INVESTIGATING LEACHATE CONTAMINATION NEAR THE QUEZON CITY CONTROLLED DUMPING FACILITY (QCCDF) USING CHLORIDE ION AS INDICATOR

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Abstract

The Quezon City Controlled Dumping Facility (QCCDF) has been the main disposal site of Quezon City, the largest city within Metro Manila since the 1970s. With the huge volume of wastes received every day and with no protective liner on the old mound and creeks directly connecting the facility to Marikina River, the main river system in eastern Metro Manila, surface and groundwater contaminations have been a critical concern. The main objective of the study is to determine the effect of the disposal site on the surface water and groundwater quality by evaluating the water quality at different points in and around the landfill. Secondarily, it aims to investigate correlations between the water quality parameters as well as determine any seasonal effects on the water quality. Sampling points from wells on and around the facility were collected for six months covering dry and wet season using Horiba water quality monitoring equipment and CHEMetrics V-2000 Photometer. Leachate quality parameters pH, turbidity, DO, and chloride are not affected by the change in seasons as evidenced by statistical t-tests. Temperature is higher during the wet season, while TDS is lower at this time which may be attributed to dilution due to rainfall. DO and turbidity in leachate is strongly negatively correlated, while temperature and Cl^- in leachate are positively correlated. In groundwater, the change in season affects temperature, TDS and chloride concentrations. This trend is not evidenced in pH and turbidity. TDS and chloride are correlated with each other. Based on the surface water quality measurements, temperature, pH, DO, and TDS are affected by the change in season while turbidity and chloride are not, based on the comparison of samples taken from different locations. Aside from strong correlation of Cl^- and TDS, as seen in groundwater, very strong correlations are also observed between Cl^- and DO, and TDS and DO. Using chloride ion as indicator of leachate, the study reveals that the leachate tends to spread downward towards Marikina River. Based on the comparison of chloride concentrations near the outfall of the leachate creek at Marikina River, it can be seen that the release of leachate at the river impacts the river as evidenced by an increase in chloride concentration downstream of the outfall.

Keywords: Chloride, Dumpsite, Landfill, Leachate quality, Monitoring landfill impacts

Introduction

The 22-hectare Quezon City Controlled Dumping Facility (QCCDF), located in Payatas, Quezon City (Figure 1) is the largest and oldest among existing dumpsites in Metro Manila and has been in operation since 1973. It was used as the main disposal site of Metro Manila with the closure of other landfills in the metropolis in the late 1990s. Currently it receives wastes from Quezon City only, with an estimated average of 1,300 tons of wastes per day.

QCCDF is situated in a critical location with respect to Marikina River, a principal river in Metro Manila. There is no leachate treatment provided and all leachate is recirculated to the waste dump. However,on times when the recirculation pump malfunctions, the leachate drains directly to Marikina River. Moreover, the dumping facility is surrounded by a dense residential area. Although water supply is sourced from the Angat Dam and conveyed through a piped network by the water utility firm, the quality of the groundwater should still be protected.

Given its location and the risks it poses, it is necessary to monitor the surface water and groundwater in and around the disposal facility. This study aims to determine the surface and groundwater quality near the QCCDF. Further, it aims to discuss whether it is being impacted by the disposal facility using chloride ion as a tracer.

Mizumura (2003) used chloride ion (Cl^-) in the groundwater, soil water, and river water to study the influence of leachate plume from sanitary landfills on groundwater because chloride ion is nonreactive, non-sorptive and does not undergo redox or precipitation reactions. The experimental results indicate the flow process of the leachate plume near the landfills; that is, most of the leachate plume is discharged into a river, and the remainder infiltrates into the ground.

Figure 1. Location of the Quezon City controlled dumping facility (QCDDF)

Aquino (2002) investigated the effects of the QCCDF on La Mesa Dam using statistical analysis of groundwater quality data collected in the study area. Chloride was one of the parameters analyzed which ranged from 12 to 240 mg/L. Also, Cl, together with conductivity, TDS, Ca and Mg were found to be high near the dumpsite relative to the concentration near the reservoir.

Xu (2010) assessed the environmental effects that the QCCDF may have caused on the soil and water quality through field investigations, such as quality of leachate, surface water, groundwater and soils. Heavy metals were selected as target contaminants in the study. The results indicate the possibility of heavy metal contamination in the groundwater is very small except for the vicinity of the dumpsite. However, there is still no study yet on determining the extent of the leachate contamination using chloride ion as a tracer conducted in the QCCDF.

Methodology

Types of Samples and Sampling Point Location

There are three types of samples that were collected, e.g. groundwater, surface water and leachate. The sampling points were defined by choosing representative sites for the upstream and downstream portions of QCCDF, the creek going to Marikina River and Marikina River itself.

