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Physicochemical characterization of an artificial pond receiving leachate influx at Aba-Eku dumpsite, Ibadan, Nigeria

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ABSTRACT

Proper leachate treatment is necessary to avoid adverse environmental impact. An artificial pond receiving leachate influx from the Aba-Eku dumpsite, Ibadan, South-Western Nigeria, was characterized to provide baseline information for appropriate treatment. Pond leachate and comparative groundwater control were sampled monthly between January 2003 and September 2004. The pH, TSS, total solids, conductivity and COD were analyzed using American Public Health methods. Calcium, magnesium and selected metals were determined using Inductively Coupled Plasma; selected anions and ammonia were determined using Ion Chromatography. T-test and correlation coefficients were used for data analysis. Results: pH: 8,21, TSS:1 44,94mg/l, total solids:1377,67mg/l, conductivity:2466,00us/cm and COD:57,63mg/l were significantly elevated ($p<0,05$) above control; pH: -7,79; TSS: 42,96mg/l, total solids:119,52mg/l, conductivity:153,09us/cm and COD: 9,80mg/l. Calcium and magnesium in leachate differed significantly from control. Metals in leachate and control showed no significant differences except for iron (5,27; 0,82mg/l); manganese (2,31; 0,04mg/l) and cadmium; (0,157; 0,03mg/l). Lead, copper, zinc, chromium and nickel were not significantly different from control. Chloride (597,98; 5,24mg/l), nitrate (12,3; 2,35mg/l) and sulphate – 118,86; 3,09mg/l) in leachate and control however differed significantly, phosphate was not detected. Ammonium correlated negatively with nitrate(-0,608) and sulphate(-0,676) $p<0,05$. Attenuation processes reduced contaminant levels. Similarities in metal content may be due to increased leachate pH which consequently reduced metal solubility. Suspended solids and chloride were parameters of concern. Nitrates and sulphates increased in the wet season probably due to ammonium oxidation reactions. There is minimal need for treatment. However, polishing of leachate effluent via physico-chemical methods may be considered.

KEY WORDS

Landfill, contaminants, leachate characterization, natural attenuation, treatment.

RESUMEN

El tratamiento de lixiviados debe ser adecuado para disminuir el impacto ambiental. En la localidad de Aba-Eku, Ibadan al suroeste de Nigeria, se encuentra una laguna de lixiviados donde se efectúa un tratamiento correcto. Durante enero del 2003 y setiembre del 2004 se tomaron muestras comparativas mensuales a la laguna y a las aguas subterráneas de: pH, TSS, solidos totales, conductividad y DQO. Se analizaron con métodos del Departamento de Salud Pública de los Estados Unidos. El calcio y el magnesio se determinaron por medio del plasma de acoplamiento inductivo, aniones seleccionados y el amoníaco por cromatografía iónica. Los coeficientes de prueba T y la correlación se utilizaron para el análisis de datos. Los resultados fueron los siguientes: pH: 8,21, SST: 144,94mg/l, sólidos totales: 1377,67mg/l, conductividad: 2466,00 us/cm y COD: 57,63mg/l fueron significativamente elevados ($p<0,05$) por encima del testigo, pH: -7,79; TSS: 42,96mg/l, sólidos totales: 119,52mg/l, conductividad: 153,09us/cm y COD: 9,80mg/l. El calcio y magnesio en lixiviados difieren significativamente del testigo. Metales en el lixiviado y el testigo no mostraron diferencias significativas con excepción del hierro (5,27; 0,82mg/l), manganeso (2,31; 0,04mg/l) y el cadmio; (0157, 0,03mg/l). Plomo, cobre, zinc, cromo y níquel no fueron significativamente diferentes del testigo. Cloruro (597,98; 5,24mg/l), nitrato (12,3; 2,35mg/l) y el sulfato - 118,86; 3,09mg/l) en el lixiviado y el testigo, sin embargo diferían significativamente y no se detectó fosfato. El amonio se correlacionó negativamente con el nitrato (-0,608) y sulfato (-0,676) $p <0,05$.

