

Leachate Characterization and Assessment of Unsaturated Zone Pollution near Municipal Solid Waste Landfill Site at Oblogo, Accra-Ghana

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Abstract: Leachate and unsaturated zone water samples were collected from landfill-site and its adjacent area at Oblogo, Accra-Ghana to study the possible impact of leachate percolation on unsaturated zone water quality. Concentration of various physico-chemical parameters including heavy metal (Cd, Cr, Cu, Fe, Mn, As, V, and Zn) were determined in unsaturated zone water and leachate samples. The moderately high concentrations of Cl^- , NO_3^- , SO_4^{2-} , Fe, Zn, Cd, Cr, Cu, Fe, Mn, and BOD in unsaturated zone water, likely indicate that water quality in the unsaturated zone is being significantly affected by leachate percolation. This suggests that leachate percolation is having an impact the unsaturated zone water which indicates the originality of the groundwater in the area is threatened.

Key words: Landfill, leachate, physico-chemical analysis, unsaturated zone water

INTRODUCTION

For centuries human have been disposing off waste products by burning, discharging in streams, storing them on ground, or putting them into landfills. In addition to contaminated surface runoff, human induced influences on surface water quality reflect direct waste discharge into a stream. Most commonly, the surface and ground water quality is affected by waste disposed and land use. One of the major sources of contamination is the storage of waste materials in excavations. Water soluble substances that are disrupted, spilled, spread or stored on the land surface eventually may infiltrate (KRAMP, 1997).

The city of Accra is developing rapidly with urbanisation of large sections of land within the Greater Accra area. Therefore Accra has spread out beyond its borders to engulf the surrounding villages. This spread has further compounded the waste disposal problem since the existing solid waste disposal systems in Accra are not enough to handle the large waste loads generated in the city. Accra presently has an estimated population of 3.3 million and an estimated amount of 1500-1800 tonnes of solid waste is generated every day (Benneh *et al.*, 1993). This increase in waste generation is in step with increasing population and improved standards of living.

The increasing population coupled with economic development has resulted in substantial pressure on the existing systems for municipal solid waste disposal.

Landfills have been identified as one of the major threats to groundwater resources (USEPA, 1982). Waste placed in landfills or open dumps are subjected to either groundwater underflow or infiltration from precipitation. The dumped solid wastes gradually release its initial interstitial water and some of its decomposition by-products get into water moving through the waste deposit. Such liquid containing innumerable organic and inorganic compounds is called 'leachate'.

The unsaturated zone is not a source of readily available water for human consumption. But it is of great importance in providing water and nutrients that are vital to the biosphere and is intensively used for the cultivation of plants. Recharge water passing through the unsaturated zone undergoes changes in chemical composition which influence ground water quality in the aquifer (Edmunds and Tyler, 2002). The unsaturated zone is an important buffer for the attenuation of acidity, metal content and some other harmful substances. The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality (Edmunds, 1996). In areas with relatively well

developed soils and a relatively thick unsaturated zone (UZ), the chemistry of underlying shallow groundwater is often determined more by processes which take place in the unsaturated zone and less by processes in the phreatic zone (Malecki and Matyjasik, 2002). The chemical composition of water in filtrating unsaturated zones evolves with depth and is influenced by the properties of the precipitation and mineralogical composition of the sediments. Major and trace metals determined in water from a particular unsaturated zone could serve as a tool in understanding the source as well as the flow and incorporation of these elements into the groundwater system (Litaor, 1988).

MATERIALS AND METHODS

Study area: Oblogo town is about 1km off Accra-Winneba road on the way to Weija. The landfill site is located on latitudes $5^{\circ}33'26''$ and $5^{\circ}33'40''$ N and longitudes $0^{\circ}18'45''$ and $0^{\circ}18'55''$ W. Area under study is generally undulating and relief ranges from 20 to 100 m above sea level. The geology consists of metamorphosed sedimentary rocks, namely; quartzite, schist and phyllites, which may be incompetent and susceptible to fracturing upon stress. The rocks were first described by (Kesse, 1985) who assigned the name Akwapimian to these rocks.

