0.20	0.24	0.16	**0.75**	*0.64*	**0.85**	0.25	0.00	0.32
Cd (mg/l)	–	-	-	-	-	-	-		0.52	–0.04	0.09	0.35	0.30	0.19	0.33	0.37	–0.01	0.10	–0.08
Zn (mg/l)	-	-	-	-	-	-	-	-		–0.37	–0.46	0.02	–0.08	0.58	0.43	**0.90**	0.26	0.08	0.17
Mn (mg/l)	–0.05	0.32	–0.06	0.10	–0.48	0.03	–0.06	-	-		0.26	–0.08	0.35	–0.20	–0.38	–0.45	0.41	0.03	–0.03
Ca^{2+}(mg/l)	–0.16	0.45	0.28	–0.16	–0.17	–0.08	–0.19	-	-	0.39		0.42	**0.71**	–0.04	0.29	–0.51	–0.12	–0.17	–0.07
Cl^-(mg/l)	–0.28	0.06	*0.59*	–0.32	0.00	0.28	0.37	-	–	–0.43	0.23		0.34	0.37	0.50	–0.02	–0.06	0.15	0.18
Total. Hard (mg/l)	0.04	–0.03	**–0.67**	0.29	–0.02	0.21	–0.04	-	-	0.01	–0.53	–0.30		0.30	0.39	–0.17	0.23	–0.03	0.12
PO_4^{2-}-P (mg/l)	–0.31	0.30	–0.18	0.32	–0.46	–0.02	0.43	-	-	0.34	–0.19	–0.13	0.50		0.78	*0.67*	0.14	–0.01	0.19
SO_4^{2-} (mg/l)	0.26	–0.27	*–0.61*	0.27	0.27	0.07	–0.14	-	-	–0.09	**–0.76**	–0.43	**0.69**	0.33		0.46	–0.23	–0.30	0.02
NO_3^--N (mg/l)	–0.18	0.14	*0.65*	–0.05	–0.31	–0.21	**0.89**	-	-	0.06	–0.03	0.32	–0.20	0.46	–0.27		0.11	0.07	0.24
DO (mg/l)	–0.19	0.46	0.02	0.32	–0.57	0.05	*0.64*	-	-	0.29	–0.24	0.04	0.40	**0.85**	0.26	*0.61*		0.31	0.37
BOD (mg/l)	–0.18	0.40	0.20	–0.02	–0.26	–0.13	0.04	-	-	–0.05	*0.59*	0.43	–0.44	–0.19	*–0.62*	0.09	–0.02		0.34
COD (mg/l)	0.33	–0.18	–0.53	0.32	0.24	0.11	0.17	-	-	–0.22	*–0.8*	–0.32	**0.74**	0.37	0.79	–0.07	0.36	–0.58	

Boldface = significance at 0.01 level; Italics = significance at 0.05 level.

Ca^{2+} and SO_4^{2-} (–0.76), Ca^{2+} and COD (–0.76), conductivity and total hardness (–0.67), conductivity and SO_4^{2-} (–0.61), temperature and salinity (–0.61) and SO_4^{2-} and BOD (–0.62). Other pairs of parameters seem to show little or no correlations with one another (**Table 3**).

4.5. Multivariate Principal Component (PCA) and Cluster Analyses (CA)

4.5.1. PCA and CA for Leachate

The dendrogram for leachate samples (**Figure 2**) suggests three distinct clusters. Cluster 1 consists of pH, Mn, BOD, DO, COD and electrical conductivity (EC). Cluster 2 comprises TDS, Cl, Salinity, total hardness, Ca, turbidity and Cd whilst cluster 3 is made up of temperature, SO_4^{2-}, PO_4^{3-}, Fe, NO_3^- and Zn.

