Assessment of groundwater pollution at municipal solid waste of Ibb landfill in Yemen

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Abstract— Groundwater samples were collected from five boreholes from Ibb landfill to study the possible impact of leachate percolation into the groundwater. The objective of the study is to assess the groundwater pollution due to Ibb landfill at Al-Sahool area, Ibb city, the Republic of Yemen. The concentrations of various physiochemical parameters include heavy metals (Pb, Zn, Ni, Cr, Cd, Cu) pH, Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), anions and nutrients (F^-, Cl^-, SO_4^{-2}, NO_2, NO_3^-, NH_3-N), and major cations (Fe, Na, K, Ca, Mg) were measured from the groundwater samples. The results show that four out of five boreholes are contaminated, where the concentration of physic-chemical parameters are above the standard acceptable levels which required for drinking water adapted by Yemen's Ministry of Water and Environment (YMWE, 1999). The study has revealed that leachate from Ibb landfill has penetrated and polluted the groundwater resource in this area. The use of leachate collection pond is highly recommended to store and treat the leachate before the pollution level gets worse.

Keywords: Ibb landfill, groundwater, pollution, heavy metals

INTRODUCTION

Pollution occurs when a product added to our natural environment adversely affects nature's ability to dispose it. There are many types of pollution such as air pollution, soil pollution, water pollution, nuclear pollution and oil pollution. A pollutant is something which adversely interferes with health, comfort, property or environment of the people. Generally, most pollutants are introduced to the environment as sewage, waste, accidental discharge and as compounds used to protect plants and animals (Misra & Main, 1991).

Groundwater is that portion of subsurface water which occupies the part of the ground that is fully saturated and flows into a hole under pressure greater than atmospheric pressure. Groundwater occurs in geological formations known as aquifer. An aquifer (gravel/sand) may be defined as a geologic formation that contains sufficient permeable materials to yield significant quantities of water to wells and springs. This implies the ability of the formation to store and transmit water (Chae, 2000).

Groundwater is an important source of drinking water for human kind. It contains over 90% of the fresh water resources and is an important reserve of good quality water. Groundwater, like any other water resource, is not just of public health and economic value; it also has an important ecological function (Armon & Kott, 1994).

Landfill is an engineered waste disposal site facility with specific pollution control technologies designed to minimize potential impacts. Landfills are usually either placed above ground or contained within quarries, pits etc. Landfills are sources of groundwater and soil pollution due to the production of leachate and its migration through refuse (Chistensen & Stegmann, 1992). The objective of the study is to assess the groundwater pollution due to Ibb landfill at Al-Sahool area.

MATERIAL AND METHODS

Ibb city (Figure 1) is located between Sana'a, the capital of Yemen, and Taiz governorates. Ibb city is located at latitude 13°58'48" and longitude 44°10'48". Ibb is situated in a fault controlled valley close to the main watershed of Wadi Zabid at an elevation of about 2000 m above sea level.

Ibb landfill is located in Al Sahool area (Figure 2) with an area of 0.8 km^2. It is an open dump. It is a fertile agricultural area, and there are plantations surrounding the site, such as quality corn, coffee, and qat plantations to the south of the site. There is a variety of wildlife, especially with reptiles. There are some cows, sheep and donkeys in the area, which have been raised by the local farmers. Some of these animals were actually inside the dump site. With the growth of the population in this governorate, the wastes of different kinds have also increased. They are dumped near the residential areas.

Groundwater samples were collected from five boreholes close to Ibb landfill (Figure 2). Glass and polyethylene bottles were used to collect groundwater samples. A few drops of concentrated nitric acid were added to all the water samples collected for heavy metals analysis to make the pH equal 2.0 to preserve the samples. The samples were then transported in a cool box to be stored under suitable temperature until analysis.