Groundwater samples were taken from wells. Three 10-15m depth shallow wells to be used as sampling points were constructed for this study in 2012: MW 2, MW 11 and MW 12 where a hand pump was installed at each well. MW 1 and MW 3 with hand pumps, which were installed in the area in 2006 are also used for the investigation. MW 4 to MW10 are shallow wells in the residential areas beside the facility, constructed by the households. MW 1 and MW 2 represent the upstream portion of QCCDF; MW 1 is near La Mesa Dam and MW 2 is on the open area of the landfill operator's office (IPM). MW 3 and MW 4 represent the left downstream; both are on the left residential area of the new dumpsite. MW 5 – MW 10 represent the right downstream; all are on the right residential area of the new dumpsite. MW 11 is located on the south side, downstream of the dumpsite. MW12 represents the groundwater along the creek.

Surface water samples, labeled SP2 to SP6 were collected from the creeks. SP 2 is from the creek which conveys both domestic wastewater and leachate from the facility draining to Marikina River. SP 3 represents the creek before it mixes with Marikina River. SP 4 is the mixture of QCCDF outfall and Marikina River. SP 5 is the point where there is a complete mixture with QCCDF outfall, creek from the residential area and Marikina River. SP 6 represents the upstream part of the river that has not been contaminated yet by the outfall of QCCDF.

SP1 which was taken from the creek represents leachate. It is located at the downstream part of the landfill and does not mix with domestic wastewater.

Figure 2 shows the relative locations of all sampling points and Table 1 shows the distances between sampling points, measured as a straight line.

Figure 2. Location of sampling points showing flow direction of surface water (dashed line) and groundwater (solid arrow line)

Groundwater and Surface Water Sampling

Groundwater, surface water and leachate sampling were done for six months from February 2012 to July 2012. The period February to April represents the dry season while May to July represent the wet season. As shown in Table 2, the range of the monthly rainfall for February to April is 2.0 – 195.5 mm while that for May to July is 313.2 to 886.2 mm.

The sampling for heavy metal analysis was done only once on February 2012. The chemical analyses of samples for heavy metals Cadmium (Cd), Chromium (Cr) and Lead (Pb) were done by commercial laboratories, using Atomic Absorption Spectrophotometry (AAS). Horiba water quality monitoring equipment was used to determine the following physico-chemical parameters: temperature, pH, DO and TDS. The determination of chloride content was done using CHEMetrics V-2000 Photometer.

Table 1. Approximate Distances between Sampling Points

Sampling Point	Sampling Point	Distance (km)
MW1	MW2	0.1997
MW2	SP2	0.93
SP2	SP3	1.506
SP3	SP4	0.4347
SP4	SP5	0.5551

Results and Discussion

Leachate Quality

The leachate quality is represented by sample SP1 which was taken from the creek located at the downstream part of the landfill and does not mix with domestic wastewater. Based on one time sampling, SP1 has the following heavy metals concentrations: 0.03 mg/L for Pb, 0.09 mg/L for Cr and less than detection limit of 0.003 mg/L for Cd. From a previous study (Seedao, 2006), buried wastes have been found to have elevated levels of heavy metal ions when they were subjected to acid digestion. It is possible that the dissolved heavy metals are easily sorbed unto either the solid wastes or the soil, and thus its transport is retarded.

The season is categorized into either dry or wet, based on the rainfall data measured in Quezon City by the Climatology and Agrometeorology Division of Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA), as shown in Table 2. The period February to April represents the dry season while May to July represent the wet season. As shown in Table 2, the range of the monthly rainfall for February to April is 2.0 – 195.5 mm while that for May to July is 313.2 to 886.2 mm.

Table 2. Rainfall Data of Quezon City from PAGASA on 2012

Month	Average Rainfall (mm)	Month	Average Rainfall (mm)
January	41.2	**July**	886.2
February	123.6	**August**	1,386.2
March	195.5	**September**	736.1
April	2.0	**October**	339.1
May	393.8	**November**	26.7
June	313.2	**December**	48.0

The descriptive statistics for the leachate characteristics are shown in Table 3. Warm temperatures on both seasons indicate active decomposition of wastes. The mean values show that temperature differs between dry and wet seasons at 95% level of significance. The higher temperature during the wet season may be attributed to the active decomposition of wastes when there is more moisture content. The pH of leachate corresponds with those from old landfill leachate which is reported in literature to be higher than 7.5. The low DO values can be explained from the decomposition of organic wastes. The turbidity of the leachate is high, which is also expected of fresh leachate. The turbidity measurements are widely spread as shown in its high standard deviation, and may be attributed to the heterogeneity of the wastes itself.

The highest chloride concentration in leachate is 3,242 mg/L (Table 4). This value is comparable with the study mentioned in Rowe (1995) wherein the landfill is similar to QCCDF with older portions of the landfill not having any leachate collectors and which has been in operation since 1972. Geometric mean concentration of 3,064 mg/L at the time of the cited study was recorded. There is no statistically significant difference between the dry and wet seasons for pH, Turbidity, DO and chloride.

The TDS during dry season is higher than the wet season (with a 90% level of significance) since an increase in rainfall allows dilution of dissolved solids and Cl^- ions.

