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Impact of Ordot Dump on water quality of Lonfit River Basin in central Guam. 1. Soil characterization of nutrient retention.

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Abstract—In 2001 surface (runoff) leachate samples emanating from Ordot Dump near the village of Ordot in central Guam were scanned for priority pollutants currently listed under the Clean Water Act. Surface and subsurface flows downgradient of the dump were periodically sampled and analyzed for nutrients and heavy metals. The subsurface samples were collected by lysimeter at 0.7–2.0 meter depths. A time-series analysis of aqueous and soil samples with emphasis on solute transport through the soil was made in this part of the study. In a separate analysis, emphasis was made on the aqueous system with special attention to possible pathogenic contaminants from the study site. The results of this investigation show that the surface leachate streams from the Ordot Dump transport substantial quantities of nitrogen, phosphorus and essential trace elements to the middle reach of the Lonfit River before they get diluted further down the stream. However, the possibility that the surface leachates will contaminate the ground water and springs oozing out of the dump is extremely small due to filtering effect of the soils surrounding the Ordot dump. As the result of kaolinitic nature of these soils and due to the fact that chemical properties of these soils are consistent with variable charge soils in which their positively charged clay particles retain contaminants such as nitrate and phosphate the potential for groundwater contamination from these ions is small. On the other hand, considerable amount of nitrate and phosphate enter the head streams adjacent to the dump as the result of leachate runoff but their concentrations are reduced due to the dilution processes further away from the dump. However, heavy metals could have a significantly negative impact on plant growth and well-being of living organisms down gradient from the dump and warrant further investigation.

Introduction

Landfills are a major source of surface and groundwater contamination worldwide (Epstein et al. 1982). In Guam, all civilian solid waste is disposed of at a single landfill located outside the village of Ordot in central Guam (Fig. 1).

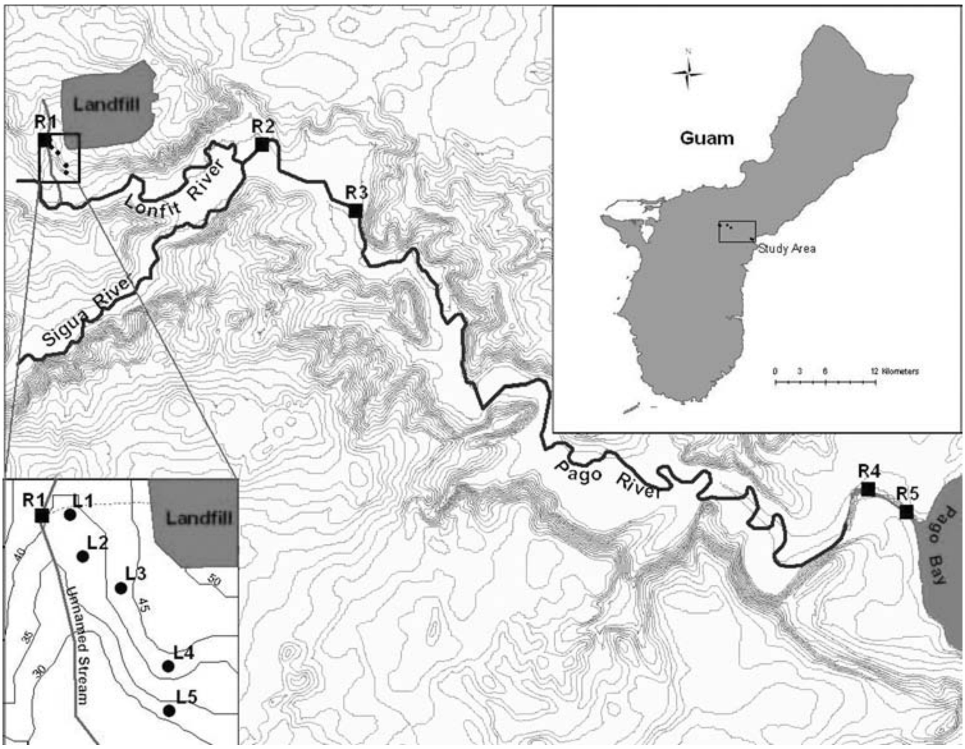

Figure 1. Showing the study sites at and near the Ordot Landfill in central Guam. R – Denotes the sampling sites along the Lonfit river systems. L – Denotes the Lysimeter sampling locations.

