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Assessment of heavy metals (Pb, Cu, Cr, Cd and Fe) in the groundwater wells in the vicinity of Nyanza Municipal Solid waste in Kigali City- Rwanda

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Abstract

The purpose of this study was to assess the impacts of Nyanza Municipal Solid Waste (MSW) dumping site on groundwater. As many groundwater resources are contaminated by dumping sites that are poorly managed, the equally poorly managed Nyanza MSW dumping site in Kigali could have impact on people depending on groundwater for their daily activities.

Leachate samples were taken at the edge of the waste bulk and groundwater samples were collected from the wells located in the vicinity of the dumping site. Sampling was done in dry and wet season using PE bottles. Heavy metals analysis was done using flame atomic absorption method.

The analytical results of leachates samples (Pb: 4.5-8.5 mg/L, Cd: 0.20-0.75 mg/L, Cr: 16.8-5.7 mg/L, Cu: 0.8-2.8 mg/L, Fe: 39.2-130.2 mg/L) showed that heavy metals are leached out from the MSW. The analytical results of groundwater from the wells located in the vicinity of Nyanza MSW dumping site (Pb: 0.25- 0.86 mg/L, Cd: 0- 0.02 mg/L, Cr: 0-2.68 mg/L, Cu: 0.02-0.12 mg/L, Fe: 0.12-0.76 mg/L) compared to the groundwater from the Masaka well located far away from the site (Pb: 2.24 mg/L, Cd: 0.00 mg/L, Cr: 0.04 mg/L, Cu: 0.08 mg/L, Fe: 0.14 mg/L), revealed that groundwater from the wells located in the vicinity of Nyanza MSW dumping site requires further physical chemical treatment to ensure their suitability for human consumption as the levels of some water quality parameters exceeded the WHO guidelines for drinking water.

Further analysis are needed with inclusion of hydrogeochemical of the area as very low concentration of heavy metals in interest were found in one of the well situated in the vicinity of Nyanza MSW dumping site. Therefore, Nyanza MSW dumping site might not be the only pollutant source for groundwater in this region.

Keywords: *Nyanza MSW, heavy metals, groundwater, landfill*

1. Introduction

Groundwater is one of the major sources of freshwater to human society it has been considered to be a readily source of water for domestic, agriculture and industrial use (Biswas, 1997). For example in England and Wales, groundwater abstraction constitutes approximately 75% of all abstracted groundwater (O'Riordan, 2000). In USA, groundwater provides more than half of the drinking water supply (O'Riordan, 2000). In Rwanda, groundwater provides 10% of the overall drinking water that is distributed by the energy, water and sanitation corporation (EWSA).

The largest use of groundwater in Rwanda is for domestic purposes. In Kigali city, this groundwater is essentially a major source of drinking water and other domestic uses such as cooking, washing... Therefore, the quality of groundwater is one of the major concerns regarding water resources management. There are many sources of groundwater pollution of which waste dumping site is the main one. However, very little attention has been paid to its impact on the availability of drinking water in Kigali. Thus, this study took into account the wells that are located in the vicinity of the Nyanza MSW (Municipal Solid GEgg) dumping site at Kicukiro District, Kigali city. There are many wells in Kicukiro District and most of them are located at the elevation below the Nyanza MSW dumping site altitude. As leachate flows from high water table height to low water table height, the leachate from Nyanza MSW dumping site may flow from the dumping site to the wells in the region.

In fact, according to Hughes et al. (2005) and Haifeng et al. (2008) during dumping, both inorganic and organic wastes release leachate, which could contaminate both surface soil and groundwater due to its toxic chemicals content. In Kicukiro area of Kigali City, the risk of groundwater pollution may be high because Nyanza MSW dumping site has no engineered liners and leachate collection systems as well as a leachate treatment plant on site.

In this paper, the physico-chemical parameters of groundwater will be examined. As many groundwater resources are contaminated by dumping sites that are poorly managed (Viessman and Welty, 1985), the equally poorly managed Nyanza MSW dumping site in Kigali (Draft Report Fukuoka University landfill experts, 2009) could have impact on the local population depending on groundwater for their activities. The projected population increase in Rwanda according to Kigali city planning will inevitably increase the demand of groundwater. Once groundwater becomes contaminated, population will be exposed to serious human health and environmental problems.

Our study aims at clarifying the characteristics of leachate produced by Nyanza MSW dumping site, the groundwater characteristics from the wells nearby and assessing whether the dumping site has significant impacts on groundwater.

2. Material and methods

2.1. Sampling site description

Nyanza MSW dumping site is located in Kicukiro District, Gahanga sector which is located in the east part of Kigali City. This dumping site lies at 2° 00.125' S and 30° 06.066' E, and at the elevation of 1678m. The residence around the dumping site has access to water from the wells located in the vicinity of the dumping site. Those wells are situated below the mentioned elevation of the dumping site (Figure 1).