PALABRAS CLAVE

Laguna de lixiviados, contaminantes, caracterización de lixiviados.

INTRODUCTION

Land disposal or landfilling is one of the major disposal methods in the solid waste management system (Ziyang et al. 2009). Landfills release a wide range of chemical compounds in the entire life cycle due to the waste degradation. Leachate is described as the water based solution of the compounds from solid wastes dumped in a landfill. Organic and inorganic constituents are taken up by the leachate through various physical, hydrolytic and fermentative processes. Thus it contains a high concentration of organic matter and inorganic ions, including heavy metals (Tchobanoglous et al. 1993). The release of indeterminate volumes of leachate can introduce risks to public health and the surrounding environment, particularly for the organisms in surface water receptors into which the leachates discharge (Christensen et al. 2001). Proper mitigation of such risks is recognized as one of the most critical issues for the landfill operator (Bilgili et al. 2008).

Leachates are usually treated before their discharge into the environment by a variety of physico-chemical and biological treatment methods such as chemical coagulation-precipitation, activated carbon adsorption as well as anaerobic and aerobic biological degradation (Durmusoglu & Yilmaz 2006). Some other methods include recirculation options and natural systems using constructed wetlands, gravel filtration, and waste stabilization ponds amongst others (Aluko et al. 2003, Kurniawan et al. 2006). The leachate quality plays a key role in the selection of a suitable means of treatment. According to Koerner & Soong (2000), an understanding of the characteristics of landfill leachates is necessary for its proper treatment. Furthermore, El-Fadel et al. (2002) highlighted the characterization of leachate quality as a critical factor in the establishment of an effective management strategy or treatment process. This is essential as leachate quality varies from site to site as well as seasonally (Durmusoglu & Yilmaz 2006). These differences may be due to the variability in waste composition, climate and operations of the landfill from site to site, amongst other factors (El-Fadel et al. 2002).

The Aba-eku site (Fig. 1) is an uncontrolled landfill which has been in use since 1994. It is located at km 13 along Akanran – Ijebu Igbo road in Ona-Ara Local Government Area and is a major repository for municipal solid wastes in Ibadan. In 1996, attempts were made by the state government to improve and upgrade the site to sanitary landfill status. This led to its subsequent closure and later reopening in 1999, after a collection system was incorporated to drain the leachates (via a system of pipes and drainage channels) into a central pond down-gradient of the dumpsite. Leachate treatment at the site is however uncertain. The pond receives leachate influx which is then discharged directly via an outlet into the Omi stream. The discharge of untreated or poorly treated leachate has implications for the organisms present in the receiving stream and highlights the need for adequate leachate treatment. Literature search showed that leachates draining into the pond at this site have not been previously studied. Previous studies (Aluko et al. 2003; Bakare & Wale-Adeyemo 2004) have focused only on raw leachate obtained directly from drains on the active fill area where domestic wastes are dumped. Hence this study characterized the leachates of the pond to complement the existing studies. This is to provide adequate baseline information necessary for appropriate leachate treatment.

METHODOLOGY

Study site

The study was carried out for 21 months (January 2003 -September 2004) on the leachate pond draining the Aba-Eku / Akanran refuse landfill site. The pond is situated within the same perimeter fence of the landfill/dumpsite, but at a distance of 250m down gradient of the active fill area, where domestic and industrial solid wastes are dumped. This distance was determined with the aid of a Geographical Positioning System (GPS) 76 garnier model. Geographically, the active fill area is located at the point (07°19’27,4” N and 003°59’14,3” E) at 160m in elevation, while the study site (i.e. the leachate collection pond) is located at the point (07°19’31,2” N and 003°59’22,7” E) at 149m in elevation. Leachates from the pond are discharged via an outlet into the nearby Omi stream which flows past the Aba-Eku settlement.

Average annual rainfall over the study area is 1390mm; average maximum temperature is 32,1°C; average minimum temperature is 23,0°C; while average relative humidity is 79,8% (Nigerian Meteorological Agency Climatic Records). Two plants dominate the vegetation in the vicinity of the study area. These are *Chromoleana odorata* (L. King & Robinson) commonly called Siam weed and *Pennisetum purpureum*.