This particular landfill has been in continuous use for over 50 years and receives about 70.8 cubic meter of solid waste per day (GEPA 1995). Until quite recently it was used as an open dump with little control over what was put in it. Vermin, flies, periodic fires and the stench or rotting garbage have plagued the site and tormented nearby residents for decades. The dump was slated for closure almost 20 years ago and has been operating at over capacity for at least ten years (USEPA 1997). Today it occupies a staggering area of almost 25 hectares and towers to ~90m at its mid-point (Smit 2001). The entire Landfill lies within the Lonfit River drainage basin, which is part of the Pago Bay watershed (Fig. 1). The western border of the dump encroaches onto wetlands that drain into the Lonfit River. This rather picturesque stream converges with the Sigua River to form the Pago River. Local residents fish all three rivers for food and the adjacent lands support a variety of agricultural activities including subsistence farming.

Unlike modern sanitary landfills, the Ordot Dump is not lined with an impervious material and does not have a leachate retention system in place. As a consequence, seasonally dependant streams of brown, foul smelling liquid emerge at a number of points along the western edge and southern toe of the dump. These flow down gradient into the Lonfit River permeating into the surrounding soil en route. The composition of this leachate has never been fully characterized despite the potential health hazard that it likely represents. Given the dump's close proximity to surface water resources and arable lands, there is understandable concern among local residents over the environmental and human health effects of sustained and uncontrolled leachate discharges into the area waters (Smit, 2001). With this in mind, a pilot study was undertaken to determine levels of chemical and biological contaminants in leachate streams arising from the Ordot Dump to monitor their surface and subsurface movement downgradient into the adjacent waters of the Lonfit River and Pago River systems. We report here on the chemical composition of leachate discharged from the dump and on nutrient and heavy metal levels in subsurface and surface waters at down gradient locations. Some physical and chemical characteristics of soils in the area are also included. Data for biological contaminants *(E. coli* and *Enterococcus)* in the aqueous samples will be reported separately.

Material and Methods

Water

Surface leachate: Surface leachate (via runoff) was sampled in December 2002 from two separate streams along the southern face of the dump and was subsequently tested for all priority pollutants listed under the Guam Water Quality Standards (GEPA 2001). The samples were collected in hand-held bottles composed of amber glass and high-density polypropylene for organic and inorganic analyses respectively. A certified commercial laboratory carried out the chemical analyses using approved USEPA methods.

Surface Stream Water: Surface water samples were sampled at approximately monthly intervals from five sites (R1 to R5 in Figure 1) along the Lonfit/Pago river systems between the dump and the ocean. They were withdrawn directly into pre-cleaned 50 ml polypropylene syringes and filtered (0.45 µm) into 100-ml plastic vials.

Subsurface Pore Waters: Subsurface soil pore water samples were taken over the same time interval from five sites (L1 to L5 in Figure 1) around the western edge and southern toe of the dump. The soil pore water collections were facilitated using suction cup lysimeters buried to depths of 0.61m (2ft), 1.22m (4ft) and 1.82m (6ft) below ground level at each site. Samples were removed from the lysimeters under vacuum and placed in acid cleaned, high-density polyethylene vials (80 ml).

All surface and subsurface water samples were stored on ice in the field. In the laboratory they were analyzed for NO_3-nitrogen (nitrate), NH_4^+-nitrogen, ortho-phosphorus and a range of heavy metals (Ag, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn). Those required for heavy metal analysis were immediately preserved with analytical grade nitric acid (100 µl/l00 ml).