Table 3. Descriptive Statistics for Leachate Characteristics

Parameters	Season	N	Mean	Standard Deviation
Temperature (°C)	Dry	7	30.00	3.51
	Wet	12	34.10	1.55
pH	Dry	8	7.53	0.22
	Wet	12	7.68	0.33
Turbidity (NTU)	Dry	8	216.48	155.97
	Wet	12	299.92	270.06
DO (mg/L)	Dry	6	1.02	0.65
	Wet	12	0.66	0.47
TDS (g/L)	Dry	6	16.57	3.77
	Wet	12	12.82	3.42
Chloride mg/L	Dry	7	2,537	384.04
	Wet	12	2,326	444.33

Table 4. Chloride Concentrations in Leachate

	Chloride (mg/L)
Feb 2012	2, 860
March 2012	2,512
April 2012	2,947
May 2012	2,525 - 3,242
June 2012	2,805 - 2,833
July 2012	2,106 - 2,446

Multi-variate Pearson analysis was performed to indicate the possible relationships between the parameters analysed (Table 5), with a p-value of < 0.005 level of significance. DO is strongly negatively correlated with turbidity for two reasons. Turbidity impedes the passage of light penetrating through water which decreases photosynthetic activity and production of DO. Likewise, turbidity indicates suspended materials, which increases water temperatures since suspended particles absorb more heat. Warm water holds less DO than cold. This also explains the correlation of DO with temperature, as well as that of between turbidity and temperature.

The positive correlation of temperature and Cl^-shows that the increase in Cl^- represents increase in amount of wastes which increase metabolic processes of microorganisms which consequently results to warmer temperature. The positive strong correlation of turbidity and pH is also an indication of biological processes in the dumpsite as biodegradation of wastes increases the pH level of leachate and groundwater. Positive correlation of turbidity and Cl^- can be explained by the fact that wastes, which is indicated by Cl^- , contribute to turbidity levels.

Table 5. Pearson Correlation Coefficients of the Leachate Characteristics

Parameter	Temp	pH	Turbidity	DO	TDS	Chloride	Rainfall
Temp	1						
pH	0.683*	1					
Turbidity	0.738*	0.867*	1				
DO	-0.716*	-0.758*	-0.917*	1			
TDS	0.605*	0.263	0.678*	-0.659*	1		
Chloride	0.842*	0.624*	0.852*	-0.829*	0.883*	1	
Rainfall	-0.294	0.111	0.065	-0.321	-0.276	-0.229	1

Groundwater Quality

Samples from monitoring wells were taken to characterize groundwater quality in the vicinity. Heavy metal concentrations of the samples based on one-time sampling are shown in Table 6. All those not reported here had heavy metal concentrations below the detection limits. MW 2 used to be part of the landfill and the area also serves as part of parking area of the dumpsite operator's trucks and other service vehicles. Leaked grease and fuels aside from the buried wastes could have contributed to lead concentration on groundwater wherein water table is found only around 1.40m below ground surface. MW 4 on the other hand is an uncovered shallow well on the waste pickers' residential area and is situated beside the road. MW12's location is beside the creek from QCCDF leading to Marikina River. Buried wastes on the area could have caused the elevated Cr and Pb concentrations.

Table 6. Concentration of Heavy Metals in Some Samples

Sampling Point	Cd (mg/L)	Cr (mg/L)	Pb (mg/L)
MW 2	<0.01	<0.04	0.05
MW 4	<0.01	<0.04	0.09
MW 12	0.01	0.09	0.14
Detection limit	0.003	0.04	0.01

The temperature from monitoring wells range from 25°C to 34°C wherein MW 11 was recorded the warmest. MW11 is the well very close to SP1, the leachate sampling station. The pH of groundwater from monitoring wells range from 5.77 to 7.67 Recorded DO of groundwater from monitoring wells range from 0.35 to 4.69 mg/L. The low DO values of the groundwater are expected. The liquid levels in these wells are located deep under the ground causing a stagnant air film to create on top of the liquid surface. This film causes the slow oxygen transfer between water surface and surrounding air.

The descriptive statistics for groundwater characteristics are shown in Table 7. Like in the leachate, the temperature during the wet season is higher than during the dry season (90% level of significance). The increased moisture content may have contributed to more leachate being transported and reaching the wells. TDS and Cl^- are higher during the dry season with 95% and 80% level of significance, respectively. This can be explained by the fact that there is no recharge to dilute the leachate in. The pH and turbidity during the dry and wet seasons do not differ significantly.