Study system (Sampling, preservation and analytical methods for leachates)

Leachates were collected in two 1,5 litre plastic containers from the leachate pond shown in Fig. 1 monthly from January 2003 to September 2004. They were collected in pre-washed polyethylene bottles and taken to the laboratory. They were stored at approximately 4°C until when analyzed. Analytical parameters determined were:

- pH using a pH meter model PHS-3B; Electrical Conductivity (EC) using a WTW conductivity meter LF 95 model; Total Suspended Solids (TSS); and Dissolved organic matter expressed as Chemical Oxygen Demand (COD) were determined using the method stipulated by APHA (1998).
- Metals and exchangeable cations determined include: Cadmium (Cd), Chromium (Cr), Lead (Pb), Nickel (Ni), Copper (Cu), Zinc (Zn), Iron (Fe) and Manganese (Mn), Calcium (Ca) and Magnesium (Mg). They were preserved as follows: 100ml of sample was acidified with 1ml concentrated nitric acid (HNO_3) for preservation prior to digestion and subsequent analysis. They were then analyzed after nitric – perchloric acid digestion (APHA 1998), using an Inductively Coupled Plasma Optical Emission Spectrophotometer - ICP-OES Perkin Elmer Optima 3000.
- The following anions and ammonium - NH_4^+ were determined using an Ion Chromatograph IC 1010 model with a detection limit of 0,005mg/l (nitrite and phosphate). They include: Sulphates (SO_4^{2-}), Chloride (Cl^-), Nitrates (NO_3^-) Nitrite (NO_2^-) and Phosphates – (PO_4^{3-}).
- Chemical Oxygen Demand (COD) was used as a measure of the organics present in the leachate sample. All analytical procedures were carried out at the Shenyang Institute of Applied Ecology, Shenyang, China.

Water samples used as control were obtained from a well located at a distance of not less than 500m away from the landfill and analyzed for similar parameters to facilitate comparison.

Statistical analysis

Analysis of the data obtained was carried out using the statistical package SPSS 13,0 and Microsoft Excel 2007. Correlation coefficients (for the inter-relationships between the parameters) and t-test (to determine statistically significant differences between the leachate and the control water sample) were the statistical parameters determined using the packages.

FIG. 1. The leachate pond - arrows show the inlet and outlet channels; inset, below left, is the leachate surface covered by floating macrophytes while inset, below right, is the outlet channel.

RESULTS

Leachate composition

The results of the physico-chemical parameters of leachate and control water sample are presented in Table 1. The general parameters: pH, TDS, TSS, TS, EC and COD showed significantly elevated parameters (T-test, $p<0,05$) in the leachate compared to the control (Table 1). Both exchangeable cations determined showed significant differences (T-test, $p < 0,05$) between the leachate and control with the higher concentrations being observed in the leachate. Of all the eight metals, only iron, manganese and cadmium were significantly higher (T-test, $p < 0,05$) in the leachate than the control (Table 1). All the anions determined as well as ammonium showed significantly elevated (T-test, $p < 0,05$) levels in the leachate compared to the control (Table 1). Phosphate and nitrite were below detection limits in both samples.