Table 1: Priority pollutants detected in Surface Leachate at the Ordot Dump (Dec. '03)

Bacteria:	Units	Results	Guam Water Quality Standards	
			Surface Waters[a]	Drinking Water
Bacteria:				
Total Coliforms	MPN Index/100 ml	2,419,200	–	0
E. coli	MPN Index/100 ml	137,400	126	0
Enterococci	MPN Index/100 ml	298,100	33	0
Nutrients:				
NOx	µg/l	604	100-500[b]	10, 1[c]
NH_4-N	mg/l	503	3.08[d]	–
Ortho-P	µg/l	166	25-100	–
Metals (total):				
Aluminium	µg/l	1600 – 4,500	1000	50-200
Antimony	µg/l	9.7	–	6
Arsenic	mg/l	0.007 – 0.046	0.15	0.01
Barium	µg/l	85 – 240	–	2000
Boron	mg/l	1.6 – 5	–	–
Chromium	mg/l	0.017 – 0.210	0.210[e, f]	0.1
Copper	mg/l	0.023 – 0.092	0.012[f]	1.3
Iron	mg/l	0.68 – 2.9	3.00	0.3
Lead	µg/l	4.7 – 45	3.20	15
Manganese	µg/l	290 – 340	–	50
Nickel	mg/l	0.050 – 0.110	0.052[f]	0.1
Vanadium	µg/l	26 – 62	–	–
Zinc	mg/l	0.083 – 21	0.11[f]	5
Pesticides:				
p-dichlorobenzene	µg/l	3.4	–	75
Organic Solvents:				
Acetone	µg/l	17	–	–
Benzene	µg/l	3.1	–	5
Ethylbenzene	µg/l	7.3	–	700
Tetrahydrofuran	µg/l	10	–	-
Toluene	µg/l	18	–	100
cis-1,2-Dichloroethane	µg/l	1.1	–	5
m,p-xylenes	µg/l	8	–	–
o-Xylene	µg/l	3.6	–	–
Others:				
Cyanide	mg/l	0.007 – 0.016	0.0052	0.2
Phenolic Compounds	mg/l	0.074 – 0.155	–	–

a = GWQS for freshwaters only; b = as nitrate nitrogen; c = as nitrate nitrogen and nitrite nitrogen respectively; d = Criteria Chronic Concentration (CCC) at pH 7.0; e = CCC for Cr^{3+} only; f = CCC estimated at total hardness of 100 mg/l; dashes indicate no standards currently available

Nutrient determinations were made using a multi-channel Quickchem 800, Flow Injection Analyzer (FIA) (Lachat Instruments). The analytical methods were those recommended by the manufacturer and were essentially the same as those described in Standard Methods, Part 4500 (APHAWW 1992) with modifications for flow injection analysis. All nutrient analyses were performed within 24-h of sample collection. The heavy metal analyses were carried out using conventional flame and flameless atomic absorption (AAS).

Soil

Soil samples were taken from five locations adjacent to each lysimeter site for pH determinations and compositional analysis (texture and organic matter). All soil samples were air dried and passed through a 2-mm sieve prior to analysis. Soil pH was measured in H_2O and in 1 M KCl (soil/solution, 1:2.5). Nutrient analysis for nitrate was performed by LACHAT QuikChem method using 2M KCl Soil Extract (Prokopy 1997). Aluminum determinations were also performed by flow injection analysis (FIA) by QuikChem using LACHAT instrument. Nutrient analysis for Phosphate was determined by using Sodium Bicarbonate Extract and performed by Spectronic visible Spectrometer.

Results and Discussion

Water:

Surface Leachate: Chemical contaminants detected in the surface runoff leachate samples are listed in Table 1 together with the appropriate surface water and safe drinking water quality standards for Guam. Of the 27 chemicals detected in the leachate samples, 12 were found at levels that exceeded one or both of the water quality standards. Nutrient levels were particularly high, especially NH_4-N. In fact, the pungent smell of ammonia was very noticeable at one of the collection sites. Copper and Pb were also high in one of the samples compared with their respective surface water quality standard. Both metals are relatively toxic to aquatic organisms. Levels of all detectable metals were several orders of magnitude above those normally encountered in uncontaminated river waters (Denton et al. 1998).

It is interesting to note that relatively few organic solvents were found in the surface runoff leachate and no pesticides other than p-dichlorobenzene were detected. Likewise, no PCBs, PAHs, dioxins or furans were detected in either sample.