Varimax rotation of the landfill leachate data is provided in **Table 4** and the scree plot in **Figure 3**. Principal component 1 (PC1), which explains ~23% of the variance, consists of TDS, salinity, turbidity, Ca, Cl^-, total hardness & SO_4^{2-}. High loading on Ca and total hardness suggests that calcium probably contributes mostly to the hardness of the leachate whereas SO_4^{2-} and Cl^- also suggest increased significance of agricultural and/or organically derived inputs. PC2 loading comprises Fe, Zn, PO_4^{3-}, SO_4^{2-} and NO_3^-. There is strong correlation between cluster 3 and PC2 suggesting that the presence of the metals Fe and Zn in leachate could have come from a common source in the landfill waste or material. PO_4^{3-}, SO_4^{2-} and NO_3^- are all likely sourced from agricultural or organic wastes in the landfill pile. PC3 is controlled by TDS, DO, BOD and COD whilst PC4 consists of pH, temperature and Cd. There is a negative loading of pH as compared to a positive loading of Cd. PC5 loading is made up of Mn, total hardness and DO.

4.5.2. PCA and CA for River (Densu) Water

The interrelationships between the various parameters measured for the river water samples are given by the dendrogram (**Figure 4**) three different clusters. Cluster 1 consists of mainly SO_4^{2-}, COD, total hardness, TDS, pH, turbidity and salinity. Cluster 2 comprises PO_4^{2-}, DO, temperature and Mn whilst cluster 3 is made up of Fe, NO_3^-, electrical conductivity, Cl, Ca, and BOD.

Table 5 and scree plot (**Figure 5**) suggest that up to ~89% of the original mean logs of the dataset is gathered in the first six components with Eigen values > 1. Principal Component 1 (PC1) gives ~27% of the variance and the parameters that are loaded in this component include electrical conductivity, Ca, total hardness, SO_4^{2-} and BOD. High loading of sulphate to water chemistry suggests contribution from agricultural activities such as use of fertilizers. PC2 consists of mainly electrical conductivity, Fe, NO_3^- and DO. High loadings of Fe may suggest dissolution of Fe-bearing bedrock in river water since the Densu River is known to drain iron-rich Birimianmetasedimentary and metavolcanic rocks in the eastern region of Ghana. Again, anthropogenic activities may not also be ignored as suggested by the high loading on nitrate. PC3 is loaded with temperature, TDS, salinity and DO whilst PC4, PC5 and PC6 are loaded with Cl^-, pH and turbidity, respectively.

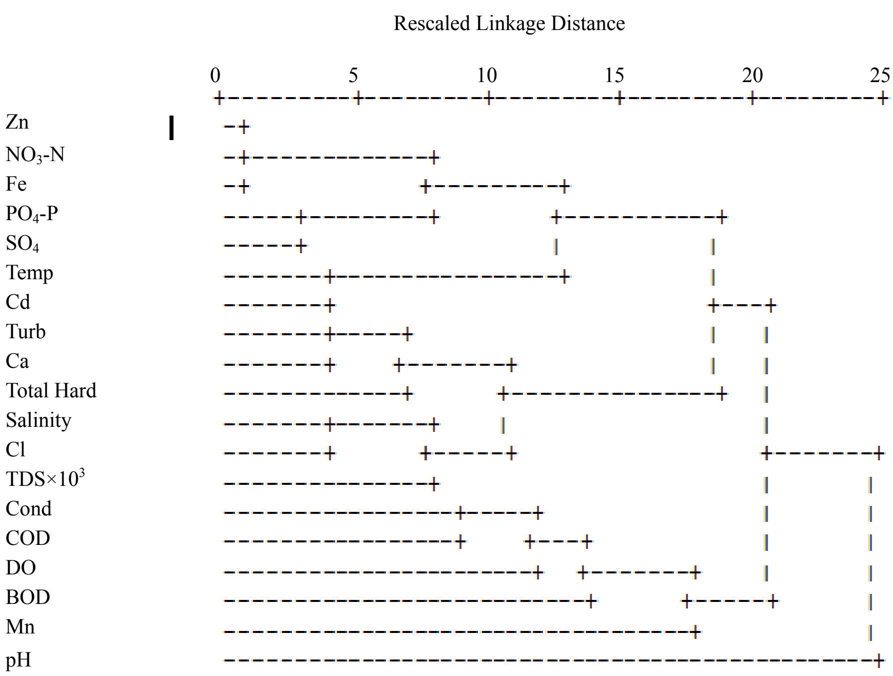

Figure 2. Dendrogram of landfill leachate parameters.

Table 4. Rotated component matrix for landfill leachate data.