TABLE 1
Physico-chemical parameters of the leachate and control

	Leachate				Control				T-test
	Min	Max	Mean	± SD	Min	Max	Mean	± SD	Sig. p. 0,05
pH	8,0	8,3	8,2	0,1	7,4	8,1	7,8	0,2	Sig.
TSS	1	460	145	118	0,0	246	43	68	Sig.
TS	433	2091	1378	397	53	342	120	75	Sig.
EC	864	3760	2466	673	107	194	153	29	Sig.
COD	29	84	58	15	4	19	10	4	Sig.
Ca	30	182	86	42	4	50	14	10	Sig.
Mg	18	175	84	41	2	7	3	1	Sig.
Fe	0,3	37,9	5,3	8,9	0,2	2,7	0,8	0,6	Sig.
Mn	0,6	5,3	2,3	1,6	0,00	0,16	0,04	0,04	Sig.
Cu	0,000	0,103	0,014	0,028	0,00	0,35	0,02	0,01	N.S
Zn	0,000	0,300	0,129	0,094	0,00	0,41	0,11	0,11	N.S
Pb	0,008	0,087	0,035	0,019	0,01	0,15	0,05	0,03	N.S
Cd	0,000	0,431	0,157	0,128	0,01	0,22	0,03	0,05	Sig.
Ni	0,000	0,100	0,021	0,022	0,00	0,04	0,01	0,01	N.S
Cr	0,000	0,035	0,013	0,009	0,00	0,05	0,01	0,02	N.S
Cl^-	149	1006	598	210	2	8	5	2	Sig.
$N0_3^-$	0,0	95,1	12,4	24,8	0,1	5,1	2,4	1,6	Sig.
NH_4^+	0,1	7,0	3,6	1,6	0,01	0,33	0,12	0,10	Sig.
$S0_4^{2-}$	10	252	119	78	2	6	3	1	Sig.
$P0_4^{3-}$	ND	—	—	—	ND	—	—	—	—

All parameters are in mg/l except for pH (no unit) and EC which was in µs/cm; Sig. = Significant at $p < 0.05$; N.S = Not significant

Seasonal variation in the leachate

Exchangeable cations Summary of the seasonal data for the leachate is shown in Table 2, while Table 3 highlights more specific trends. Due to the low levels of heavy metals observed, seasonal comparisons for these parameters were omitted. No specific trend was observed in the exchangeable cations across the seasons sampled (Tables 2 and 3).

Anions and other general parameters

Results for the dry season of 2003 for these parameters are not presented. The anions (nitrates and sulphates) showed a distinct trend of higher levels in the wet season, compared to the only dry season observed. Ammonia showed an opposing trend, being higher in the dry season. Chloride also showed elevated levels in the dry season (Tables 2 and 3), pH levels were within close range although slightly higher mean values were obtained in the wet seasons. TSS showed no particular trend across the seasons (Table 3). The results of the organic matter expressed as COD showed that the dry season witnessed higher organic matter levels, compared to the wet seasons (Tables 2 and 3).

Correlation coefficient matrix for the leachate parameters

The results of the correlation coefficient matrix for the leachate are presented in Table 4. Significant correlations 0,6 and above were considered and highlighted in bold. pH correlated negatively with lead (Pb) at -0,630, $p<0,05$, while ammonia correlated negatively with nitrate at -0,608, $p<0,05$ and also with sulphate at -0,676 (Pearsons, $p<0,01$). Iron correlated positively with suspended solids at 0,798 (Pearsons, $p<0,01$), while it also correlated

TABLE 2
Summary of the seasonal data for the leachate

Physico-chemical parameters	Range (dry)	Mean ± SD (dry)	Range (wet)	Mean ± SD (wet)
pH (no unit)	8,1-8,2	8,2 ± 0,06	7,99-8,3	8,2 ± 0,1
COD	53-84	70 ± 13	29-65	51 ± 13
EC (µs/cm)	2281-3760	2945 ± 624	864-3150	2268 ± 655
Ca	38-115	72 ± 28	30-119	95 ± 50
Mg	56-169	91 ± 41	18-119	68 ± 29
Fe	0,5-13,8	5,1 ± 5,4	0,3-37,9	6,2 ± 11,0
Mn	0,6-4,4	2,7 ± 1,5	0,6-5,3	2,3 ± 1,7
Cl^-	608-1006	781 ± 176	149-793	529 ± 194
$N0_3^-$	0,0-25,6	6,8 ± 12,6	0,0-95,1	15,6 ± 29,5
$S0_4^{2-}$	10-75	32 ± 29	59-252	147 ± 66
NH_4^+	3,4-7,0	5,0 ± 1,8	0,1-5,1	3,0 ± 1,4

Units in mg/l except otherwise stated.