Table 7. Descriptive Statistics for Groundwater Quality

Parameters	Season	N	Mean	Standard Deviation
Temperature	Dry	56	26.87	1.09
(°C)	Wet	60	27.21	0.78
pH	Dry	64	6.43	0.28
	Wet	60	6.46	0.41
Turbidity	Dry	64	56.62	118.84
(NTU)	Wet	54	35.49	82.65
TDS	Dry	64	0.84	0.27
(g/L)	Wet	60	0.63	0.20
Chloride	Dry	35	121.13	100.37
(mg/L)	Wet	60	97.54	39.82

The Cl^- concentrations in groundwater are shown in Table 8. Majority of the sampling points have Cl^- concentrations decreasing from dry to wet seasons except for MW 7, 8 and 12. Higher Cl^- concentration on MW 7 and 8 during wet seasons may have been caused by domestic activities. MW 12 show the same trend with SP 1, SP3 and SP4. These sampling points are located on the dumping facility and creek draining to Marikina River. Cl^- values show that concentration peaked on May-June when wet seasons started and begin to decrease on July as the ground become saturated.

MW 3, 4 and 11 are the monitoring wells which recorded chloride concentrations higher than 250 mg/L, which is the limit stipulated in the National Drinking Water Standards (Department of Health, 2007). The high amount of chloride concentration can be attributed to their locations. MW 3 and MW 4 are near the dumpsite and are on residential areas of waste pickers while MW 11 is located at the southern end of the dumpsite, beside the leachate collection point.

Applying the Pearson correlation analysis (Table 9), the parameters that are closely related are TDS and chloride indicating that chloride is the main contributor to the TDS. Other parameters are not correlated. Unlike leachate which was collected from one sampling point only, at the creek, the groundwater samples were collected from 12 wells from different locations which would be characterized by different hydrogeological conditions, thus contributing variations. The soil strata provides filtration to suspended solids thus there is no relationship established between Cl^- and turbidity which was observed in leachate quality.

Table 8. Chloride Concentration (mg/L)

	MW 1	MW 2	MW 3	MW 4
Feb 2012	116.70	30.65 - 85.4	438.60	264.00
March 2012	107.10 - 109.70	34.26 - 50.80		158.35
April 2012	110.25	37.54		161.65
May 2012	82.20	60.20 - 81.10		146.55
June 2012	54.75 - 104.15	40.72 - 52.45		127.0 - 132.40
July 2012	90.15 - 93.90	44.25 - 59.30	204.80 - 247.93	114.80 - 139.90

	MW 5	MW 6	MW 7	MW 8
Feb 2012	138.50 - 483.0	213.25	122.35	83. 84
March 2012		202.20	62.90	73.15
April 2012	102.60	164.05	71.15	75.95
May 2012	90 - 104.85	169.65 - 170.10	77.10 - 91.50	73.75 - 76.45
June 2012	81.25 - 87.40	144.55 - 151.0	77.30 - 126.80	67.25 - 84.10
July 2012	87.50 - 107.50	116.55 - 146.05	124.85 - 134.40	74.85 - 87.70

	MW 9	MW 10	MW 11	MW 12
Feb 2012	114.64	34.02	2,494 - 2,593	60.70
March 2012	76.55	107.50	1760.00	49.47 - 51.75
April 2012	79.50	101.75	2593.00	65.10
May 2012	80.70 - 88.10	83.55 - 105.65	1,901 - 2,003	60.70 - 71.30
June 2012	68.70 - 81.35	86.90 - 95.70	1,800 - 2,024	56.95 - 93.55
July 2012	83.20 - 85.50	99.90 - 105.25	2,096 - 2,131	15.88 - 60.80

Table 9. Pearson Correlation Coefficients of Groundwater Characteristics

Parameter	Temp	pH	Turbidity	TDS	Chloride	Rainfall
Temp	1					
pH	0.431	1				
Turbidity	0.442	0.546	1			
TDS	0.007	0.018	0.009	1		
Chloride	-0.079	0.113	-0.033	0.741*	1	
Rainfall	-0.018	0.045	-0.099	-0.289	-0.006	1

Effect of Disposal Facility on the Groundwater

The groundwater level and flow contour lines are shown in Figures 3a and 3b, respectively (Chea, 2014). The flow is from La Mesa Reservoir (with msl of 74m) towards Marikina River (with msl of 13 to 11m).

The chloride monitoring data shown in Table 8 was plotted using Groundwater Modeling System (GMS) to show lateral spread of chloride through interpolated contour maps. Dry and wet season contour map is shown in Figures 4a and 4b, respectively.

Both figures show that Cl^- tend to spread downwards towards Marikina River. It shows that residential areas along the creek are more at risk than those at Payatas communities. The spread of the contaminant follows the direction of the groundwater flow. Based on the sampling data, the spread is limited to the immediate vicinity of the dumpsite and the chloride concentration tends to decrease as the sampling point moves away from the dumpsite, specifically from the leachate collection point.