There are no bottom liners for any of the dumping sites (Tigme, 2005). Monitoring boreholes that are to serve as a check on groundwater pollution are absent. Leachate emanating from the dump mainly flow into enclosed sumps (manholes) where it is stored temporarily till it overflows in drainage channels through Oblogo Township and eventually joins River Densu. Oblogo has two dumpsites, one to the western side and the other is to the eastern side of the town are all exuding leachate into the environment. There are two major paths of leachate movement from the landfills, therefore the need for the study to find out where the leachate drains to and what effects the leachates may the unsaturated zone at the Oblogo Township. The sampling points for the area of study are OB1 (East) and OB2 (West), Fig. 1 shows a sketch map of the flow direction of leachate and piezometric points in study area. PO1, PO2, PO3 and PO4 are piezometers which are in the direction of the eastern landfill. OB1 and OB2 are leachates from these landfills, the leachate from the (OB1) flows directly to the Densu River. The leachate from the western landfill (OB2) flows to a road and gets lost; where does this end? Therefore the study is mainly based on the effect of the eastern landfill site on the unsaturated zone. To help understand this phenomenon, four piezometers were drilled towards the Densu River to attempt to follow the leachate to the river. PO1 was 200 m from the landfill on the eastern side with PO2, PO3 and PO4 being 100 m apart. PO4 being the closest to the river.

Field sampling and laboratory analysis: Soil auger was used to make drills to a level that water in the unsaturated zone with depths ranging from 1 to 2 m. Two inches P.V.C pipes with both ends capped (piezometers) were inserted into the drills. The sides of the pipes were perforated to allow water to percolate into the pipes. A peristaltic pump 12VDC with tube specification of min.2.0 and max.2.2 was used to pump the water collected in each piezometer for laboratory analysis. At the sampling points, the piezometers were pumped for about three (3) times to purge it of stagnant water to acquire fresh aquifer samples for analysis.

Sampling points have been designated PO1 to PO4 representing 4 piezometers previously installed approximately between 200 m down gradient of the landfill location (Fig. 1). The four water samples from the piezometers were used for this study. Sampling was carried out at Oblogo, Accra-Ghana (Fig. 2) from August to December, 2008.

A composite surface leachate sample scooped from the two landfills base is designated OB1 and OB2. Both the leachate and water samples were analyzed for parameters of interest characteristic to general mineral constituents in municipal landfill leachate such as Total Dissolved Solids (TDS), chloride and heavy metals. The parameters were selected based on their relative importance in municipal landfill leachates composition, and their pollution potential on groundwater resource in particular (Bagchi, 1989; Lee and Jones-Lee, 1993b). Chloride was included in the water quality assessment because of its measure of extent of dispersion of leachates in groundwater body (Chapman, 1992).

Water samples were collected in plastic containers which were previously cleansed with nonionic detergent and finally rinsed with deionized water prior to usage. As part of the quality control measures, samples were rinsed with sampled groundwater before being filled. Samples for the measure of heavy metals were collected in 1.5 L polyethylene bottles and preserved using 2 mL concentrated HNO_3 acid. All samples were preserved at 4°C and transported to the laboratory for analysis. Physico-chemical analyses of sampled water followed standard analytical methods. About 100 mL of the samples were collected in a conical flask, using a Mettler Toledo Seven Multi meter to take the pH, electrical conductivity, TDS, Temperature and salinity.

Levels of nitrate, phosphate and sulphate were determined using UV/visible spectrophotometer, wavelength 200-1000 nm, and chloride was determined by silver nitrate titration. Levels of heavy metals of interest, cadmium, copper, chromium, iron, manganese, arsenic and zinc were measured using INAA (Instrumental Neutron Activation Analysis).