Surface Stream Waters: Noticeable inorganic nitrogen enrichment was evident at Site R1 just inside the point of confluence between the surface leachate streams and the Lonfit River (Table 2). Levels determined further downstream were reasonably typical of groundwater-impacted streams on Guam (Denton et al. 1998) except at the coast (Site 5) where relatively high levels were occasionally encountered. Such findings again point towards the domestic wastewater inputs in the lower Pago basin area.

Table 2: Nutrients in surface waters of the Lonfit-Pago River systems (Oct. '02 – Oct '03)

Site #	Distance from Discharge Point (m)	Nutrients (mg/l) NOx-N	Nutrients (mg/l) Orthophosphate-P
		Mean (Range)	Mean (Range)
Surface Leachate	0	0.359 (0.213 – 0.604)	355 (166 – 759)
1	10	3.85 (1.35 – 9.44)	0.002 (<0.001 – 0.005)
2	500	0.361 (0.229 – 0.499)	0.001 (<0.001 – 0.003)
3	1,500	0.316 (0.111 – 0.546)	0.001 (<0.001 – 0.002)
4	4,500	0.196 (0.050 – 0.567)	0.002 (<0.001 – 0.005)
5	5,000	0.305 (0.047 – 10.0)	0.001 (<0.001 – 0.004)

Means are geometric mean

The absence of detectable levels of soluble inorganic phosphorus immediately downstream from the dump was unexpected considering the elevated concentration determined in the surface leachate. Presumably, this nutrient is rapidly scavenged from the water column by iron ions as it changes oxidation state and precipitates out of solution as the hydrated ferric oxide.

Elevated heavy metal levels shown in the surface leachate streams were quickly diluted as they entered the Lonfit River estuary at Site 1 and were undetected or were at normal baseline levels at all sites further downstream (Table 3). However, Fe and Mn were typically the most common elements detected and were generally followed in decreasing rank order of abundance by Cu>Zn>Pb>Cr and Ni. Levels of Cd, and Pb were consistently below the limits of analytical detection at all sites (Table 3).

In all probability, much of the soluble heavy metal load in the surface leachate streams (runoff) rapidly partitions out onto suspended particulates upon entering the watershed and ultimately ends up in bottom sediments. These contaminated sediments would be gradually mobilized downstream and dumped in the Pago River estuary and adjacent waters.

It is suggested that sediment cores taken at strategic locations along the Pago-Lonfit River systems and out into Pago Bay would provide a more realistic measure of heavy metal distribution and abundance in this area. Such a sampling program would also provide a better understanding of the potential impact of these contaminants on the biota, particularly the suspension and deposit feeders and those organisms living in intimate contact with bottom deposits.

Subsurface Pore Waters Analysis

Nitrate

Nutrient levels found in soil pore waters are summarized in Table 4. NOx–N enrichment was evident in the majority of samples from the shallower depths and occasionally at the deepest level. Substantial reduction in NOx –N concentration can be observed in the samples from the deeper lysimeter (Table 4).

Table 3: Elemental Composition of Surface Stream Waters (the Lonfit-Pago River system) Down Gradient of Ordot Dump (Oct. ‘02 – Oct ‘03)