TABLE 3
Seasonal variation in the physico-chemical parameters

	pH	COD	TSS	NH_4^+	Cl^-	SO_4^{2-}	NO_3^-	Ca	Mg	Fe	Mn
DRY 2003 AV.	—	—	—	—	—	—	—	59,86	99,59	4,370	1,488
DRY 2004 AV.	8,16	68,33	137,40	5,41	813,89	18,04	0,46	83,82	83,09	5,893	3,853
WET 2003 AV.	8,19	49,92	93,06	2,51	411,93	144,05	19,66	59,32	52,02	0,935	1,117
WET 2004 AV.	8,22	52,46	210,31	3,56	646,66	150,30	11,43	138,47	86,23	12,538	3,784

Units in mg/l except for pH.

positively with manganese at 0,622, p<0,01. There were significant correlations between chloride and electrical conductivity (Pearsons, 0,966, p<0,01); total solids also correlated with electrical conductivity at 0,961 (Pearsons, p<0,01 Table 4).

COD also correlated with conductivity at 0,654 (p<0,01). Manganese also correlated positively with chloride (0,698, p<0,01); Mn & total solids (0,654, p<0,01); Mn and conductivity (0,633), which was significant at p<0,05. Total suspended solids and total solids also correlated positively at 0,620 and this was significant at p<0,05 Table 4.

DISCUSSION

Leachate composition

The entire surface of the pond was covered with floating macrophytes which masked the color of the leachate. However, physical appearance of the leachate showed that it was light brown with no obvious perceptible odor. Chloride is often used as a conservative tracer of landfill leachate (Breukelen & Griffoen, 2004). The range of chloride levels in the pond, when compared to the control; and with typical ranges for chloride in leachates of a tropical country and an Ibadan dumpsite is suggestive of leachate influx into the pond. Run-off from high rainfall at the site may however be a likely contributory factor to the low levels of contaminants observed in leachate from the pond.

The mean sulphate-chloride ratio of the leachate which was computed from the results obtained was 0,2. Generally, the sulphate chloride ratio of leachate falls with increasing age of a landfill; while pH levels tend to increase reflecting the prevalence of anaerobic conditions (Lo 1996, Reinhart & Grosh 1998). The site was about 4-5 years old at the time of the study (from the date of reopening). Considering the relatively low sulphate-chloride ratio and the increased pH of the leachate, coupled with the fact that organic compounds tend to decrease more rapidly than inorganics in a landfill (Reinhart & Grosh 1998, Kylefors 2002); implies that some degree of stabilization may have occurred in the leachate and this further suggests that it is likely to be in the methanogenic phase of waste degradation (Lo 1996, Christensen et al. 2001).

Similarities in metal content between the leachate and control may imply that the metals are held by sorption or precipitation, both natural attenuation mechanisms in the soil or sediments (Scow & Hicks 2005). On the other hand, the increased pH of the leachate may also have reduced the solubility of the metals in the leachate, as metal solubility shows an inverse relationship with pH (Navas & Machin 2002, Rieuwerts et al. 2006). This implies that increases in pH may lead to metal precipitation

TABLE 4
Correlation coefficient for the leachate parameters

	Fe	Mn	Pb	COD	Cl^-	NO_3^-	NH_4^+	SO_4^{2-}	EC	pH	TSS	TS
Fe	1											
Mn	0,622**	1										
Pb	-0,051	0,001	1									
Ni	-0,155	-0,239	-0,162									
Cr	-0,210	-0,145	0,284									
COD	-0,333	0,113	0,021	1								
Cl^-	0,323	0,698**	0,411	0,570	1							
NO_3^-	-0,139	-0,144	0,164	0,120	-0,090	1						
NH_4^+	0,414	0,505	0,426	-0,145	0,463	-0,61*	1					
SO_4^{2-}	-0,255	-0,222	-0,347	0,066	-0,303	0,430	-0,676**	1				
EC	0,250	0,633*	0,385	0,654**	0,966**	0,071	0,302	-0,082	1			
pH	0,188	-0,083	-0,63*	0,297	0,097	0,123	-0,409	0,288	0,176	1		
TSS	0,798**	0,399	0,114	-0,226	0,416	0,219	0,213	-0,197	0,379	0,334	1	
TS	0,450	0,654**	0,359	0,487	0,943**	0,127	0,319	-0,126	0,961**	0,251	0,620*	1

*p= 0,05; **p= 0,01

out of solution (Olade 1987). This may be particularly pronounced in the case of lead as pH showed a significant negative correlation with lead.