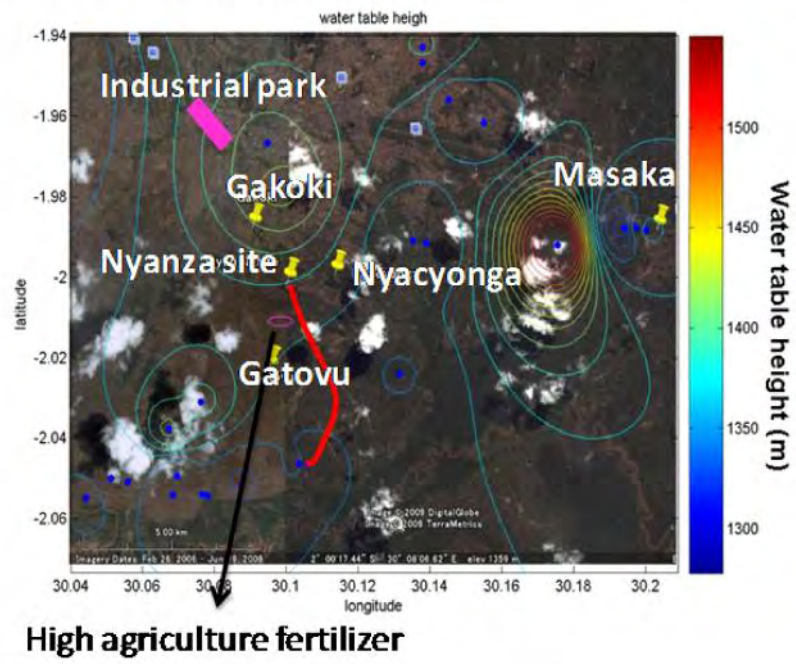

Figure 1: Sampling sites and groundwater flow interpolation

Figure 1 shows that apart from the Nyanza dumping site, there are other activities that may affect the groundwater quality of the area such as the waste water from industrial park and agriculture activities.

2.2. Sample collection and analysis

Sampling consisted of collecting leachate from the dumping site and groundwater from wells used by the population in the vicinity of Nyanza MSW.

Samples were taken using polypropylene plastics containers. These containers were cleaned using nitric acid and rinsed twice with deionized water. The containers were always rinsed with the water/leachate sample before collection. Samples for heavy metals analysis were acidified with nitric acid and preserved at 4^o c in refrigerator.

Samples were collected during the dry season and wet season although some parameters could not be measured in both seasons.

Leachate samples were collected at two edges of Nyanza MSW dumping site; first leachate sample site was located upstream at the edge of the dumping site at distance of 4-5m from the dumping site and at about 50 cm of depth; the second leachate sample site was located downstream the first site at a distance of 7-8 m from the dumping at about 70 cm of depth. Groundwater samples were taken at three wells located in the vicinity of Nyanza dumping site and one well located far from Nyanza MSW used as indicator of non pollution. The sampling in the vicinity of Nyanza consist of Nyacyonga well in Gahanga sector located at 2° 00.000' S and 30° 06.753' E with the elevation of about 1412 m; and at 1270 m from Nyanza MSW, Gakoki well in Gatenga sector located at 1° 59.370' S and 30° 05.521' E, at the elevation of 1502m; and at 1680 m from Nyanza MSW and Gatovu well in Gahanga sector that lies at 2° 01.318' S and 30° 05.779' E, at the elevation of 1429 m; and at 2260 m from Nyanza MSW dumping site (Figure 1). The last well used as indicator was Masaka located at 1° 59.299' S and 30° 11.651' E.

Although, there are many kinds of pollutants that may be generated by Nyanza MSW dumping site, this research focused on the following parameters which are among the greatest concerns: pH, temperature, electric conductivity, total dissolved solids, COD, cadmium, chloride, chromium, copper, iron, and lead. pH, temperature, electric conductivity, total dissolved solids, COD, and chloride were measured in situ. pH was measured using a pH meter. Temperature, electric conductivity, total dissolved solids were measured using a portable EC-TDS meter (Hanna Hi 99300). Chloride was measured using chloride detection tubes (Komyo Rikagaku). This uses the reaction of chloride with silver chromate to precipitate silver chloride. If chloride ion exists in the sample solution, a discoloration will occur in the detecting reagent layer from its inlet and the discolored layer shall be given according to the concentration of chloride ion. COD was measured using a high (for leachate) and Low (for groundwater) Kyoritsu COD Pack test which uses potassium permanganate method (COD-Mn).

Samples for heavy metals analysis were done using a Varian AA 240 atomic absorption spectrophotometer which is a flame AA method. Leachate samples were digested in aquaregia and filtered prior to the analysis (Kruis, 2007).

3. Results and discussions

3.1. Leachate physic-chemical characteristics

Table 1 presents the leachate average concentration of different physico-chemical parameters.

Table 1: Leachate physic-chemical characteristics

	Upstream leachate		Downstream leachate	
Sampling	**Dry season**	**Wet season**	**Dry season**	**Wet season**
pH	8-9	8-9	8-9	8-9
Temperature (^oC)	30	18	27.3	24
EC (µs)	ND	13660	22200	20500
TDS (mg/L)	ND	6720	11100	10300
Cl^-(mg/L)	1750	1770	1200	4000
COD (mg/L)	ND	1200	ND	6000
Pb (mg/L)	ND	4.5	ND	8.5
Cd (mg/L)	ND	0.20	ND	0.75
Cr (mg/L)	ND	5.7	ND	16.8
Cu (mg/L)	ND	0.8	ND	2.8
Fe (mg/L)	ND	39.2	ND	130.2

nd: not determined

3.1.1. pH, Electrical conductivity (EC) AND Total dissolved solids (TDS) variation

The pH values of leachate collected downstream and upstream during both in the dry and wet seasons were between 8 and 9.The observed pH range did not differ from the pH (8.45) of the leachate originating from major landfill site (Fatta et al., 1998, Ikem et al., 2002); and this pH falls within the WHO recommended values (5-9) for wastewater and industrial discharge.