Element	Units	Sites									
		1		2		3		4		5*	
		Mean	(Range)	Mean	(Range)	Mean	(Range)	Mean	(Range)	Mean	(Range)
Al	µg/l	5.9	(3.1 –10)	2.1	(<1.1 – 5.5)	3.5	(0.5 – 7.1)	14	(6.9 – 40)	10	(7.8 – 21)
Ba	µg/l	176	(162 –194)	8.8	(4.2 – 48)	10	(4.1 – 121)	18	(8.4 – 51)	18	(9.0 – 51)
Ca	mg/l	90	(84 – 100)	45	(35 – 50)	47	(34 – 54)	110	(70 – 137)	118	(84 – 145)
Cd	µg/l	<0.16	(<0.16 – 1.9)	–	(all <0.16)	–	(all <0.16)	–	(all <0.16)	–	(all <0.16)
Cr	µg/l	1.1	(0.87 – 1.4)	<0.2	(<0.14 – 0.26)	<0.16	(<0.14 – 0.20)	–	(all <0.14)	–	(all <0.14)
Cu	µg/l	2.5	(0.9 – 9.1)	0.34	(<0.33 – 1.0)	0.42	(<0.33 – 1.7)	–	(all <0.33)	–	(all <0.33)
Fe	µg/l	76	(65 – 99)	11	(10 – 49)	32	(16 – 50)	16.3	(6.2 – 38)	9.2	(4.7 – 24)
Mg	mg/l	25	(24 – 27)	8.8	(6.6 – 10)	9	(6.5 – 11)	205	(129-299)	236	(162 – 299)
Mn	µg/l	348	(260 – 471)	30	(13 – 49)	30	(10 – 51)	74	(48 – 118)	70	(45 – 117)
Ni	µg/l	14	(12 – 18)	0.81	(<0.72 – 1.2)	0.75	(<0.72 – 1.2)	–	(all <0.72)	–	(all <0.72)
Pb	µg/l	<1.1	(<1.0 – 1.7)	<1.4	(<1.0 – 2.0)	<1.2	(<1.0 – 3.0)	–	(all <1.0)	–	(all <1.0)
Zn	µg/l	1.4	(0.18 – 11)	–	(all <0.36)	<1.0	(<0.36 – 7.5)	<1.9	(<0.36-8.1)	<1.9	(<0.36 – 9.6)

Means are geometric means

*site 5 is where the Lonfit River enters the Pago Bay

**not detectable

Table 4: Nutrients in Soil Pore Water Down Gradient of Ordot Dump (OCT.'02-Oct '03)

Depth (m)	Nutrients (mg/l)		
	NO_3-N	Ammonia-N	Ortho-P
	Mean (range)	Mean (range)	Mean (range)
0.61	0.309 (0.001 – 35.4) N* = 25	0.003 (<0.002 – 0.023) n = 15	0.003 (<0.001 – 0.051) n = 20
1.22	0.351 (<0.001 – 17.8) n = 22	0.004 (<0.002 – 0.141) n = 16	0.004 (<0.001 – 0.049) n = 23
1.83	0.190 (0.003 – 12.3) n = 20	0.004 (<0.002 – 0.035) n = 18	0.003 (<0.001 – 0.059) n = 25

Means are geometric means

n* : number of samples

These findings highlight the limited mobility of the NO_x –N anion down through the soil profiles. The low level of NO_x –N (nitrate) in the lower depth could be due to the denitrification process. As referred to by Jury et al. (1991), nitrate is stable in soil solution except when biologically transformed by denitrification, which occurs in wet soil or inside soil aggregates at high moisture content. Since the soils at the Ordot landfill site are generally wet specially during the wet season (at least six months a year) as the result of high rainfall (mean annual rainfall of approximately 90 inches (2540mm)), it is highly likely that low level of nitrate in lower depth soil is due to the transformation of nitrate via denitrification process under wet conditions at the study site.

On the other hand, the limited mobility of nitrate anions down through the soil profile could be due to, at least in part, the fact that these soils contain positively charged clay particles. Anions such as NO_3^- are generally assumed to be non-reactive during their displacement through clay mineral dominated soils as the negatively charged ions are excluded from the region near the negatively charged clay mineral surfaces. As described by Wagenet (1983), anion exclusion from a discrete volume of soil pore water has been considered an anion transport and not an anion exchanger. This is in fact not the case when the negatively charged ions are effectively adsorbed by the positively charged clay minerals. These data indicate that the negatively charged nitrate ions are being held by some positively charged clay particles as the nitrate moves from surface to the lower soil profile hence limiting its mobility further down the soil profile at the Ordot study site. This is an example of the effect of highly weathered soil rich in iron and aluminum oxide with variable charge (some positive) minerals (Uehara and Gillman, 1981). As shown in Table 5, the sign and magnitude of ΔpH (Δ pH* = pH KCl - pH H_2O) corresponds to the sign and magnitude of the surface charge (Uehara and Gillman, 1981). A positive, zero, or small negative DpH value (less than –0.5) generally indicates a soil dominated by variable charge minerals (Uehara and Gillman, 1981). As it is shown in Table 5, the pH measured in water and 1N KCl shows a slight decrease in ΔpH indicating that the soil pH is very near pH_0. Small negative ΔpH values indicate the presence of variable charge minerals