The laboratory of Ibb Water and Sanitation Local Corporation (IWSLC) was used for analyzing of water samples. Spectrophotometer HACH (DR 4000 models 48000 and 48100) was used for measuring of PO_4, SO_4, NO_3, NO_2,

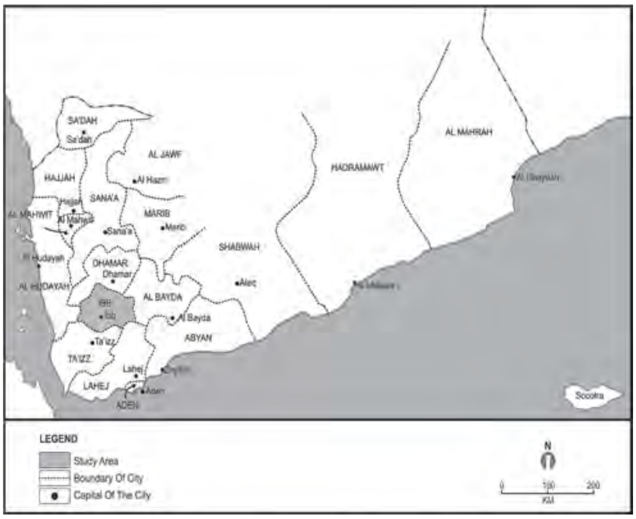

Figure 1: Location of Ibb city.

Table 1: *In situ* parameters in Al-Sahool area.

Parameter	pH	T	EC (µS/cm)	DO (mg/l)	TDS (mg/l)
BH1	7.23	24.9	3256.7	0.4	2116.85
BH2	7.20	27.2	1313.2	2.2	853.56
BH3	7.81	26.5	1185.3	3.3	770.47
BH4	7.82	29.6	1049.5	2.3	682.18
BH5	8.42	25.4	645.3	2.03	419.47
YMWE,1999	6.5-9	25	450-1000	-	1500
WHO, 2004	6.5-9.5	-	-	-	1200

F, and NH_3. Flame photometer (PFP 7) was used to determine sodium (Na) and potassium (K). The Yemen Standardization Metrology and Water Quality Control Organization in Sana'a were used for preparing and analyzing of heavy metals by using Inductively Coupled Plasma of Optical Emission Spectrometry (ICP-OES) model Vista MPX.

Chloride was measured by the mercuric nitrate titrimetric method. Twenty five ml of water samples was placed in Erlenmeyer flask, and then Diphenylcarbazone regent was added to the sample. The solution was blue-green, when mercuric nitrate was added as a titrant, the solution was turned from blue-green to purple, making the end point of the titration.

Calcium was measured by the EDTA titrimetric methods which involves the use of solutions of ethylene di amin titra acetic acid. Twenty five ml of water sample was placed in a conical flask, and then 2 ml of buffer solution was added to the sample. Man Ver 2 calcium indicator was also added to the sample. The solution was wine red, when EDTA was added as a titrant, the solution was turned from wine red to blue, making the end point of the titration.

The hardness was measured by the EDTA titrimetric methods which involves the use of solutions of ethylene di amin titra acetic acid. twenty five ml of water sample was placed in a conical flask, and then 2 ml of buffer solution was added to the sample. Man Ver 2 hardness indicator was also added to the sample. The solution was wine red, when EDTA was added as a titrant, the solution turned from wine red to blue, making the end point of the titration.

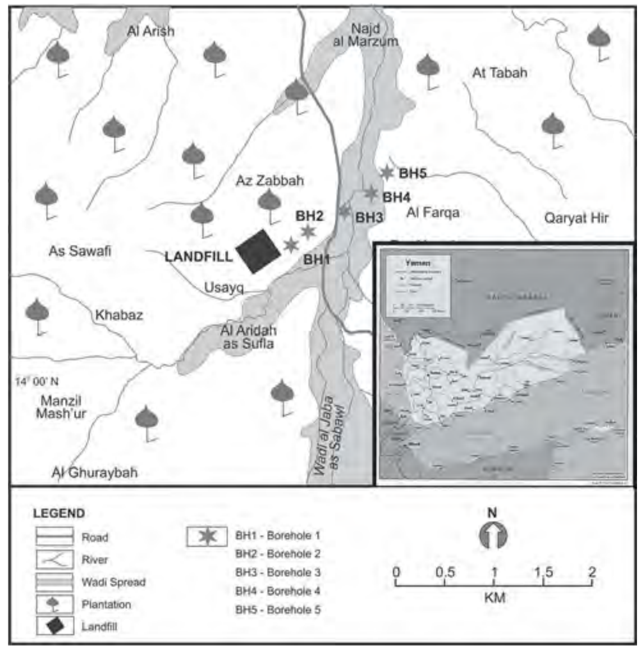

Figure 2: Location of the landfill and boreholes.