The Electrical Conductivity (EC) is the major indicator of solid waste dumped at the surface (Singh et al., 2008). The EC high value of leachate from Nyanza MSW dumping site was found during the dry season were 22200 µs in the leachate collected from downstream edge. During the wet season, EC values were 20500 µs in the leachate collected from downstream edge and 13660 µs in the leachate collected from upstream edge of Nyanza MSW dumping site.

The high values of EC indicate elevated concentration of ions in the leachate, generally major cations and anions (Al-Yaqout and Hamoda, 2003; Fatta et al., 1998). This was confirmed by the elevated concentration of TDS average values that ranged from 6820 to 14550 mg/L.

3.1.2. Variation of Chloride variation

Chloride is considered to be a conservative contaminant which is not affected either by the biochemical processes taking place in the landfill body or by the natural decontamination reactions in which the leachate is involved during their penetration in the vadose zone (Fatta et al.,1998). Thus there is a need to assess its variation.

During the dry season the chloride concentration in the leachate from downstream edge of Nyanza MSW dumping site was 1200 mg/L and 1770 mg/L from the leachate collected from upstream of Nyanza MSW dumping site. In wet season the chloride' average concentration in the leachate collected from downstream edge of Nyanza MSW dumping site was 3950 mg/L and 1750 mg/L in the leachate collected from downstream edge of Nyanza MSW dumping site.

The high concentrations of chloride in the leachate collected in the downstream edge of Nyanza MSW dumping site during the wet season compared to the dry season is due to high leaching process during the wet season. If the leachate is not properly treated before discharge, the pick up of dissolved organics and soluble salts can leach into the water table creating adverse effects on water quality (Muttamara and Leong, 1996). As there is no treatment facility at Nyanza MSW dumping site, the high concentration of chloride during wet and dry season may have impact on groundwater due to untreated leachate. Therefore, the high chlorides concentrations in the leachate samples constitute a serious threat for the water table of the area. The average of Cl^- was found to be high in leachate collected from downstream of Nyanza MSW dumping site compared to leachate collected from upstream.

3.1.3. Chemical Oxygen Demand (COD) variation

COD concentrations were found to be 6000 mg/L in the leachate collected downstream edge and 1200 mg/L in the leachate collected upstream edge of Nyanza MSW dumping site. COD consists both of biodegradable and non-biodegradable materials. During chemical oxidation, both biodegradable and resistant substances are being oxidized.

This high value may be influenced by other substances as Kylefors and Ecke (2002) mentioned that inorganic substances such as iron, sulphide, manganese, ammonia nitrogen, nitrite, and chloride occuring in high concentrations in landfill leachate may affect the COD value. Many of these substances are found to be high in the landfill leachate as chloride case mentioned above. This results are also in agreement with what was reported by Muttamara and Leong, (1996) that COD value is high for downstream than updstream leachate samples.

3.1.4. Variation of Heavy metals (Iron, lead, cadmium, chromium and copper)

Iron average concentrations were found to be 130.2 mg/L in the leachate sample taken at downstream edge of Nyanza MSW dumping site and 39.2 mg/L in the leachate sample taken at upstream edge of Nyanza MSW dumping site. The high level of Fe in the leachate sample indicates that iron, steel and household equipments made in iron are 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). Leachate samples from downstream edge of Nyanza MSW dumping site had high intense dark brown color compared to the leachate samples collected from upstream, which means that oxidation and complexations processes happened in Nyanza MSW dumping site. The downstream and upstream leachate concentration in Fe exceeds the European standard for industrial waste water which shall not be discharged into surroundings (10 mg/L).

The concentrations of Pb were found to be 8.5 mg/L in the leachate collected downstream and 4.5 mg/L in the leachate collected upstream from Nyanza MSW dumping site. The presence of Pb in the leachate samples indicates the plausible disposal of Pb batteries, chemicals for photograph processing, Pb-based paints and pipes at the landfill site (Moturi et al., 2004; Mor et al., 2005). At Nyanza MSW dumping site the discharged Pb batteries were observed. Other possible sources would be Pb-based paints and pipes may be the source of lead in the leachate samples. Lead concentration in leachate samples were above the European standard for industrial waste water which shall not be discharged into surroundings (1 mg/L).

The average concentration of Cd was 0.75 mg/L from the downstream leachate and 0.20 mg/L from the upstream leachate of Nyanza MSW dumpsite. Upstream leachate concentration in Cd exceeds the European standard for industrial waste waters that are allowed to be discharged only into specific water bodies permitted by authority agencies (0.02 mg/L). The downstream leachate concentration in Cd also exceeds the European standard for industrial waste water which shall not be discharged into surroundings (0.5 mg/L).

Chromium (Cr) average concentrations in the leachate collected from Nyanza MSW dumping site were 16.5 mg/L at the downstream edge and 5.7 mg/L at the upstream edge. Both upstream and downstream leachate concentrations exceed the European standard for industrial waste water which shall not be discharged into surroundings (0.5-2 mg/L). The high Cr concentration at Nyanza MSW dumping site might be due to the paint containing chromium or more likely the medical wastes that may have been discharged at Nyanza MSW dumping site.

The leachate samples collected at Nyanza MSW dumping site had the copper (Cu) average concentrations of 2.8 mg/L and 0.8 mg/L at downstream and upstream respectively. These low values may be due to complexation of copper ions as metal solubility generally decreases with increasing pH (Gould, 1989, Esakku et al., 2003). The pH values of Nyanza MSW dumping site were between 8 and 9, thus copper might have been removed by precipitation and complexation process. The order reason for low copper concentration would be that few the discharged solid waste at Nyanza MSW do not contain bioavailable copper forms.