Due to the low permeability characteristics of the underlying strata, the spread of the contamination in groundwater is not a critical concern. The QCCDF area is situated at the northeastern end of the Guadalupe Plateau. The Guadalupe Plateau is underlain by a thick

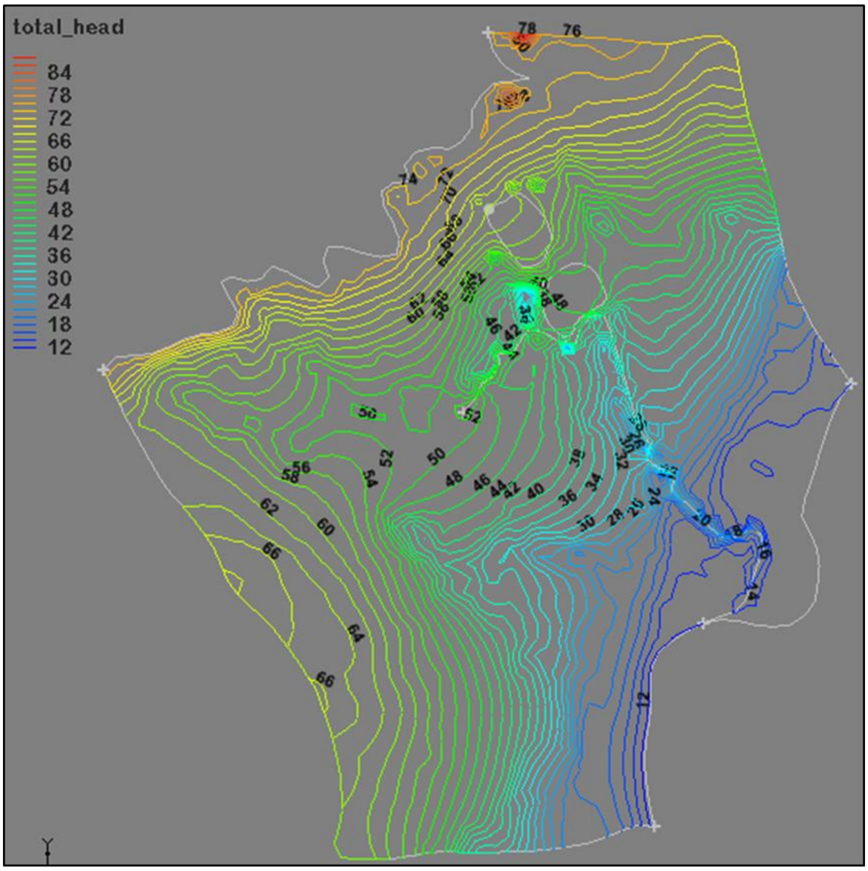

Figure 3a. Head contour lines in meters (taken from Chea, 2014)

sequence of rocks comprised of thin to medium bedded tuffs, tuffaceous sandstone/ siltstone and conglomerate generally termed as the Guadalupe Formation deposited during

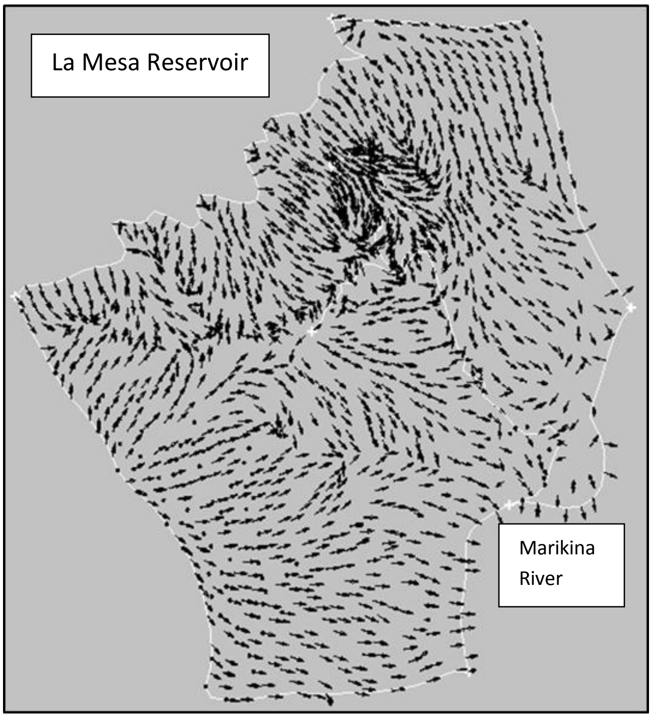

Figure 3b. Groundwater flow direction (taken from Chea, 2014)