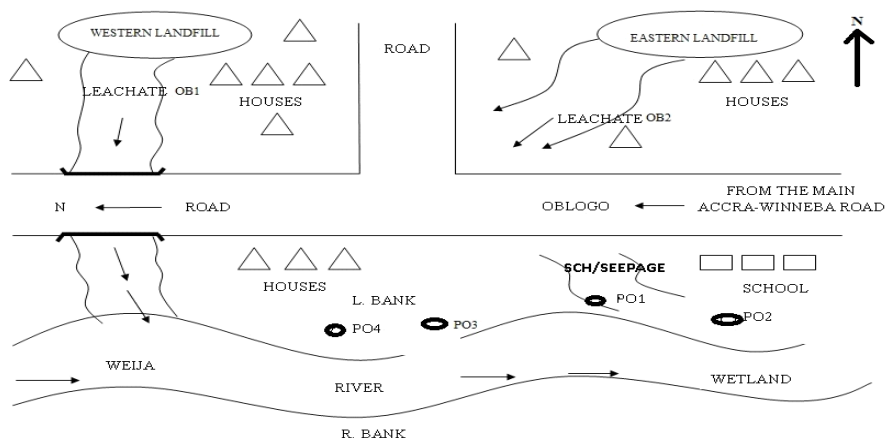


Fig. 1: Sketch Map of Oblogo showing leachate migration from landfill

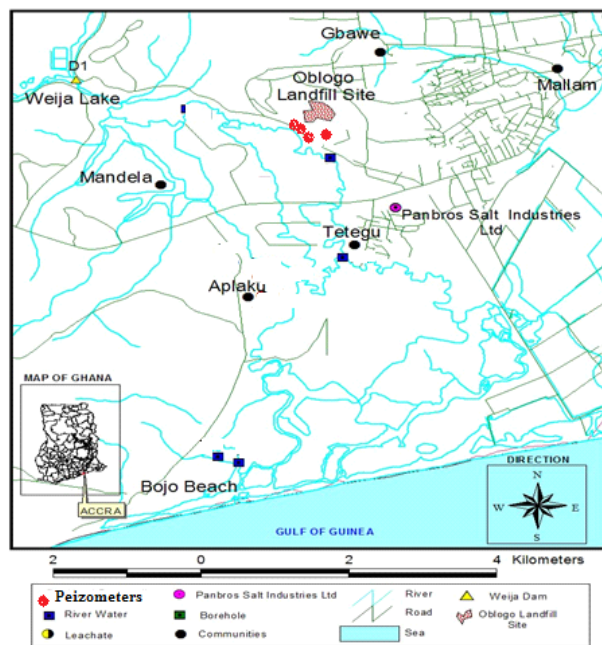


Fig. 2: Map showing Oblogo landfill

RESULTS AND DISCUSSION

Leachate: Physico-chemical characteristics of the leachate depend primarily upon the waste composition and water content in total waste. The characteristics of the leachate samples collected from the Oblogo landfill sites have been presented in Table 1. The pH values of the collected samples were found to be 8.4 and 8.6 for OB1 and OB2, respectively. For the leachate samples OB1 and OB2, respectively, relatively high values of EC (2630 and 8169 $\mu\text{S}/\text{cm}$) and TDS (1239 and 4088 mg/L) indicate the presence of inorganic material in the samples. The presence of high BOD (2583 and 1178 mg/L) and COD

(155 and 108 mg/L) indicates the high organic strength. High concentrations of NO_3^- (5.57 and 6.19 mg/L) were also observed in the leachate samples. The high level of Fe (3.83 and 5.96 mg/L) in the leachate sample indicates that Fe and steel scrap are also dumped in the landfill. The dark brown color of the leachate is mainly attributed to the oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with fulvic/humic substance (Chu *et al.*, 1994). The presence of Zn (7.42 and 4.64 mg/L) in the leachate shows that the landfill receives waste from batteries and fluorescent lamps. The presence of Al (10.83 and 12.67 mg/L) in the leachate samples indicates the major sources of aluminum