The general observation from heavy metals analyzed in the leachate samples is that leachate samples from downstream have higher concentrations of heavy metals, more than twice of the heavy metals concentrations of the leachate from upstream. This is the indication of high leaching process in Nyanza MSW dumping site.

3.2. Assessment of Groundwater contamination

Groundwater analysis was carried out to assess the characteristics of water from the wells in the vicinity of Nyanza MSW dumping site. The selected parameters were analysed in groundwater from three wells (Nyacyonga, Gakoki, Gatovu) located at 1260 m, 1860m and 2260 m respectively from

Nyanza MSW dumping site and from the well located far from Nyanza MSW dumping site at Masaka as a blank reference located at 10430 m from Nyanza MSW dumping site. The results of both field and laboratory analyses are presented in table

Table 2: Physic-chemical characteristic of groundwater wells

	Gakoki		Gatovu		Nyacyonga		Masaka
Parameters	**Dry season**	**Wet season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**	**Wet season**
pH	5-8	6-7	6-8	5-6	5-7	6-7	6-7
Temperature (^oC)	20.5	23.0	25.4	23.6	24	23.5	23.4
EC (µs)	725	377	393	318	224	169	344
TDS (mg/L)	359	188	196	159	113	84	171
Cl^-(mg/L)	135	83	56	60	27	33	35
COD (mg/L)	20-120	350	126	60	70	350	30
Pb (mg/L)	nd	0.25	nd	0.86	nd	0.36	2.24
Cd (mg/L)	nd	0.02	nd	0.00	nd	0.01	0.00
Cr (mg/L)	nd	2.68	nd	0.00	nd	1.86	0.04
Cu (mg/L)	nd	0.02	nd	0.12	nd	0.04	0.08
Fe (mg/L)	nd	0.14	nd	0.12	nd	0.76	0.14

3.2.1. pH, Electric conductivity (EC) and Total Dissolved Solids (TDS)

The pH values of all groundwater collected from the wells Gakoki, Gatovu, Nyacyonga and Masaka are around the neutral pH and within the permissible values of pH for drinking water.

EC and TDS average values from the wells ranged respectively from 224 to 725 **µs** and 113 and 359 mg/L. Figure 2 shows that EC and TDS values in dry season were higher than EC and TDS values in wet season.

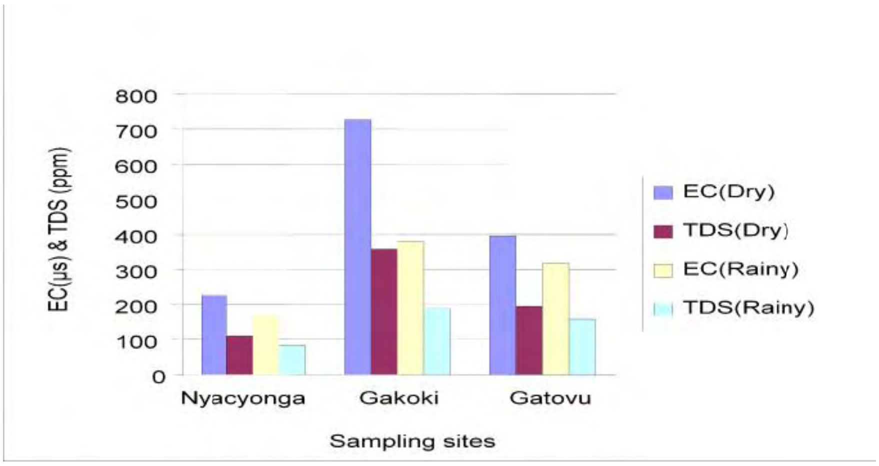

Figure 2: EC and TDS of Groundwater samples.

The average EC and TDS values in groundwater from the wells in the vicinity of Nyanza MSW dumping site compared to EC and TDS values in groundwater from Masaka showed that Gakoki well have the highest values of EC and TDS of 725 and 359 mg/L respectively, this is most likely linked to the geology in the area with sandy soil which favor the leaching process of chemicals.

3.2.2. Variation of Chloride (Cl^-)

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). Faust and Aly (1983) illustrated that chloride in reasonable concentration is not harmful, but it causes corrosion in concentrations above 250 mg/L, while it causes a salty taste in water when the concentration reaches 400 mg/L. Increase in Cl^- level is also detrimental to people suffering from heart or kidney diseases.

Groundwater from Nyacyonga, Gatovu and Masaka wells had reasonable concentration (ranging from 33 to 60 mg/L) compared to groundwater from Gakoki wells ranging from 83 and 135 mg/L. This concentration did not change much across the dry and wet seasons while there is a reduction in Cl^- concentration of groundwater from Gakoki well in wet season compared to dry season (table 2) as rain season may impact on recharge zones thus water from different areas with low level of chloride concentration diluting the water reservoir. The high difference in Cl^- concentration in groundwater from three wells (Nyacyonga, Gatovu and Masaka) compared to Gakoki well may relate to the structure of the wells.

Nyacyonga, Gatovu and Masaka wells have a sand filtering system and are constructed protecting groundwater from these wells to be in contact with the soil while Gakoki well has no filtering system and water from underground is always in contact with soil.