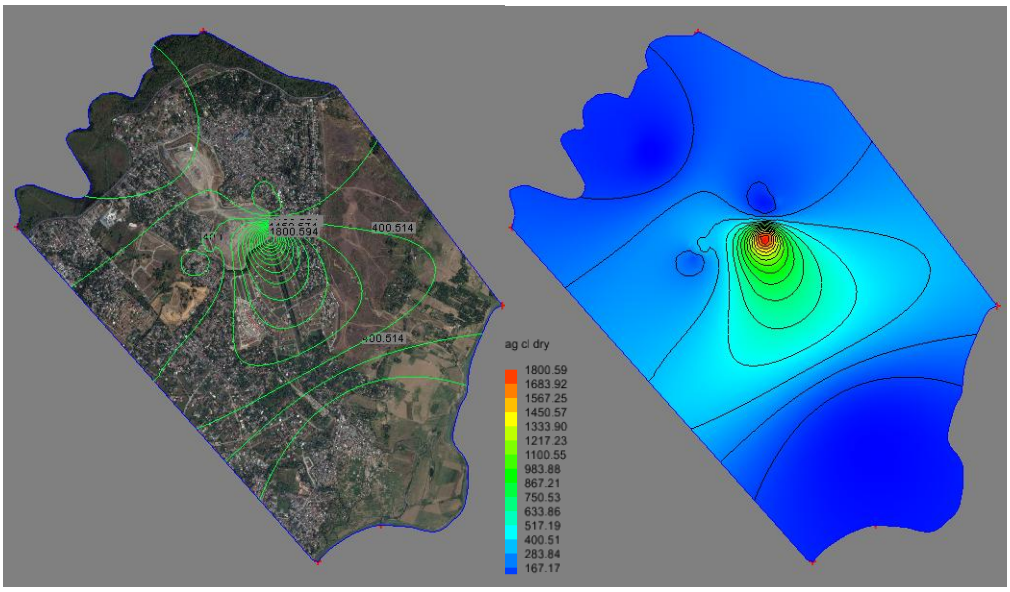

Figure 4a. Chloride contour map on dry season

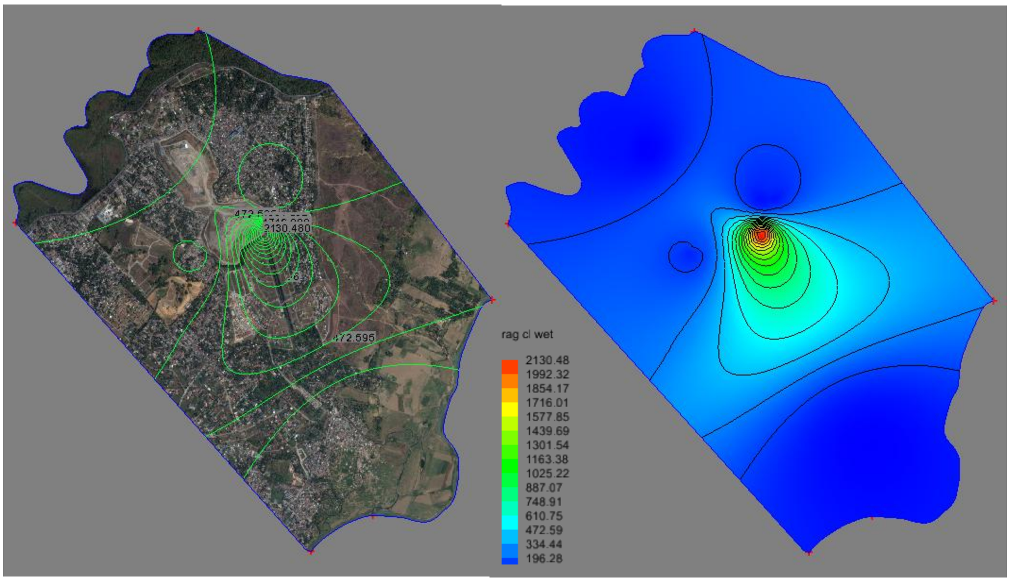

Figure 4b. Chloride contour map on wet season

the Pleistocene Age. An approximation of the vertical profile of the dumpsite is given in Figure 5 (Xu, 2010), as extrapolated from a limited number of boreholes.

Surface Water Quality

The descriptive statistics for the surface water characteristics are shown in Table 10. The temperature during the dry season is slightly higher than during the wet season (80% level of significance). The pH values during the two seasons are close to each other although a t-test reveals that the two values are not equal, at 95% level of significance. A higher DO is observed during the wet season (80% level of significance) which can be attributed to mixing caused by turbulent flow of the stream as well as a cooler temperature. The Cl^-

concentrations and turbidity do not change significantly with the change in season. This can be explained by the fact that the samples were taken from different locations which offer other sources of variations. TDS is lower during the wet season, which can be attributed to dilution due to more rainfall.

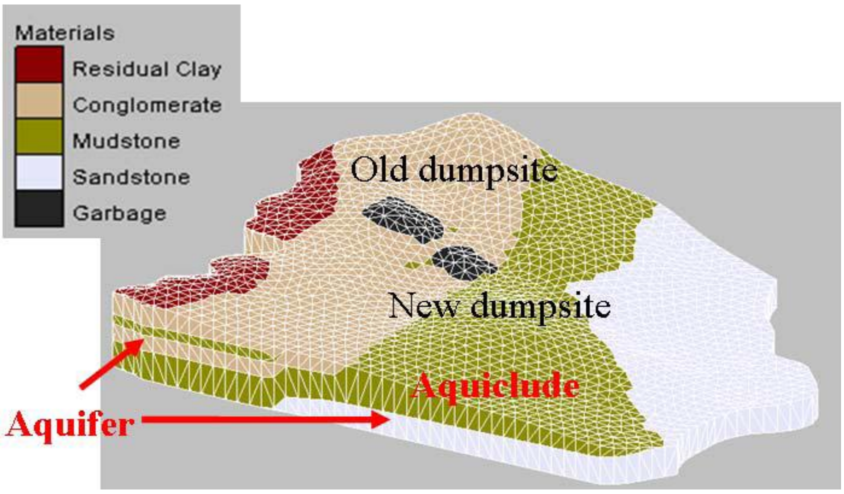

Figure 5. Vertical profile of Payatas (taken from Xu, 2010).