Magnesium was measured by calculation as the difference between total hardness and calcium hardness as follows:

Total hardness (as $CaCO_3$) =

$$2.497\,[Ca^{2+}, mg/l] + 4.118\,[Mg^{2+}, mg/l].$$

then

$$4.118\,[Mg^{2+}, mg/l] = \text{total hardness (as CaCO3)} - 2.497\,[Ca^{2+}, mg/l]$$

where Ca hardness = Ca^{2+} ion × 2.5; Mg hardness = Mg^{2+} ion× 4.11.

RESULTS AND DISCUSIONS

In-situ Parameters

The results of the measured *in-situ* parameters including pH, temperature (T), electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) are shown in Table 1.

The pH values of all boreholes are shown in Table 1. The highest value of 8.42 was measured in BH5, whereas the lowest value of 7.20 was measured in BH2. These values are greater than the values of 6.38 – 7.08 obtained by Bahaa (2005) and are also lower than the values of 8.05 obtained by Abdulatif (2001). Most natural waters having values within the range of 6 to 8.5 (Hem, 1970). The pH values are within the recommended values of 6.5 to 9 by Yemen's Ministry of Water and Environment (YMWE, 1999). These results are in within the values for drinking water (6.5 to 9.5) suggested by (WHO, 2004). pH usually has no direct impact on consumers. However, it is one of the most important operational water quality parameters. If the pH is above 7, this will indicate that water is probably hard and contains calcium and magnesium (David, 2004).

Electrical conductivity (EC) values showed very different results between boreholes. The highest value was from BH 1 (3257 µS/cm), whereas the lowest value recorded in BH 5 (645.3 µS/cm). These results are higher than the results obtained by Abdulatif (2001). The high values of EC in BH 1, BH 2, and BH 3 are not within the range values of 450 to 1000 µS/cm set by Yemen's Ministry of Water and Environment (YMWE, 1999). On the other hand, EC values in BH4 and BH5 are within the Yemen standard value for drinking water. The high values of EC in BH1, BH2, and BH3 can be related to the effect of the leachate seepage towards these boreholes. Conductivity can give idea of the amount of dissolved chemicals in water. The elevated values of EC in the first three boreholes suggested that there are some inorganic pollution in these boreholes compared to the last two boreholes. According to Langenger (1990), the importance of electrical conductivity is its measure of salinity, which greatly affects the taste and thus has a significant impact on user's acceptance of the water as being potable.

The concentrations of total dissolved solids (TDS) were different between boreholes. The highest value of 2117 mg/l was measured in BH1, whereas, the lowest value of 419 mg/l was measured in BH5. These results are in agreement with the range values of 396 to 3239 obtained by Bahaa (2005).

TDS concentration in BH 1 is not within the standard acceptable levels for drinking water by YMWE (1999), and WHO (2004). On the contrary, the TDS concentrations in BH 2, BH3, BH4, and BH 5 are in agreement with the YMWE (1999) and WHO (2004).

The high value of TDS in BH1 can be attributed to the affect of leachate from Ibb landfill, which contains high concentration of dissolved salts to the groundwater.

Dissolved oxygen (DO) measurements are varied. The highest concentration of 3.3 mg/l was measured in BH3, whereas the lowest concentration of 0.4 mg/l was measured in BH1.

According to Freeze and Cherry (1979), the biogeochemical processes are active during early stage of landfill development. The lowest concentration of DO in BH1, BH2 and BH3 indicating the affect of these boreholes by the migration of leachate from the body of the landfill. They also indicate that these boreholes are rich with organic matter where bacteria has used the oxygen to biodegrade it. It has been assumed that these pollutants are transported from leachate and most likely will be transported to the groundwater and pollute it.