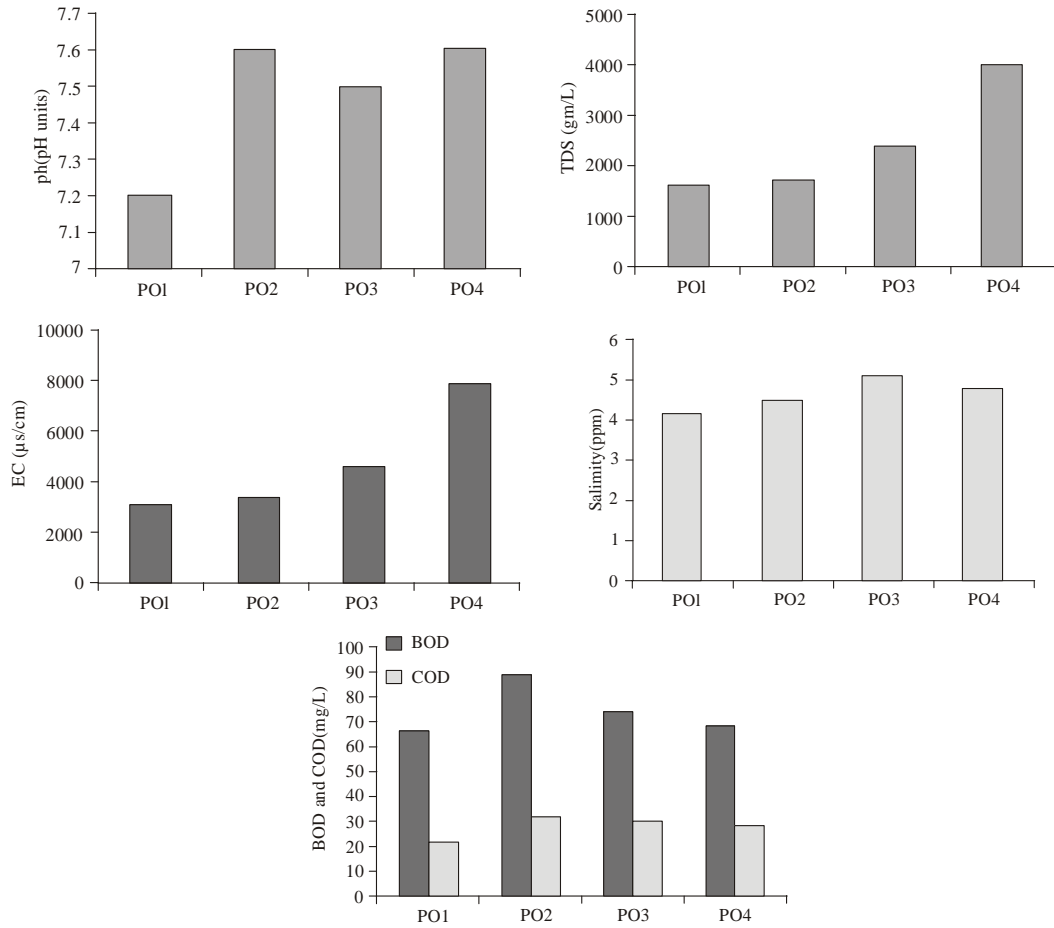


Fig. 3: Concentrations of pH, EC, TDS, Salinity, BOD and COD in unsaturated zone water