Twelve of the twenty parameters determined were within the range (although slightly exceeding the lower limit) of various parameters in landfill leachate as suggested by Christensen et al. (2001). Chromium, total solids, electrical conductivity (EC), COD, nitrate, and ammonium were however all below the ranges specified by the authors. All the parameters except for nitrate and sulphate were also well below the values stated in Mangimbulude et al. (2009) for leachates from a tropical country - Nigeria. This further confirms the action of various attenuation processes on the leachate (Table 5).

Furthermore, with the exception of pH, nitrate and sulphate, all the values obtained were much lower than those obtained by Aluko et al. (2003) – in their studies on the characterization of leachates from a municipal landfill in Ibadan, Nigeria (Table 5). However, leachates used in their study was obtained from leachate drains on the dump / landfill site, whereas those of this study were obtained from the leachate lagoon 250m down-gradient of the landfill active fill area, suggesting further that attenuation processes may have acted on the leachate thereby reducing the contaminant mass and mobility. The low COD levels may suggest significant microbial degradation action on leachate organic matter (Christensen et al. 2001). It may also be linked to the low levels of easily degradable wastes such as food wastes – 6,5%; while slowly degrading organic wastes like paper constituted a higher proportion of the organic waste fraction at 18% at Aba-Eku dumpsite (Oni 2010). The influence of easily degraded material on leachate quality is well known (Reinhart & Grosh 1998, Kylefors 2002).

Natural attenuation is a reduction in contaminant mass without human intervention (Scow & Hicks 2005). Considering the distance (250m) between the dump site and the pond from which the leachates were obtained, the effects of the reduction in contaminant mass and mobility can be inferred from the results obtained. Natural attenuation processes are relatively easy to identify. Loss of contaminant mass is an evidence of natural attenuation. Natural attenuation is important as it reduces contaminant levels before they have a harmful effect on streams, springs or water supplies. However, natural attenuation reactions need to be quantified before contamination sites can be left to reduce naturally (Williams 1999).

The parameters in the leachate were also within the Nigerian Federal Ministry of Environment (FMEnv) standards (for treated waste waters discharging into natural waterbodies) with the exception of total suspended solids which exceeded the standards of 30mg/l (FEPA 1991) (Table 5). In addition, parameters such as chloride exceeded the standards in some seasons although overall mean values were within range. Chloride exceeded the standards of 600mg/l throughout the dry season; and mean values for one wet season also exceeded the regulatory limits. Furthermore, the mean value for chloride is approximately at the FMEnv limit. The correlation between iron and manganese may not be unconnected with co-precipitation and formation of insoluble precipitates (Olade 1987). It may also be indicative of similar natural or anthropogenic origin for both metals. Furthermore, the formation of such precipitates as hydroxides or sulphides may perhaps explain the correlation between iron and suspended solids (Karsten et al. 2004).

Seasonal variations in the leachate

Some of the observed parameters showed reduced levels in the wet seasons compared to the dry. As stated by Linde et al. (1995) in the article by Fan et al. (2006), the water which percolates through a landfill is mainly precipitation, but sometimes also ground water and surface water leak into the landfill. Generally, about 15-50% of the precipitation becomes leachate, but the ratio varies greatly from landfill to landfill. However, according to Trankler et al. (2005), more than 60% of precipitation forms leachate. Recharge by rainfall causes mixing and dilution of contaminants, which is one of the natural attenuation mechanisms (Yong-Lee et al. 2001). Consequently, this results in the reduction of several parameters in the wet season and higher amounts in the dry. Dilution is the major attenuation mechanism for chloride (Christensen et al. 2001); and this parameter showed a pattern of reduced amounts in the wet seasons.