Table 10. Descriptive Statistics for Surface Water Characteristics

Parameters	Season	N	Mean	Standard Deviation
Temperature (°C)	Dry	21	29.47	2.08
	Wet	29	28.66	1.31
pH	Dry	21	7.40	0.21
	Wet	29	7.63	0.23
Turbidity (NTU)	Dry	21	149.24	76.31
	Wet	29	137.32	73.72
DO (mg/L)	Dry	21	1.55	1.06
	Wet	29	2.02	1.83
TDS (g/L)	Dry	21	0.78	0.32
	Wet	29	0.55	0.30
Chloride (mg/L)	Dry	17	69.05	39.97
	Wet	28	68.16	44.97

Chloride concentrations from the surface water samples are shown in Table 11. MW 12, SP 1, 3 and 4 all show the same trend. These sampling points are located on the dumping facility and creek draining to Marikina River. Cl^- values show that concentration peaked on May-June when wet seasons started and begin to decrease on July as the facility and ground become saturated. Chloride in wastewaters from QCCDF travel along the creek and increases slightly as it passes residential areas which discharge untreated wastewater. Chloride from upstream river shows lower values and mixes with the outfall from QCCDF, thus diluting the wastewater as validated by SP 5.

The samples were also tested for Cd, Cr, and Pb, and one time sampling show that concentrations are below the detection limits, as well as the Philippines' Department of

Environment and Natural Resources (DENR) as contained in DENR Administrative Order 34 (DAO 34).

Pearson correlation coefficients of surface water characteristics are shown in Table 12. Aside from strong correlation of Cl^- and TDS, like in groundwater, very strong correlations are also observed between Cl^- and DO, and TDS and DO which also have p-value < 0.005 level of significance. Increase in Cl^- can indicate increase in the amount of wastes (which are composed of organic compounds) which undergoes metabolic processes and results to lower DO. Negative correlation of DO and TDS may be caused by metabolic processes of microorganisms and photosynthesis of aquatic plants and algae. Rainfall has strong negative correlation over temperature and TDS with a p-value < 0.005 level of significance. Increase in rainfall cools down the surface water temperature and also dilutes contaminants and particulates.

Table 11. Chloride Concentrations in Surface Water Quality

Surface Water Quality

	SP 2	SP 3	SP 4	SP 5
Feb 2012		140.70	84.25	13.40 - 23.27
March 2012		90.25 - 115.40	66.60 - 84.05	39.91
April 2012	107.50	106.25	76.75	26.60 - 32.51
May 2012	92.20 - 103.90	124.75 - 116.20	70.45 - 92.05	13.705 - 21. 79
June 2012	80.25 - 103.90	124.65 - 154.10	78.80 - 105.45	9.57 - 10.245
July 2012	81.50 - 97.50	97.75 - 107.15	42.56 - 83.60	

	SP 6
March 2012	11. 235
April 2012	29.68
May 2012	16.67
June 2012	8.77
July 2012	5.855 - 6.09

Table 12. Pearson Correlation Coefficients of Surface Water Characteristics

Parameter	Temp	pH	Turbidity	DO	TDS	Chloride	Rainfall
Temp	1						
pH	0.009	1					
Turbidity	-0.270	0.025	1				
DO	-0.676*	0.022	0.671*	1			
TDS	0.496	-0.131	-0.662*	-0.774*	1		
Chloride	0.457	0.439	-0.687*	-0.813*	0.848*	1	
Rainfall	-0.537	0.320	0.108	0.318	-0.430	-0.104	1

Effect of Disposal Facility on Surface Water

The mean chloride concentrations with the standard deviation error bar during the dry and wet seasons are graphed in Figure 6. Majority of the surface water sampling points have mean Cl^- concentrations decreasing from dry to wet season except for SP3 and SP4. Higher mean Cl^- concentration on SP 3 during the wet season can be attributed to domestic activities. This sampling point is located in the creek draining to Marikina River and situated in residential areas. As the surface water from QCCDF travels along the creek, Cl^- increases slightly as it passes through residential areas which discharge untreated wastewater. SP6 represents the upstream point, located before the discharge point from

QCCDF outfall. At SP4, the creek conveying the leachate mixes with the river and SP6. The increase of mean Cl^- at SP4, relative to SP6, clearly indicates that leachate from QCCDF affects the quality of the river.