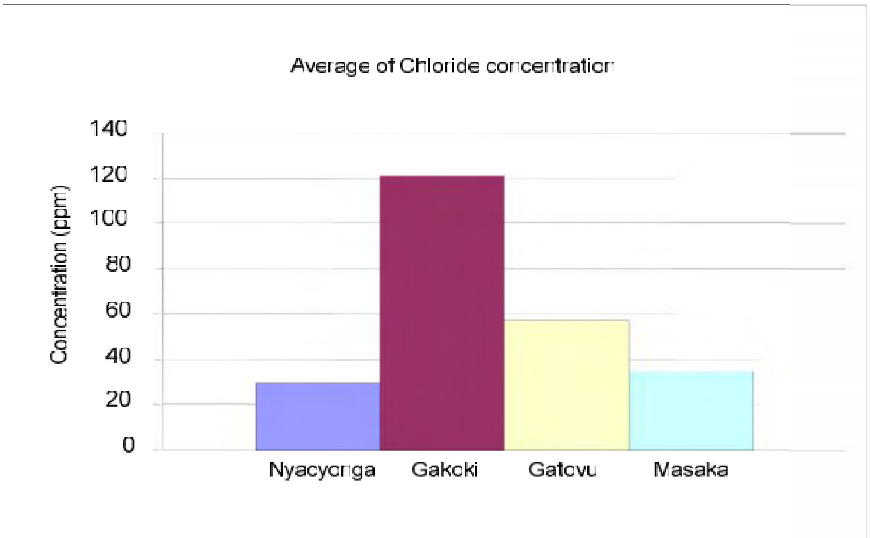

Figure 3: Comparison of Chloride concentration in groundwater.

There is no evidence that chloride in these wells is coming from the Nyanza MSW, Masaka well taken as originating in low polluted area indicates similar concentration as Nyacyonga and gatovu wells (Figure 3).

3.2.3. Variation of Chemical Oxygen Demand (COD)

COD values in groundwater from the wells in the vicinity of Nyanza MSW dumpsite are shown in Table 2. Drinking water supply should not exceed COD of 2.5 mg/L and potable water of COD content greater than 7.5 mg/L is regarded as poor (Esa, 1983). Groundwater from Gakoki, Gatovu, Nyacyonga wells have very high COD values ranging from 60 to 350 mg/L, and these are indications of polluted groundwater. Masaka well, as indicator of low pollution, had a low average concentration of 30 mg/L (Figure 4).

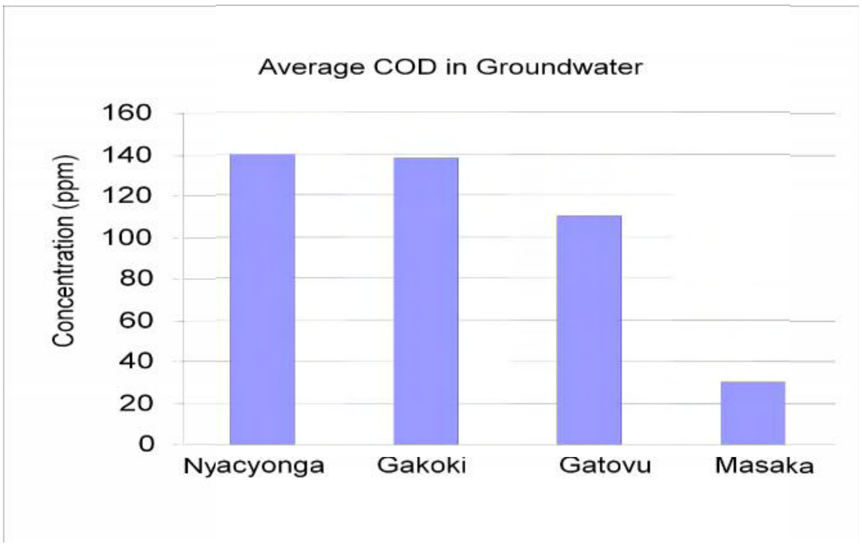

Figure 4: Variation of Chemical oxygen demand in Groundwater.

As reported by Muttamara and Leong, 1996; COD values are usually high in dry season compared to wet season. However, the results of groundwater from Nyacyonga, Gakoki and Gatovu wells did not show the same trend. In order to know how COD changes and the possible cause of the changes in groundwater from the wells located in the vicinity of Nyanza MSW dumping site, a one day COD variation follow up experience was conducted.

In one day during wet season COD at Gakoki wells was measured from 8:00 to 5:00 with an interval of three hours between each measurement. The result (Table 3) shows that COD values at the well where groundwater was taken could depend on the environment instantaneously. Therefore, results variation on table 3 might not reflect the seasonal changes of COD, but simply pick up some other signals in the vicinity of Nyacyonga, Gakoki and Gatovu wells. COD needs to be measured several times a day across the season in order to characterize the seasonal changes.

Table 3: One day variation of COD measurement during wet season at Gakoki well

Time	COD (mg/L)	OBSERVATIONS
8:00	210	People were around taking water
11:00	720	One hour after it rained, high value due to surface runoff
14:00	1050	Four hours after it rained, matter already dissolved in water
17:00	120	Seven hours after it rained, water sample was clear compared to other samples (11:00 and 14:00)

Table 3 shows that COD varies with time and weather as rain would affect very much the concentration of COD. The daily changes may be coming from different recharge sources and time.

3.2.4. Variation of heavy metals

WHO has proposed permissible values for Pb, Cd, Cr and Cu as 0.01, 0.003, 0.05 and 2 mg/L respectively in drinking water and EU standard has proposed the permissible value of 0.2 mg/L for iron in drinking water.