	Component				
	1	2	3	4	5
pH	0.02	0.00	–0.22	**–0.83**	0.05
Temp	0.32	0.34	–0.09	**0.73**	–0.02
Cond	0.01	0.08	**0.80**	0.02	0.15
TDS	**0.62**	0.03	0.23	0.15	**–0.55**
Salinity	**0.87**	0.12	0.21	0.02	0.06
Turb	**0.86**	–0.07	–0.10	0.08	0.01
Fe	0.03	**0.92**	0.13	0.27	–0.03
Cd	0.19	0.32	–0.09	**0.81**	0.09
Zn	–0.27	**0.82**	0.14	0.39	–0.06
Mn	0.10	–0.42	0.17	0.04	**0.78**
Ca^{2+}	**0.81**	–0.23	–0.29	0.01	0.27
Cl^{-}	**0.78**	0.11	0.12	0.31	–0.26
Total Hard	**0.67**	0.17	–0.02	–0.01	**0.62**
PO_4-P	0.25	**0.85**	0.09	–0.07	0.05
SO_4^{2-}	**0.51**	**0.75**	–0.31	–0.02	–0.11
N-NO^{3-}	–0.28	**0.86**	0.16	0.22	–0.18
DO	–0.14	0.15	**0.62**	0.06	**0.56**
BOD	–0.13	–0.16	**0.60**	0.35	–0.07
COD	0.23	0.21	**0.79**	–0.14	-0.10
Eigenvalues	4.296	4.159	2.471	2.429	1.832
% of Total variance	22.61	21.89	13.00	12.78	9.64
Cumulative %	22.61	44.50	57.51	70.29	79.93

5. Discussion and Environmental Implications

The eight ionic species dominant in leachate, *i.e*. Ca, Cl, SO_4 (PC1), Fe, Zn, PO_4, SO_4, NO_3 (PC2), Cd (PC4) and Mn (PC5) (**Table 4**) suggest decomposition of landfill materials through a combination of physico-chemical (inorganic) and biological (organic) processes and subsequent release into the effluent discharge or leachate. The seasonally wet and dry climate, together with the generally heterogeneous, unsorted or mixed nature of refuse dumped at the landfill site, may have enhanced leaching of both organic and inorganic constituents of decomposing waste by percolating rain water. Tigme [14] characterized waste at the Oblogo landfill site into dominantly organic components (70%) followed successively by inert material (13%), plastics (9%), metal scraps (4%), paper (3%) and textile products (1%). The Togo host rocks [15] within which the landfill is situated is dominantly composed of quartzite and sandstone and may, hence, not contain significant amounts of ionic species such as observed in leachate, suggesting that most of these species were derived from refuse at the landfill. Though the proportion metals in the waste stream is low [14], the fairly significant presence of some metals in leachate may be an indication of the extent of decomposition of the metallic constitutents of the waste. The relatively high Ca, Cl and nutrient contents are likely reminiscent of decomposition from the high agricultural or organic inputs of waste.