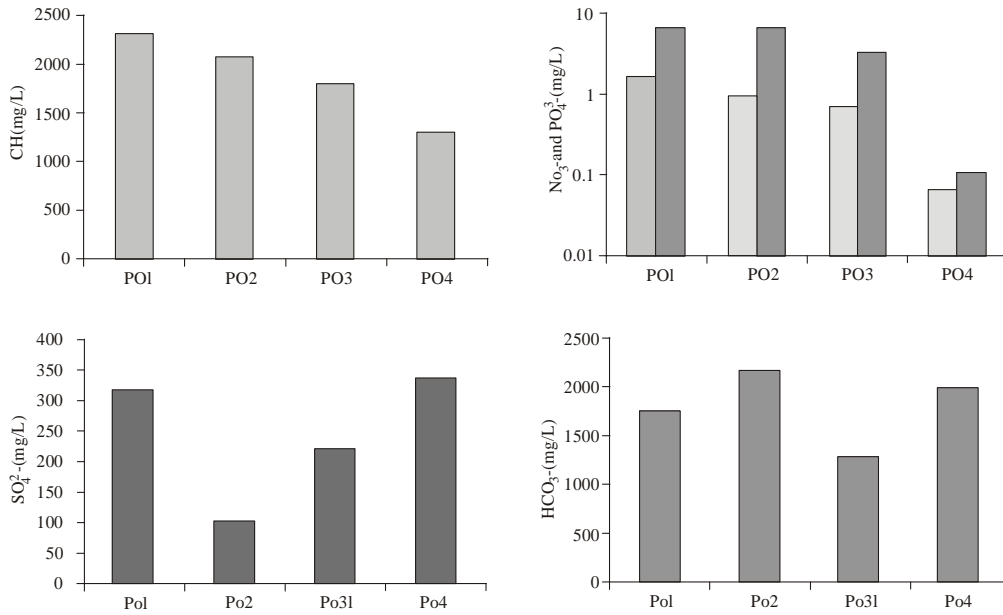


Fig. 4: Concentrations of Cl^- , NO_3^- , PO_4^{3-} , SO_4^{2-} and HCO_3^- in unsaturated zone water

Table 1: Physico- chemical characteristics of the leachate

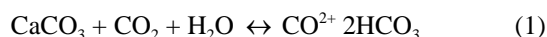
Parameters	Unit	OB1	OB2
Temp	(°C)	26.67	27.03
pH	(pHunits)	8.4	8.6
EC	(µs/cm)	2630	8169.67
Sal	(ppm)	5.1	4.88
TDS	(mg/L)	1239.33	4088.33
Na ⁺	(mg/L)	2340	1831.67
K ⁺	(mg/L)	147.67	122.67
Ca ²⁺	(mg/L)	208.33	171.87
Mg ²⁺	(mg/L)	2.84	9.56
Cl ⁻	(mg/L)	5423.33	5554
SO ₄ ²⁻	(mg/L)	15.92	1362.15
HCO ₃ ⁻	(mg/L)	87.42	3923
PO ₄ ³⁻	(mg/L)	1.19	0.75
NO ₃ ⁻	(mg/L)	5.57	6.19
BOD	(mg/L)	2583.33	1178
COD	(mg/L)	155	108.67

are domestic waste, industrial solid waste, and aluminum production waste. Aluminum found in domestic waste, i.e., raw municipal solid waste comes from cans, doors, siding, car engine and body parts, wrapping foil, pie plates, frozen food trays, flexible packaging, cigarette and candy wrappings, and a long list of other miscellaneous domestic trash. (Moturi *et al.*, 2004; Mor *et al.*, 2005). Cr (0.23 and 0.05 mg/L), Cu (13.78 and 8.97 mg/L) Cd (0.14 and 0.20 mg/L), Mn (2.32 and 1.86 mg/L), As (0.10 and 0.27 mg/L) and V (2.25 and 0.99 mg/L) were also present in the leachate samples. A variety of waste is dumped at Oblogo landfill site, which likely indicate the origin of Zn, Cd, Cr, Cu, As, Mn and V in leachate (Moturi *et al.*, 2004; Mor *et al.*, 2005). Christensen *et al.* (1994) have also reported the presence of these compounds in leachate.

Unsaturated zone: The pH of all the water samples from the unsaturated zone was about neutral, the range being 7.2 to 7.6 (Fig. 3). The EC is a valuable indicator of the amount of material dissolved in water. The EC in the studied area range between 3120 and 7890 µS/cm and was found to be high (Fig. 3). These high conductivity values obtained for the unsaturated zone water near the landfill is an indication of its effect on the water quality. TDS indicates the general nature of water quality or salinity. The range of TDS at all sites falls in between 1611 and 3940 mg/L (Fig. 3). The TDS concentration was found to be remarkably high. As per the classification of Rabinove *et al.* (1958) based on TDS, all samples were moderately saline, (Table 4). This high value of TDS may be due to the leaching of various pollutants into the unsaturated zone water. Olaniya and Saxena (1977) also reported the groundwater pollution from refuse in the vicinity of the dumping sites detectable through increased TDS concentration of water. COD is a measure of oxygen equivalent to the organic matter content of the water susceptible to oxidation by a strong chemical oxidant and thus is an index of organic pollution. The BOD and COD