Lead concentrations in groundwater from Gakoki, Gatovu, Nyacyonga wells ranged from 0.25 to 0.86 mg/L and were above the WHO permissible value of 0.01 mg/L (Figure 5). Pb concentration in those wells is presented in the following order: Gatovu> Nyacyonga> Gakoki. The high concentration of Pb at Gatovu may come from the dumping site, as shown in Figure 1. Groundwater flows is highly towards Gatovu well than Nyacyonga well and leachate is known to flow with groundwater; other possible source of Pb in Gatovu well is the fertilizer preparation site located at 1380 m from Gatovu well. This may be the cause of high Pb concentration at Gakoki well compared to Nyacyonga well which is located close to Nyanza MSW dumping site. Groundwater from Gakoki well has low concentration of Pb due to the distance from Nyanza MSW dumping site and to the estimation of leachate flow (see Figure 1). Masaka well has high concentration of Pb compared to wells located in the vicinity of Nyanza MSW dumping site (Figure 5). This should be further explored as Pb contamination sources and other heavy metals in general in the Kigali groundwater system might be complex.

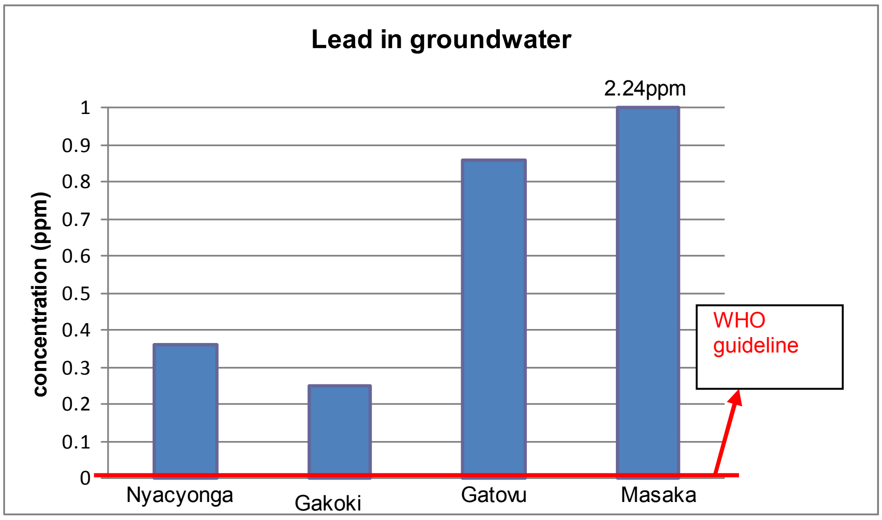

Figure 5: Variation of lead concentration in groundwater

Cadmium concentrations in groundwater from Gakoki and Nyacyonga wells were above the WHO permissible value of 0.003 mg/L (Figure 6). In Gatovu and Masaka wells, Cd was not detected in the groundwater. The concentration of Cd in groundwater from Gakoki was higher compared to the groundwater from Nyacyonga. Cadmium in groundwater is an indicator of anthropogenic pollution as Gakoki well is located downstream of the Gikondo Industrial park (figure 1).

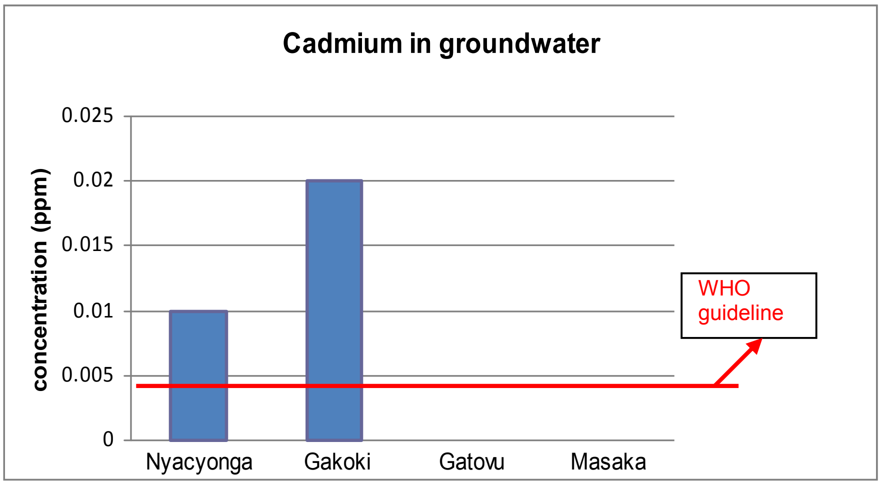

Figure 6: Variation of cadmium concentration in groundwater

As indicated on figure 7, groundwater from Gakoki and Nyacyonga wells showed the Cr concentration above the WHO permissible value of 0.05

mg/L but Cr concentration in groundwater from Gatovu well was below the detection limit. The concentration of Cr in groundwater from Gakoki was higher than the Cr concentration in groundwater from Nyacyonga well. Groundwater from Masaka well had Cr concentration of 0.04 mg/L which is close to the WHO permissible value (0.05 mg/L).