In river water, Fe, Mn, SO_4 and NO_3 are the most sig-

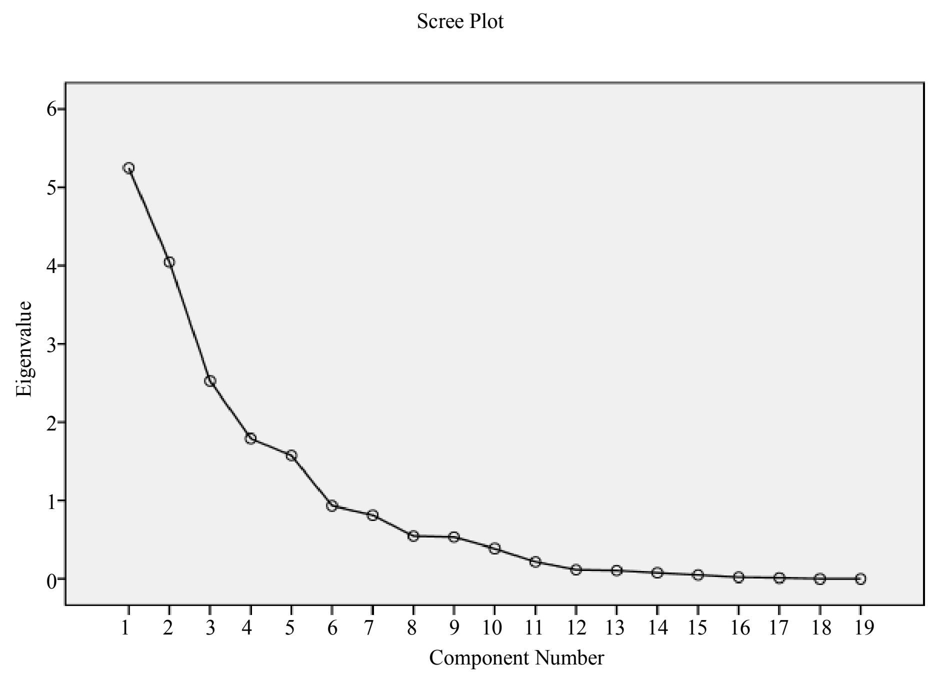

Figure 3. Scree plot of eigenvalues for landfill leachate.

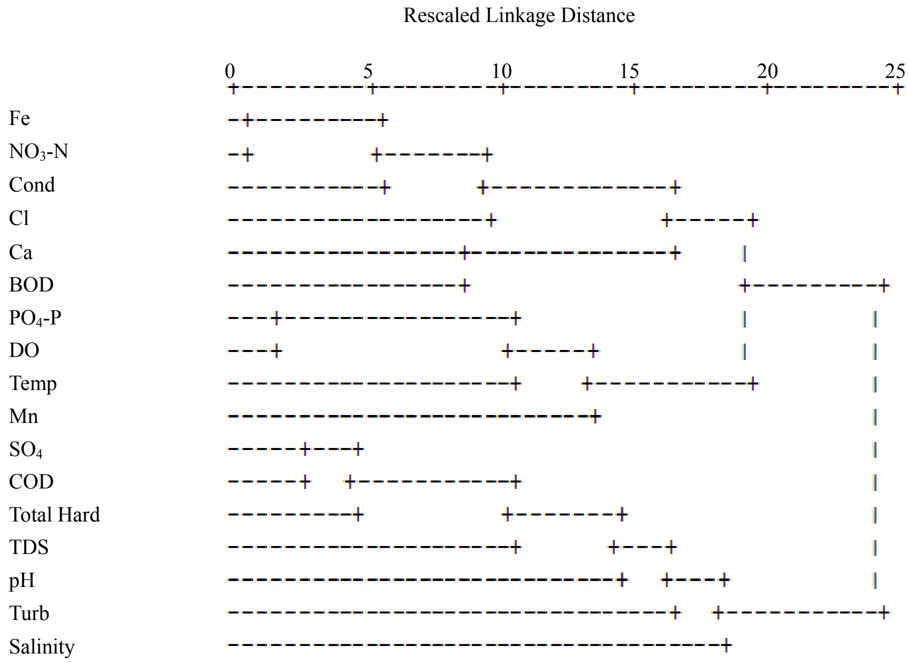

Figure 4. Dendrogram for river water data.

Table 5. Rotated component matrix for river water data.

	Component					
	1	2	3	4	5	6
pH	0.17	–0.14	0.12	0.00	**0.92**	0.06
Temp	–0.29	0.07	**0.85**	0.14	0.01	0.15
Cond	**–0.58**	**0.66**	–0.38	–0.08	0.01	0.17
TDS	0.29	–0.09	**0.77**	0.06	0.28	0.03
Salinity	0.18	–0.25	**–0.57**	–0.39	0.34	–0.37
Turb	0.11	–0.15	0.17	–0.03	0.09	**0.95**
Fe	0.06	**0.95**	0.00	–0.13	–0.11	–0.09
Mn	–0.16	0.02	0.20	**0.91**	–0.10	0.04
Ca^{2+}	**–0.85**	–0.16	0.19	0.18	–0.12	–0.04
Cl^-	–0.38	0.34	–0.07	**–0.65**	–0.24	0.41
Tot Hard	**0.83**	–0.15	0.22	0.04	–0.24	0.09
PO_4-P	0.45	0.45	0.43	0.32	–0.44	–0.05
SO_4^{2-}	**0.91**	–0.15	–0.02	0.05	0.08	–0.05
NO_3^--N	–0.12	**0.96**	0.08	0.03	–0.04	–0.07
DO	0.36	**0.65**	**0.53**	0.18	–0.29	0.05
BOD	**–0.69**	–0.03	0.43	–0.37	–0.19	–0.15
COD	**0.92**	0.08	0.09	–0.11	0.19	–0.03
Eigenvalue	4.664	3.188	2.619	1.753	1.558	1.324
% of Total Variance	27.43	18.76	15.41	10.31	9.16	7.79
Cumulative %	27.43	46.19	61.60	71.91	81.07	88.86