Table 5.: Some of the Soil Chemical Characteristics at the lysimeter sites

	pH			Soil Texture			Organic Matter
Site	Water	KCl	ΔpH*	Clay	Silt	Sand	(%)
1	7.58	7.29	–0.29	47.5	33.9	18.5	4.8
2	7.18	6.87	–0.31	56.8	18.5	24.6	2.7
3	7.48	7.15	–0.33	36.8	30.1	33.2	3.5
4	7.34	6.87	–0.47	32.6	20.7	46.6	2.2
5	6.37	5.86	–0.51	13.9	16.6	69.4	1.6

Δ pH* = pH KCl – pH H_2O Δ pH < 0 , soil has net negative charge
Δ pH > 0 , soil has net positive charge

implying that some of the clay particles are positive in charge. Anions such as nitrate and phosphates are able to adsorb onto oxide surfaces when the surface charge is zero, positive or even negative in which both types of charges (positive and negative charges) may occur on a single particle (Uehara and Gillman, 1981). This could very well be the case since the soils under study fall under Agfayan-Akina association category, which includes both Agfayan (montmorillonitic and slightly acidic to neutral) as well as Akina (Kaolinitic and acidic) soil series.

Phosphate

As shown in Table 4, the ortho-phosphate levels found in soil pore waters are generally low at all depths. This is due to the fact that ortho-phosphates form precipitates with Fe^{3+} and Al^{3+} in acid soils and with Ca^{2+} in basic soils called phosphate fixation (retention). The fixation of phosphate as various Ca-phosphate compounds in basic soils, where Ca^+ activity is high is among the reasons for phosphate retention (Bohn et al. 1979). As reported by Arbestain et al. (2002), aluminum-organic co-precipitates have been shown to retain large amount of PO_4 and they (Arbestain et al. 2002) reported that Fe and Al-humus complexes were the primary source of the PO_4 sorption capacity. It has been establish that due to the chemical behavior of the oxyanion, PO_4 is specifically adsorbed on variable charge mineral (Al, Fe, and Mn oxides; allophanes, imogolite), forming inner-sphere complexes (Violante and Pigna, 2002). These oxyanions may form different surface complexes; a bidentate-binuclear complex, and a bidentate-mononuclear complex in different proportions, depending on surface coverage (Liu et al. 2001, O'Reilly et al. 2001). The reaction of phosphates with iron and aluminum oxides is an example of chemisorption, in which there is an interaction of a specific functional group of the adsorbing species with a hydroxyl or aqua site on the iron and aluminum oxide surfaces (Hassett and Barnet, 1992). This chemisorption process is coupled with the release of OH^- ions (Ippolito et al. 2003) thus the process is favored by high pH values and high organic matter content of the soil.

Table 6.: Nutrient elements in soil samples at lysimeter sites

Soil Depth (m)	Number of Samples	Nutrient (ppm)		
		NO_3 Mean (range)	P Mean (range)	Al Mean (range)
0.61	5	5.3 (3.8 – 6.9)	0.02 (0.01 – 0.07)	594.1 (346.4 – 1053.6)
1.22	5	4.1 (3.2 – 5.5)	0.04 (0.01 – 0.08)	555.9 (314.2 – 2585.3)
1.83	5	3.8 (3.2 – 4.5)	0.04 (0.01 – 0.14)	540.4 (440.9 – 3074.1)