Major anions and nitrogenous compounds

These include fluoride (F^-), chloride (Cl^-), sulfate (SO_4^{-2}), nitrites (NO_2^-), nitrates (NO_3), and ammonia-N (NH_3-N). The results are shown in Table 2.

The highest concentration of F^- was measured in BH1 with the value of 0.83 mg/l, whereas the lowest concentration in BH5 with the value of 0.35 mg/l. In general, the values of F^- in all boreholes are in within the standard levels for drinking water by YMWE (1999) and WHO (2004). The concentrations of Cl^- between boreholes were different. The highest concentration of Cl^- was measured in BH1with the value of 1495 mg/l, whereas the lowest concentration of Cl^- was measured in BH5 with the value of 74 mg/l. The Cl^- concentrations in BH1, BH2, and BH3 are higher than the standard for drinking water by YMWE (1999) and WHO (2004). On the other hand, the Cl^- concentration in BH1 was higher than the Cl^- concentration obtained by Bahaa (2005), but the Cl^- concentration in other boreholes lies within the range values obtained by Abdulatif (2001).

In comparison to leachate, groundwater in BH2, BH3 and BH4 has high Cl^-, perhaps due to the presence of leachate in groundwater. Baha'a (2005) in a study of leachate characteristics of landfills with operating ages from 7 to 20 years has shown that Cl^- concentrations range from 45 to 968 mg/l.

The high Cl^- ion usually provides early indication of the presence of leachate in the groundwater (Bouwer, 1978). Cl^- concentration of 4317 mg/l was measured in Ibb landfill leachate. This result was in agreement with the range results obtained by Christensen *et al*. (2002). On the other hand, Yoshida *et al*. (2002) reported high concentrations of Cl^- ranging from 512 to 39050 mg/l in the landfill in Tunisia.

There was a significant difference in the concentration of SO_4 between the boreholes. The highest concentration was measured in BH1 with the value of 51.0 mg/l, whereas the lowest concentration was measured in BH5 with the value of 24.2 mg/l. The result (170.5 mg/l) obtained by Singh *et al*. (2007) is high compared to the result in the present study. In general, the concentration of SO_4 in the groundwater is very low and do not pose any water quality problems because these results are within the standard acceptable levels for drinking water by YMWE (1999) and WHO (2004).

The NO_2 levels in the groundwater are varied. The highest level was recorded in BH1 with the value of 0.187 mg/l, whereas the lowest level was recorded in BH5 with the value of 0.002 mg/l. The NO_2 levels in BH1 is high in compared to the standard afor drinking water by YMWE (1999) and WHO (2004). The reason may be due to the migration of leachate from the body of Ibb landfill. On the other hand, the NO_2 levels in the other boreholes are very low and do not pose any significant water quality problem.

The NO_3 levels in the boreholes were very low and do not pose any significant water quality problem. Nitrate is reduced to nitrite in the stomach of infants, and nitrite is able to oxidize haemoglobin (Hb) to methaemoglobin (metHb), which is unable to transport oxygen around the body. Guideline value for combined nitrate plus nitrite should not exceed 1 (WHO, 2004). In this study the combined of nitrate plus nitrite did not exceed 1.

The PO_4 concentrations in all boreholes were very low. The highest content was reported in BH1 with the value of 0.54 mg/l, whereas the lowest content was reported in BH3 with the value of 0.179 mg/l. The PO_4 concentrations in all boreholes did not show any water quality problem, because these results are within the standard for drinking water determined by YMWE (1999) and WHO (2004).

Table 2: Concentration of major anions and nitrogenous compounds.

Parameter	F^- (mg/l)	Cl^- (mg/l)	SO_4^{-2} (mg/l)	NO_2^- (mg/l)	NO_3^- (mg/l)	NH3-N (mg/l)
BH1	0.83	1495.3	51.0	0.187	5.0	2.29
BH2	0.62	428.6	33.7	0.026	11.7	0.01
BH3	0.80	322.1	32.4	0.173	8.0	0.06
BH4	0.61	247.1	31.3	0.031	15.3	0.29
BH5	0.35	73.8	24.2	0.002	19.0	0.00
YMWE ,1999	1.5	250	250	0.1	50	0.5
WHO, 2004	1.5	250	250	0.1	50	-

Table 3: Concentration of major cations.