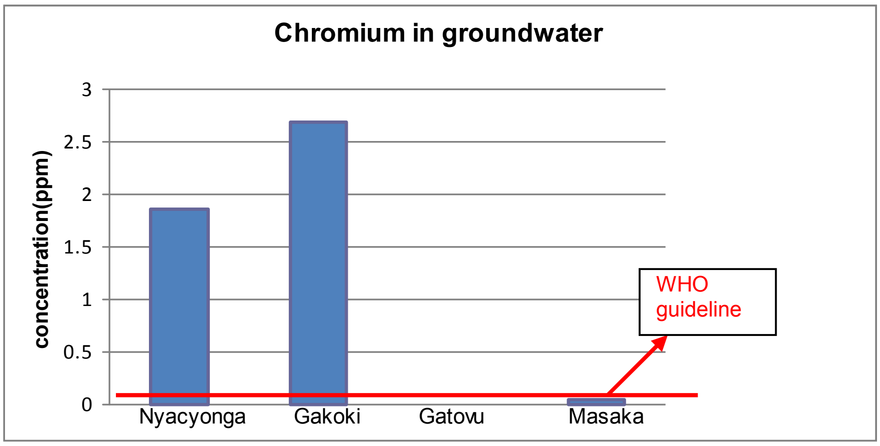

Figure 7: Variation of Chromium concentration in groundwater with guideline

The concentrations of Cu in groundwater at those four wells are below the WHO permissible value of 2 mg/L for Cu (Figure 8).

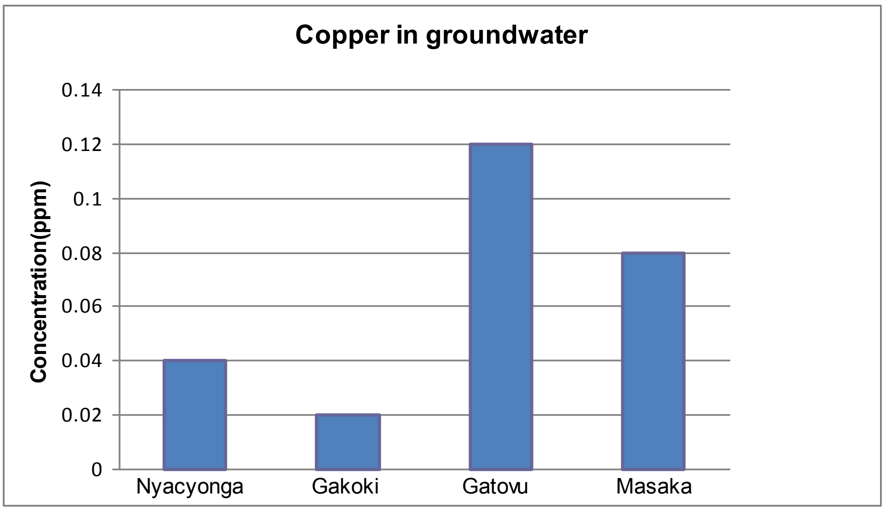

Figure 8: Variation of Copper concentration in groundwater and guideline

The concentration of Fe in groundwater from (Nyacyonga) well was above the European standard for Fe (0.2 mg/L) (Figure 9). But groundwater from Gakoki, Gatovu and Masaka wells showed the Fe concentrations are below the EU standard. Agriculture activities around Nyacyonga well might have contributed to the high Fe quantity in Nyacyonga well.

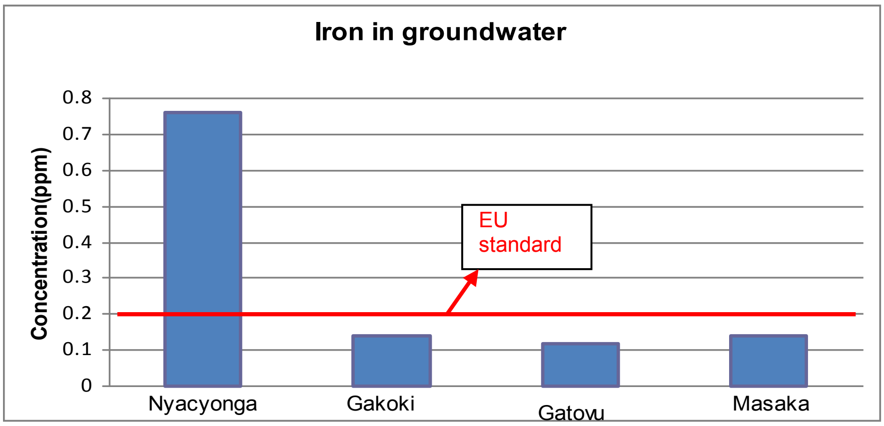

Figure 9: Variation of Iron concentration in groundwater and guideline

In general, the concentrations of different metals concentrations in the groundwater wells have not been linked to the Nyanza MSW. It should be noted that they would be different sources of these metals such as agricultural activities, industrial park in the surrounding area as shown on figure 1. Note that our estimation of groundwater flow uses interpolation because the water table height at Nyanza MSW dumping site is not known. In case that water table at Nyanza MSW dumping site is higher than the water table height at Gakoki well, pollutants can flow northward toward Gakoki well. Therefore, it is essential to investigate the water table height at Nyanza MSW dumping site in the future studies. The assessment using tracers such as isotope should be looked at in future studies.