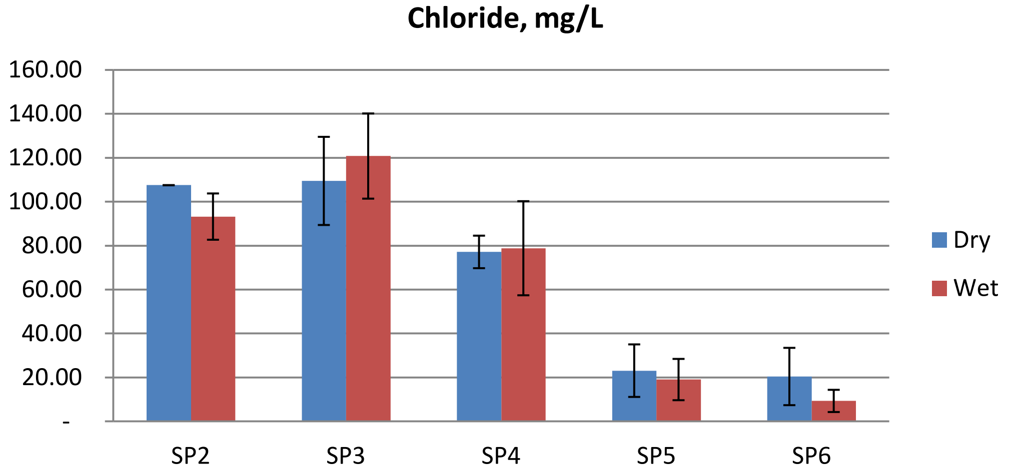

Figure 6. Chloride concentration levels at surface water sampling points

Conclusions

- The water quality parameters pH, temperature, DO, TDS, chloride and heavy metals (Pb, Cd, and Cr) in leachate, surface water and groundwater were measured for a period of six months and can be used as baseline information for future monitoring.
- Leachate quality parameters pH, turbidity, DO, and chloride are not affected by the change in seasons as evidenced by statistical t-tests. Temperature is higher during the wet season, while TDS is lower at this time which may be attributed to dilution due to rainfall. DO and turbidity in leachate is strongly negatively correlated, while temperature and Cl^- in leachate are positively correlated.
- In groundwater, the change in season affects temperature, TDS and chloride. This is not evidenced in pH and turbidity. TDS and chloride are correlated with each other.
- Based on the surface water quality measurements, temperature, pH, DO, and TDS are affected by the change in season while turbidity and chloride are not, based on the comparison of samples taken from different locations. Aside from strong correlation of Cl^- and TDS, as seen in groundwater, very strong correlations are also observed between Cl^- and DO, and TDS and DO.
- Higher concentrations of Pb were measured on groundwater sampling points with wastes buried underground. Heavy metals in surface waters are all below the effluent standards of the Philippines' Department of Environment and Natural Resources (DENR) as contained in DENR Administrative Order 34 (DAO 34).
- Based on the chloride concentration in groundwater contour maps, the lateral spread of leachate as indicated by chloride is concentrated in the immediate vicinity of the dumpsite. The potential for groundwater contamination is low considering that the underlying strata is made of low permeability materials.
- Based on the chloride concentration in surface water, it is evident that the leachate from QCCDF impacts the Marikina River.

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References

[1] C. Aquino, *Groundwater Quality Monitoring with Emphasis on Data Analysis at the Payatas –Novaliches Reservoir Area*, Thesis (Master's), University of the Philippines Diliman, Quezon City, Philippines, 2002.

[2] K. Chea, *Modeling of Chloride Leaching at Quezon City Controlled Dumping Facility*, Thesis (Master's), University of the Philippines Diliman, Quezon City, Philippines, 2014.

[3] Department of Environment and Natural Resources Environmental Management Bureau (DENR –EMB), *Administrative Order No.35*, [Online]. Available: http://cdmdna.emb.gov.ph/elaws/Images/DAO%201990-35.pdf

[4] Department of Health, *Philippines National Standards for Drinking Water,* Administrative Order 2007-0012, Manila, Philippines, 2007.

[5] K. Mizumura, "Chloride Ion in groundwater near disposal of solid wastes in landfills," *Journals of Hydrologic Engineering*, Vol. 8, pp. 204-213, 2003.

[6] R.K. Rowe, *Leachate Characteristics for MSW Landfills*, Geotechnical Research Centre Report, Canada, 1995.

[7] C. Seedao, *Determination of Cu, Cd, Pb and Hg in Soil Samples taken from the Payatas Controlled Dumping Facility*, Thesis (Master's), University of the Philippines Diliman, Quezon City, Philippines, 2008.

[8] W. Xu, *A Study of Effects of the Quezon City Controlled Dumping Facility (QCCDF), Manila on Soil and Water Environments*, Thesis (Master's), Tokyo Institute of Technology, Tokyo, Japan, 2010.