Means are geometric mean

Soil Analysis

Soils at the study sites belong to the Agfayan-Akina associate soil series and are classified as very fine, kaolinitic, isohyperthermic Oxic Inceptic Haplustox (Gavenda, 2005 personal communication, USDA-SCS 1988). These soils being Agfayan-Akina Associate resemble the properties of both soil series. The Agfayan soils formed in residuum derived dominantly from marine-deposited tuffaceous sandstone. Typically, the surface layer is black clay about 20 centimeters thick. Below this are black and yellowish brown clay about 16 centimeters thick. The pH of these soils is slightly acid to neutral (USDA-SCS 1988). The Akina soils on the other hand are very deep, well drained soils on volcanic uplands. They are formed in colluviums and residuum derived dominantly from tuff and tuff breccias. The surface layer of these soils is dark reddish brown silty clay about 10 centimeters thick. The subsoil however, is dark red clay about 51 centimeters thick with moderate or high base saturation. Mixed red and white silty clay saprolite is at a depth of 61 centimeters. The pH of these soils is generally acidic in nature (USDA-SCS 1988).

Soil sample analysis showed considerably low level of extractable nitrate and phosphate (Table. 6) indicating that these ions are tightly adsorbed to soil particles. The adsorption of anions by soil solids can be due to relatively simple electrostatic attractions of anions to positively charged surface sites (as explained earlier) or to very specific reactions of the anions with the adsorbing surfaces, such as the replacement of hydroxyls from metal hydroxide sites (Hassett & Barnet 1992). However, low level extractable soil nitrate (Table 6) could also be due to purported soil saturation and high denitrification processes in these soils.

The hydrous oxides and hydroxides of Fe and Al are typical examples of soil materials, which allows for specific adsorption of anions to occur (Yong et.al. 1992). The adsorption of anions (e.g. NO_3) can also be non-specific, by electrostatic or coulombic forces, and is generally confined to pH-dependent clay particle surfaces at pH values below the zero point charge (ZPC) (Yong et.al. 1992). Moreover, the edges of layered silicate minerals (clay) can also expose positively charged groups, which can tightly adsorb anions (i.e. NO_3^-) (Winegardner 1996).

On the other hand and despite low level of Al ions in lysimeter pore waters (Table 7) a high level Al ions were extracted from the soil samples (Table 6).

Table 7: Elemental Composition of Soil Pore Waters (Lysimeter samples) at Various Depths Down Gradient of Ordot Dump (Oct. ‘02 – Oct ‘03)

Element	Units	Sampling Depth (m)					
		0.61		1.22		1.83	
		Mean	(Range)	Mean	(Range)	Mean	(Range)
Al	µg/l	21	(7.9 – 1231)	10.9	(<1.1 – 55)	12	(4.7 – 141)
Ba	µg/l	58	(1.1 – 369)	52	(<0.13 – 240)	55	(2.2 – 347)
Ca	Mg/l	54	(12-186)	46	(6.6 – 173)	43	(1.4 – 336)
Cd	µg/l	0.12	(<0.16 - 0.55)	<0.16	(<0.16 - 0.20)	<0.16	(<0.16 - 0.18)
Cr	µg/l	0.23	(<0.14 – 226)	0.14	(<0.14 - 0.90)	<0.16	(<0.14 - 1.2)
Cu	µg/l	2.9	(0.62 – 13)	2.2	(<0.33 – 11)	1.7	(<0.33 – 64)
Fe	µg/l	6.8	(0.6 – 2682)	3.4	(<0.78 – 121)	1.8	(<0.78 – 17)
Mg	mg/l	19	(5 – 48)	16.1	(4.3 – 44)	17	(1.3 – 83)
Mn	µg/l	7.7	(0.14 – 3510)	8.1	(<0.27 – 2743)	8.9	(<0.27-1010)
Ni	µg/l	3.1	(<0.72 – 115)	3.3	(<0.72 – 48)	4.3	(1.3 – 39)
Pb	µg/l	<1.3	(<1.0 – 26)	<1.1	(<1.0 - 2.0)	<1.1	(<1.0 - 2.0)
Zn	µg/l	4.9	(<0.36 – 135)	3.7	(<0.36 – 27)	1.5	(<0.36 – 20)

- Means are geometric means; reporting limits and half-reporting limits used to calculate means of data sets with <50% quantifiable data

Half reporting limits used to calculate means of data sets data sets with 50% or more quantifiable data and are given as positive values.