nificant species. Because the Densu River drains a significant portion of Fe and Mn-containing Birimian rocks [15], these two elements could have been sourced from the dominant underlying geological formation. Again, increased human activities such as use of fertilizers in subsistence agriculture in the Densu River catchment area may have contributed significant SO_4 and NO_3 contents to the river water.

Farquhar [1] who provided data on expected contaminant types and ranges of concentrations in leachate as function of refuse age noted chloride concentrations of 1000 - 3000 mg/l for landfills in age category 0 - 5 years. Because chloride contents obtained in leachate in this study agrees fairly well or falls within this range, it could reasonably be predicted that various physico-chemical and biological decomposition processes within the landfill may result in increased pollutant levels in leachate which would, in turn, be shed into the surrounding media for well some time before decreases in concentrations could be expected as the landfill ages [1]. As observed by Mizumura [24], chloride ion is non-reactive, non-sorptive and has no redox or precipitation. This suggests that much of the chloride in the leachate plume will find its way into the surrounding river and groundwater as well as soils.

Because the rocks in which the landfill is situated are highly bedded [15], the landfill not engineered [11] andno leachate collection systems in place, continuous discharge of leachate may pose serious threats to the surrounding soils, water bodies, the Densu Ramsar wetland area and also possibly on the health of people who

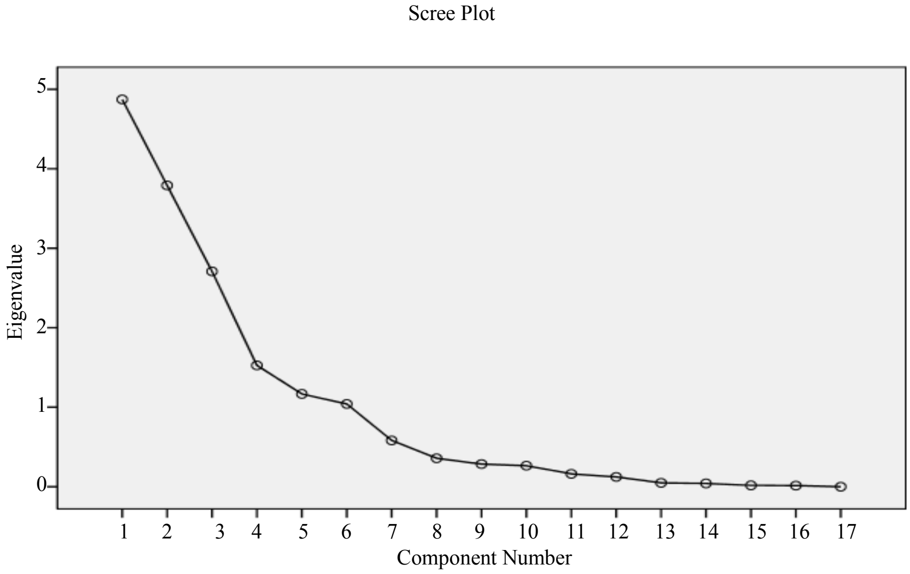

Figure 5. Scree plot of eigenvalues for river water.

depend a lot on the environmental resources of the area [25]. Furthermore, local communities and especially the urban poor who live around the landfill utilize water (from rivers, streams, shallow wells and boreholes) and soils for domestic and subsistence agriculture. Others also undertake fishing activities as a means of livelihood [26]. Food crops grown and the fish obtained from these areas mainly go to feed the urban population. Leachate also egresses through many low-income residential areas, presenting potential threats to the health of people especially children who constantly attend school in or play around such leachate contaminated areas.