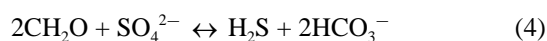
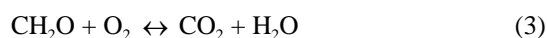
for the water from the unsaturated zone are 67 and 23 mg/L for PO1, 89 and 32 mg/L for PO2, 74 and 30 mg/L for PO3 and 69 and lastly 29 mg/L for PO4, indicating the presence of organic contaminants in the water (Fig. 3) and can be used as organic indicators to assess the groundwater pollution caused by landfill.

The range of HCO₃⁻ at all sites falls in between 1708 and 1952 mg/L. Reportedly water within the approximate pH range of 4.3 to 8.3 contains bicarbonate alkalinity and weak acids such as carbonic acid (carbon dioxide in solution) can also exist. Natural processes such as the dissolution of carbonate minerals and dissolution of CO₂ gas from the atmosphere and soils could be a mechanism, which supply HCO₃⁻ into the groundwater:



In addition, anthropogenic CO₂ gas should be considered as a potential source of bicarbonate in groundwater. Potential sources of CO₂ gas are:

- CO₂ gas originating from municipal wastes within unlined landfill sites
- CO₂ gas due to the oxidation of organic materials leaked from old latrines and sewage systems in the downtown area
- HCO₃⁻ from sulfate reduction of organic materials in the aquifer (Clark and Fritz, 1997).



Multivalent cations, particularly Mg²⁺ and Ca²⁺ are often present at a significant concentration in natural waters. Ca²⁺ concentration in unsaturated zone water ranged from 1240 to 1350 mg/L (Fig. 5). Ca²⁺ often comes from carbonate-based minerals, such as calcite and dolomite. Ca²⁺ may also come from the dissolution of concrete in streets and the sidewalks. The concentration of Ca²⁺ found to be very high in samples. The concentration of Mg²⁺ ions varied from 442 to 492 mg/L (Fig. 5). The concentration of Na⁺ in water samples varied from 468 to 1730 mg/L (Table 2). K⁺ has been reported to be an indication of the leachate effect (Ellis, 1980). The concentration of K⁺ in the water samples varied from 10.5 to 189 mg/L and was found to be well within the permissible limit at Oblogo (Table 2). An excess of Cl⁻ in water is usually taken as an index of pollution and considered as tracer for groundwater contamination (Loizidou and Kapetanios, 1993). The concentration of Cl⁻ the unsaturated zone water samples ranged between