The reporting limits were used to calculate means for data sets with <50% quantifiable data and are given as ‘less than’ values.

- *nd = not detected

- **NS = No sample

Initially, high soil test Al levels may indicate that the positively charged Al ions were tightly held by the hydroxyl ions (OH^-) as the result of generally high pH level (Table 5) in these soils. As reported by Xu & Ji (2003), increase in Al adsorption with the increase in pH, is caused presumably by an increased proportion of Al $(OH)^{2+}$, and particularly of Al $(OH)_2^+$, compared with that of Al^{3+}. Factors affecting the adsorption and desorption of Al include the ionic form of aluminum itself, the quantity of other anions capable of forming complexes with Al ions, and the surface charge of kaolinite (Xu & Ji 2003).

On the other hand the possibility of Al-PO_4 precipitation should also be considered. Precipitation is a major factor in the retention of heavy metals in soils and can occur at the range of solubility of metal hydroxide species at low and high pH values (Yong et.al. 1992). As referred to by Ippolito et. al (2003), researchers (Cox et al. 1997, Van Riemsdijk et al. 1975) observed P immobilization associated with Al-bound phosphate precipitation. Also, as reported by De Cristofaro et al. (2000), aluminum-organic co-precipitates have been shown to retain large amount of phosphate in highly weathered kaolinitic soils. Kaolinite is the dominant clay mineral in highly weathered soils in tropic and subtropical regions (Xu

& Ji 2003) and being Agfayan-Akina Associate at least 30% of the clay mineral of the soil under the study is kaolinitic in nature.

Detailed information about OH and Al fluxes, the number of carboxyl groups and organic C composition could possibly aid in the interpretation of these results, and thus, are needed in a further investigation. The above findings however, recognize one of the prime characteristics of the buffering and filtering capacity of the soil clay particles since they control the transport and fate of the pollutants (i.e., NO_x, PO_4)) (Yong, 2001).

Positively charged clay particles however, could withhold the orthophosphate-P and nitrate ions limiting their mobility further down the soil profile and in a sense filtering the phosphate and nitrate ions from reaching the ground water. Heavy metal levels in the soil pore water samples (Table. 7) suggests that all elements of interest are at, or close to, the limits of analytical detection with the possible exception of Al, Fe and Mn.

Concluding Remarks and Recommendations

The current study represents the very first attempt to evaluate the potential buffering effect of soils surrounding the Ordot landfill area on the nutrient water contaminants such as nitrate and ortho-phosphate. The result of the study showed that sorption of certain contaminants (i.e., nitrate, phosphate) would be an effective filtering process under the current environmental conditions. The information reported in this work provides better understanding of the role of soils in preventing the potential contaminants from entering the ground water resources in this area.

The results of this investigation show that the surface leachate streams from the Ordot Dump transport substantial quantities of nitrogen, phosphorus and essential trace elements to the middle reach of the Lonfit River before they get diluted further down the stream. However, the possibility that the surface leachates will contaminate the ground water and springs oozing out of the dump is extremely small due to filtering effect of the soils surrounding the Ordot dump. As the result of kaolinitic nature of these soils and due to the fact that chemical properties of these soils are consistent with variable charge soils in which their positively charged clay particles retain contaminants such as nitrate and phosphate the potential for groundwater contamination from these ions is small.

On the other hand and as shown in Table 2, considerable amount of nitrate and phosphate enter the head streams adjacent to the dump as the result of leachate runoff but their concentrations are reduced due to the dilution processes further away from the dump. However, heavy metals could have a significantly negative impact on plant growth and well-being of living organisms down gradient from the dump and warrant further investigation.

Concentrations of PCBs, chlorinated pesticides (other than p-dichlorobenzene), PAHs, furans, dioxins, Hg, Cd, and the majority of organic solvents currently classified as priority pollutants by the USEPA, were undetectable in dump leachate and are not considered to be of any immediate importance. However, the continued and regular surveillance of all priority pollutants emanating from the dump is strongly recommended in order to identify any future quantitative and qualitative changes in contaminant concentrations.

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