The increase in nitrates and sulphates in the wet seasons can be highly related with newly recharged water from rainfall (Yong-Lee et al. 2001). Increase in nitrates and sulphates may also result from oxidation reactions of ammonium and sulphides (Manahan 2001). Increased turbulence in the wet season may increase oxygenation, thereby promoting these oxidation reactions. This may be likely as ammonium shows the reverse trend of reduced levels in the wet season. Furthermore, its significant negative correlation with nitrate as well as with sulphate suggests that oxidation reactions of the ammonium may have contributed to the increased levels of nitrates and sulphates in the wet season. The inverse relationship shown between ammonium and nitrates may also be suggestive of the action of nitrate reducing bacteria, which acts on the nitrates reducing it to ammonia (Jorstad et al. 2004). Furthermore, the relatively low sulphate-chloride ratio suggests a possible fall in this ratio, which may in turn suggest the prevalence of anaerobic conditions.

TABLE 5
Comparison of Aba-Eku leachate with landfill leachate composition ranges

Parameter	Landfill Leachate Composition[a]	Landfill Leachate Composition[b]	Landfill Leachate Composition[c]	Aba-Eku Leachate Lagoon (Mean ± SD)[d]	FMEnv, Nigeria Effluent Limits[e]
pH	4,5-9	8,03-8,28	8,17	8,21 ± 0,11	6-9
TSS	—	—	176,92	144,94 ± 117,99	30
TS	2000-60 000	—	4270	1377,67 ± 396,85	—
EC(μs/cm)	2500-35 000	4800-5600	—	2466,00 ± 673,02	—
COD	140-152 000	2802-3066	—	57,63 ± 15,11	—
Ca	10-7200	—	—	86,40 ± 41,81	200
Mg	30-15 000	—	—	83,85 ± 41,09	200
NH_4^+	50-2200	622-1316	—	3,55 ± 1,64	—
Fe	3-5500	122,4-180,4	148,55	5,27 ± 8,87	20
Mn	0,03-1400	—	22,63	2,31 ± 1,60	5
Cu	0,005-10	—	—	0,014 ± 0,028	<1
Zn	0,03-1000	—	—	0,129 ± 0,094	<1
Pb	0,001-5	—	1,49	0,035 ± 0,019	<1
Cd	0,0001-0,4	—	0,330	0,157 ± 0,128	<1
Ni	0,015-13	—	—	0,021 ± 0,022	<1
Cr	0,02-1,5	—	—	0,013 ± 0,009	<1
Cl	150-4500	1271-1606	1450,08	597,98 ± 209,73	600
$N0_3^-$	14-2500	0,47-0,58	0,58	12,37 ± 24,79	20
$S0_4^{2-}$	8-7750	65,33-111,2	84,86	118,86 ± 77,65	500
$P0_4^{3-}$	0,1-23	—	—	ND	5

a= (Christensen et al, 2001);
b= Mangimbulude et al., (2009)
c= Aluko et al., (2003)
d= Present study
e= Effluent limits for the disposal of treated wastewaters into natural water bodies

Under these conditions, sulphates will be reduced to sulphides. Although sulphide was not determined, the inverse correlation shown by sulphates, nitrates and ammonia may suggest the prevalence of anaerobic conditions under which nitrates are reduced to ammonia; and sulphates to sulphides (Lo 1996). Sulphide precipitates heavy metals which may in turn explain the low levels of heavy metals observed in the leachate. The increased pH of the leachate also corroborates this assertion.

Suspended solids and chloride were the only parameters exceeding regulatory limits in the leachate, suggesting minimal need for treatment. However, the leachate effluent may require further polishing before discharge. Durmusoglu & Yilmaz (2006) stated that physico-chemical methods are suitable for leachate effluent polishing. Physico-chemical methods may therefore be considered for polishing of the leachate effluent of the site. Maintenance costs however need to be taken into consideration.

Conclusion

Leachate characterization studies of leachate from the Akanran / Aba-Eku landfill showed a reduction in the levels of most contaminants to well below the regulatory standards. However, suspended solids and chloride levels in the leachate are still a cause for concern. The low levels of most contaminants suggest minor need for leachate treatment (Table 5). However, physico-chemical processes may be considered for further polishing of the leachate effluent. Maintenance costs may however need to be considered before this can be implemented.

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