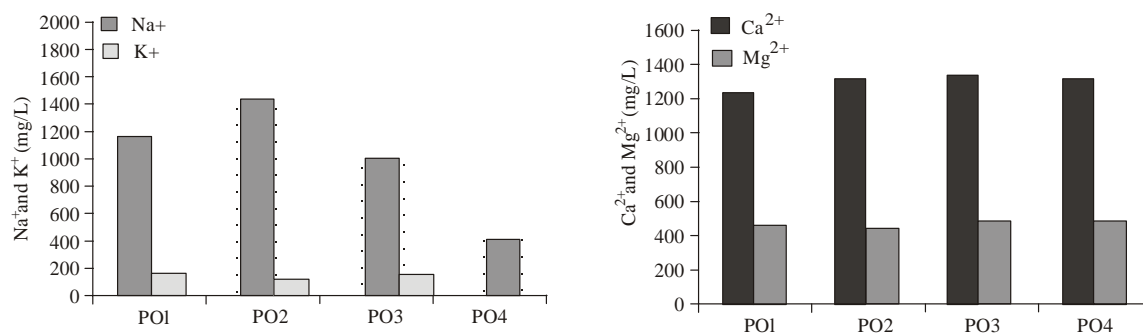


Fig. 5: Concentrations of Na⁺, K⁺, Ca²⁺ and Mg²⁺ in unsaturated zone water

Table 2: Physico- chemical characteristics of the unsaturated zone water

Parameters	Unit	PO1	PO2	PO3	PO4	WHO Standard
Temp	(oC)	25.8	26.5	27.1	27.8	22-29
pH	pHunits)	7.2	7.6	7.5	7.6	6.5-8.5
EC	(µs/cm)	3120	3414	4500	7890	700
Sal	(ppm)	4.12	4.56	5.11	4.82	
TDS	(mg/L)	1611	1742	2400	3940	1000
Na ⁺	(mg/L)	1400	1730	1200	468	200
K ⁺	(mg/L)	183	135	189	10.5	30
Ca ²⁺	(mg/L)	1240	1321	1350	1322	
Mg ²⁺	(mg/L)	458	442	488	492	
Cl ⁻	(mg/L)	2367	2129	1862	1339	250
SO ₄ ²⁻	(mg/L)	312	98	219	340	250
HCO ₃ ⁻	(mg/L)	1708	2196	1220	1952	
PO ₄ ³⁻	(mg/L)	1.66	0.91	0.77	0.07	<0.3
NO ₃ ⁻	(mg/L)	7.1	6.2	3.6	0.11	50
BOD	(mg/L)	67	89	74	69	<3.0
COD	(mg/L)	23	32	30	29	250

Table 3: concentrations of heavy metals in leachate and the unsaturated zone water

Parameters	Unit	PO1	PO2	PO3	PO4	OB1	OB2	WHO Standard
Cd	(mg/L)	0.14	0.11	0.1	0.04	0.14	0.2	0.05
As	(mg/L)	0.04	0.2	0.1	0.2	0.1	0.27	0.005
Zn	(mg/L)	3.08	2.1	3.81	3.91	7.42	4.64	
Cr	(mg/L)	0.2	0.01	0.1	0.12	0.23	0.05	
Cu	(mg/L)	3.36	2.18	1.47	2.86	13.78	8.97	0.05
V	(mg/L)	0.53	6.17	2.63	0.22	2.25	0.99	
Al	(mg/L)	9.55	7.36	170	15.67	10.83	12.67	0.2
Mn	(mg/L)	2.92	10.33	13.29	4.06	2.38	1.86	0.5
Fe	(mg/L)	3.96	5.1	2.12	1.67	3.83	5.96	0.3

Table 4: classification by Rabinove *et al.* (1958) based on TDS

Type of groundwater	TDS (mg/L)	Samples
Non-Saline	<1000	Nil
Slightly Saline	1000-3000	Nil
Moderately Saline	3000-10,000	04
Very Saline	>10,000	Nil

1339 mg/L to 2367 mg/L. High Cl⁻ content of water is likely to originate from pollution sources such as leachate, domestic effluents, and from natural sources such as rainfall, the dissolution of fluid inclusions. The concentration of NO₃⁻ in water sample varied from 0.11 to 7.1 mg/L (Table 2). Jawad *et al.* (1998) have also reported increase in NO₃⁻ concentration in groundwater due to wastewater dumped at the disposal site and likely indicate the impact of leachate. PO₄³⁻ in the water sample was well below the permissible limit and the

concentration varied from 0.07 to 1.66 mg/L (Table 2). Concentration of SO₄²⁻ in water sample ranged from 98 to 340 mg/L (Fig. 3) and was significantly high, reportedly, sulphate occurs naturally in water as a result of leaching from gypsum and other common minerals Manivaskam (2005). Discharge of industrial wastes and domestic sewage tends to increase its concentration; indicating that the landfill leachate may be having an influence on the unsaturated zone. (Fig. 4, 5, Table 3 and 4).