Authors including Combs Jr. [27], Nordberg & Cherian [28], Frew [29] and Kurniawan [30] have pointed out adverse health effects of substances such as cadmium, chloride and zinc all of which occur in the leachate samples studied. As noted by Oteng-Yeboah [17], the wetland is known to be very rich in various species of fauna and flora and therefore deserves maximum protection, not the least from contamination through landfill leachate which could be controlled or managed. Loss of biodiversity in the internationally recognized Densu Wetland as a result of pollution from the landfill leachate could also not be entirely ruled out. Assessment techniques to provide information on early warning indicators of pollution in the wetland, as suggested by Van Dam *et al*. [31], could provide an important first step towards sustainable management of this ecologically important wetland and surrounding environment. Kao *et al*. [32] also suggested using network Geographic Information System (GIS) for the siting of landfills in order to reduce the potential for spread of infection through run off during rain as well as groundwater contamination.

Effects of landfill leachate on surrounding media, some resulting directly from pollutants in leachate or through bioaccumulation of leachate constituents in living organisms over time, have been documented by workers such as Schrab *et al*. [6], Stephens *et al*. [33], Kjeldsen *et al*. [4]. Kurniawan *et al*. [34-36] have worked extensively on recalcitrant contaminants in landfill leachate especially those that pose serious hazards not only to living organisms but also to public health in the long term. In Uganda, Nigeria and many other countries [8,9,37], the potential effect of leachate on surface and groundwater resources could be very significant. Rocks within which the landfill is located have a well bedded structure [38,39] and, in addition, typically weather into permeable sandy to silty soils. In addition, absence of bottom liners and artificially constructed drains to trap and channel leachate into channelized flow, respectively, likely promote increased infiltration of leachate into the surrounding environment.

Research to investigate the distribution and possible attenuation of hazardous substances in uncontrolled leachate from landfills [40], especially if done at many such landfills in the Accra Metropolis and throughout the country, could help provide invaluable data for remediation efforts. In addition, assessment of the spatial variability in leachate migration from landfills along the lines done by Kjeldsen [4] in Denmark could help identify plumes of pollution that may be contaminating various media around landfills. Finally, because chloride is non-reactive, non-sorptive and has no redox or precipitation, it is often used as a tracer element in leaching studies in soils [24,41,42]. Mizumura [24], in particular, investigated the influence of leachate plumes from sanitary landfills on groundwater by determining the concentration of chloride ion in the groundwater, soil water and river and observed that most of the leachate plume was discharged into a river whilst the remainder infiltrated into the ground through the weathered geological layer near the landfills. Such investigations may also be relevant in the present situation given that untreated leachate not only directly drains into the Densu River and adjoining Ramsar wetland (at a distance less than 0.3 km from the point or landfill source) but also egresses continuously through households, soils and possibly into the groundwater system in the area.

6. Conclusion

The current study has revealed fairly high levels of ionic constituents including Cl, SO_4, PO_4, NO_3 and moderate to high contents of Ca, Cd and Zn in leachate discharged without treatment from the Oblogo landfill site in Accra into the immediately surrounding environment, a situation which makes the area very vulnerable to pollution. The significantly high concentrations of chloride and, to some extent, other chemical species, present formidable challenges that may need to be addressed in order to minimize possible short- and long-term stresses on the immediate environment. It is suggested that simple but cost-effective techniques such as construction of manually excavated holes or ponds ("dug-outs") in the vicinity of the landfill to impound leachate for considerable period of time could provide a necessary first step towards facilitating natural breakdown or settling of some constituents in leachate. The "environmental cost" of any such initiative could, under the circumstances, be a much better option than the present indiscriminate and uncontrolled discharge of leachate into the immediate ecologically important Ramsar environment. Ultimately, the risks posed by possible organic contaminants, pathogenic microorganisms and other toxic substances that may additionally be present in leachate would have to be analyzed and/or monitored to also prevent or minimize their impact on the environment. In addition, it may be necessary to study the leachate migration patterns in tandem with leachate composition to gather information for future planning and remediation efforts.

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