4. Conclusions and recommendations

The purpose of this study was to assess the impacts of Nyanza MSW dumping site on groundwater. The analytical results of leachates samples (Pb: 4.5-8.5 mg/L, Cd: 0.20-0.75 mg/L, Cr: 16.8-5.7 mg/L, Cu: 0.8-2.8 mg/L, Fe: 39.2-130.2 mg/L, COD: 1200-6000 mg/L and Chloride: 1200-4000 mg/L) showed that the dumping site contains heavy metals and high quantity of inorganic waste. The analytical results of groundwater from three wells located in the vicinity of Nyanza MSW dumping site (Cl^- : 25-140 mg/L, COD: 10- 1050 mg/L, Pb: 0.25- 0.86 mg/L, Cd: 0- 0.02 mg/L, Cr: 0-2.68 mg/L, Cu: 0.02-0.12 mg/L, Fe: 0.12-0.76 mg/L) compared to the groundwater from the well located at Masaka far from the dumping site (Cl^- : 35 mg/L, COD: 30 mg/L, Pb: 2.24 mg/L, Cd: 0.00 mg/L, Cr: 0.04 mg/L, Cu: 0.08 mg/L, Fe: 0.14 mg/L), revealed that groundwater from the wells located in the vicinity of Nyanza MSW dumping site requires further analysis to ensure their suitability for human consumption because the levels of some water quality parameters exceeded the WHO guidelines EU standards for drinking water.

The analysis of Cd and Cr in groundwater from Gatovu well showed that Nyanza MSW dumping site has minimal impact on this well, while Pb analysis resulted in its high concentration in Gatovu well as well as in Masaka well where Pb was found to be abundant compared to Gatovu well. Therefore Nyanza MSW dumping site might not be the only pollutant source for groundwater.

All possible sources of groundwater pollution in Kigali should be studied in order to clarifythe contribution of the Nyanza MSW on groundwater pollution. Groundwater from the wells nearby Nyanza site should not be used for direct consumption.

References

1. Abu-Rukah Y. and Al Kofahi O. (2001)**,** the assessment of the effect of landfill leachate on ground-water quality-A case study El-Akader landfill site in north Jordan, *Journal of Arid Environments,* 49, 615-630.
2. Al-Yaqout A.F. and Hamoda M.F. (2003), Evaluation of landfill leachate in arid climate-a case study, *Environmental International,* 29, 593-600.
3. Biswas A. (1997), Water Resources, *Environmental Planning and Development*, 117-118.
4. Chu L. M., Cheung K. C. and Wong M. H. (1994), Variations in the chemical properties of landfill leachate, *Environ. Manage.* 18, 105–117.
5. Consultancy and Feasibility Study on Application of Fukuoka Method to a New Landfill Facility in Kigali Urban Development Policy Project, Rwanda (2009).
6. Esakku S., Palanivelu K. and Kurian J. (2003), Assessment of Heavy Metals in a Municipal Solid Waste Dumpsite *Workshop on Sustainable Landfill Management,* 139-145.

7. Fatta D., Voscos C., Papadopoulos A., and Loizidou M., Leachate (1998) Quality of a MSW Landfill, *j. environ. sci. health,*volume 5, 749-763.
8. Faust S.D. and Aly O.M. (1983), Chemistry of Water Treatment, *Butterworth Publisher: WoburnMA*, 723.
9. Gould, J.P., Cross, W.H. and Pohland, F.G., (1989), Factors influencing mobility of toxic metals in landfills operated with leachate recycle, *Emerging technologies in hazardous waste management, ed. Tedder ,T.W. and Pohland, F.G., ACS symposium series*, 422.
10. Haifeng Zuo Wei Jiahua Wang Guanggian and Yaping Chi (2008), *Study on the evaluation method of groundwater vulnerability to pollution from informal landfills in Regional Scale.*
11. Hem J.D. (1991), Study and interpretation of the chemical characteristics of natural groundwater, *U.S Geological Survey Water Supply*, 1473.
12. Hughes K.L., Christy A.D. and Heimlich J.E. (2005), Abandoned Dumps: Yesterday and Tomorrow, *Extension Fact Sheet of the Ohio State University*, CDFS-140-05.
13. Ikem A., Osibanjo O., Sridhar M.K.C., Sobande A. (2002), Evaluation of groundwater quality characteristics near twowaste sites in ibadan and lagos, Nigeria, *Water, Air, and Soil Pollution,* volume 140, 314-318.
14. Kruis Fred (2007), Environmental chemistry, selected methods for water quality analysis, UNESCO-IHE, 9-20.
15. Kylefors K. and Ecke H. (2002), Accuracy of COD test for landfill leachates, P 152- 168
16. Loizidou and Kapetanios (1993), Characterization of landfill leachate at waste disposal site in Kuwait, *Environment international,* Volume 21, P 399-405.
17. Mor S., Ravindra K., Dahiya R. P. and Chandra A. (2006), Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site, Environmental Monitoring and Assessment, 435-448.
18. Moturi, M. C. Z., Rawat, M. and Subramanian, V. (2004), Distribution and fractionation of heavy metals in solid waste from selected sites in the industrial belt of Delhi, India, *Environ. Monit. Assess.* , Volume 95, P183–199.
19. Muttamara S. and Leong S. T.(1996) Environmental Monitoring and Impact Assessment of a Solidwaste Disposal Site, *Environmental Engineering Program, School of Environment, Resources and Development, Asian,* P 1-14.

20. O'Riordan T. (2000), *Environmental Science and Environmental Management*, second edition P351-352.
21. Singh K.U., Manish K., Chauhan R., Pawan P. J., Ramanathan AL. and Subramanian V. (2008), Assessment of the impact of landfill on groundwater quality: A case study of the Pirana site in western India, *Environ Monit Assess,* volume 141, P 309-312.
22. Viessman W.and Welty C. (1985) Water Management: *Technology and Institutions*