The unsaturated zone water samples were analyzed for heavy metal such as Cd, As, Cr, V, Al, Cu, Fe, Mn and Zn, because these metals may infiltrate into the groundwater system, which are characterized as undesirable metals in drinking water. Cadmium (Cd) values range from 0.04mg/L to 0.14 mg/L, for water in

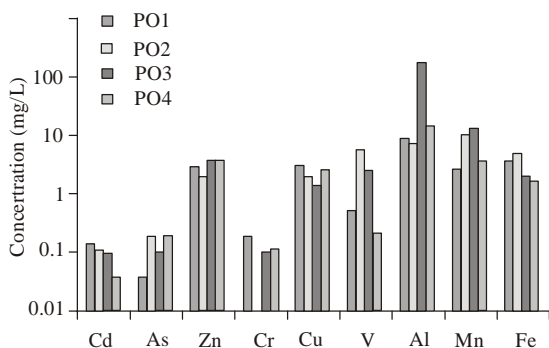


Fig. 6: Concentrations of heavy metals in the unsaturated zone

the unsaturated zone (Fig. 6). Cadmium concentration in the unsaturated zone is lower than that of the leachate Cd (0.14 and 0.20 mg/L) this may due to adsorption, Adsorption have been reported as another important mechanism controlling the heavy metal concentration (Lu *et al.*, 1985).

Zinc (Zn) values measured range from 2.1 mg/L to 3.91 mg/L for water in the unsaturated zone (Table 3). Leachates from the landfills might have contributed to the high levels of zinc in the unsaturated zone. The mean concentration of zinc in the water was far above the natural background level of 0.03 mg/L, a situation which needs to be controlled to prevent further pollution of the unsaturated zone posing potential threat to the unsaturated zone. Vanadium, levels in the water from unsaturated zone are PO1 (0.53 mg/L), PO2 (6.17 mg/L), PO3 (2.63 mg/L), and PO4 (0.22 mg/L) also As levels in the soil water from unsaturated zone are PO1 (0.04 mg/L), PO2 (0.2 mg/L), PO3 (0.10 mg/L), and PO4 (0.2 mg/L) Fig. 6. The results from the piezometers indicate that concentrations of V and as in the leachate are higher. This may be because metal mobility is also controlled by physical sorptive mechanisms and landfills have an inherent *in situ* capacity for minimizing the mobility of toxic heavy metals (Pohland *et al.*, 1993). Chromium (Cr) concentrations range from a minimum of 0.01 mg/L and a maximum of 0.2 mg/L, (Table 3). The most probable source is the landfill leachate since the geology does not support availability of chromium. Copper (Cu) values measured from water in the unsaturated zone range from 1.47 to 3.36 mg/L. (Fig. 6). The concentration is well above the natural background level of 0.005 mg/L. The level of copper in water in the unsaturated zone could also be from the leachate from the landfills, since there were some disposal of paints and pigment alloys and solder there (Tigme, 2005) Manganese values measured range from a minimum of 2.92 mg/L and a maximum of 10.33 mg/L (Fig. 6). Manganese can occur naturally in water by weathering processes. The concentration of Mn was far above the natural background level of 0.12 mg/L., posing potential threat to plants and the saturated zone. Iron

concentration measured range from 1.67 mg/L to a maximum of 5.1 mg/L. (Table 3). Iron (Fe) naturally occurs and by weathering process the element could be released into waters. Naturally occurring iron oxide is water soluble. The level of iron (Fe) in the water may be due to weathering of iron bearing rocks, which gradually dissolve into water at the unsaturated zone. Generally levels of heavy metals in the leachates are higher than that of the water from the unsaturated zone with the exception of Al and Mn. Metal solubility generally decrease with increasing pH. In addition, the hydrogen ion concentration will indirectly influence metal solubility by its impact on such processes as the dissociation of an acid to yield a precipitant anion and reduction-oxidation reactions (Gould *et al.*, 1989). With time, moderate to high molecular weight humic-like substances are formed from waste organic matter in a process similar to soil humification. These substances tend to form strong complexes with heavy metals. The high levels also indicate that the leachates are also influencing the unsaturated zone.

CONCLUSION

The high concentration of EC, TDS, Cl^- , SO_4^{2-} , NO_3^- , Na^+ Cd, Cr, Cu, Mn and Fe etc. in unsaturated zone water near landfill deteriorates its quality, posing threat to the quality of groundwater in the area. Further, the presence of Cl^- , NO_3^- BOD and COD can be used as tracer with relation to leachate percolation. As there is no natural or other possible reason for high concentration of these pollutants, it can be concluded that leachate has significant impact on unsaturated water quality near the area of Oblogo landfill site.

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