Parameter	Fe (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)
BH1	0.047	117.33	1.75	396.8	128.94
BH2	0.3	93.0	1.05	134.8	44.64
BH3	0.075	75.42	3.60	132.8	40.8
BH4	0.109	83.92	1.15	114	35.28
BH5	0.03	51.67	1.00	75.6	29.28
YMWE 1999	0.3	200	-	75	30
WHO, 2004	0.3	200	-	75	30

The concentrations of ammonia NH_3-N for all boreholes gave different values. The highest concentration of ammonia was detected in BH1 with the value of 2.29 mg/l, whereas ammonia was not detected in BH5. The high concentration of NH_3-N in BH1 can be attributed to the effect of leachate seepage from Ibb landfill. The concentration of NH_3-N (49.67 mg/l) in Ibb landfill leachate was very high in compared to the results obtained by Bahaa (2005).

According to Atxotegi *et al*. (2003), ammonium ion NH_4 is transformed into ammonia NH_3 based on pH through the following reaction:

$NH_4 \rightarrow NH_3 + H^+$ or

$NH_4OH \rightarrow NH_3 + H_2O$

YMWE (1999) and WHO (2004) recommended 0.2 mg/l as the maximum concentration of NH_3-N in groundwater used for drinking water. The high concentration of NH_3-N in BH1 and BH3 can be attributed to the leachate seepage from Ibb landfill.

Major cations

The major cations include Fe, Na, K, Ca, and Mg. The concentrations of cations are given in Table 3. Pujari and Deshpande (2005) in a study of groundwater around landfill found (0.38 mg/l) of Fe concentration, while Abdulatif (2001) in his study found the highest Fe concentration around (0.47 mg/l).

As shown in Table 3, BH1 has the highest concentrations of Na and K when compared to the others boreholes. This strongly suggest the presence of inorganic pollution in this borehole. Na ion concentration in groundwater frequently exceed 50 mg/l (Chapman, 1996). The Na salts are highly water soluble, and it is one of most abundant elements on the earth and its concentrations in all boreholes are lower than WHO (2004) guideline of 200 mg/l.

K was found in low concentrations in natural waters since rocks that contain potassium are relatively resistance to weathering. In natural waters, K usually occurs in concentrations less than 10 mg/l Chapman (1996). The K concentration in groundwater is derived from weathering of K-feldspars, and since these minerals are very insoluble so that K levels in groundwater normally are much lower than Na concentrations (Bouwer, 1978).

The level of Ca in BH5 was low if compared to the boreholes close to the landfill. BH1 showed the highest level of Ca followed by BH2, and then BH3. The Ca concentration in natural waters are typically less than 15 mg/l and for waters associated with carbonate rocks levels may reach 30 to 100 mg/l (Chapman, 1996). Among all the cations analysed, Ca showed high concentrations level in all boreholes. The highest concentration of Ca was measured in BH1 with the value of 396.8 mg/l, whereas the lowest Ca concentration was measured in BH5 with the value of 75.6 mg/l. Concentration of Ca in BH1, BH2, BH3, and BH4 are not within the standard levels for drinking water by MWE (1999) and WHO (2004).This means that, BH1, BH2, BH3, and BH4 are affected by the migration of Ibb landfill leachate to the groundwater.

Similarly for Mg, where BH1 has the highest concentration, whereas BH5 showed the lowest concentration of Mg. All these levels, except BH1 and BH2, in all boreholes are not within the natural levels of Mg in natural fresh water which determined by YMWE (1999) and WHO (2004). This elevated values which occurred in these boreholes might be due to the leachate effect seeping in this direction from the hilly waste body.

The high concentration of hardness was reported in BH1 with the value of 1537 mg/l followed by BH2 with the value of 523 mg/l, whereas the lowest concentration was reported in BH5 with the value of 432 mg/l. There are two types of water hardness, temporary and permanent. Temporary hardness is removed when the water is boiled; this process leaves deposits of calcium carbonate on water heaters and kettles. Permanent hardness is formed as the cations pass over rocks containing sulphate ions (David, 2004). Table

4 shows the levels of water hardness and type of water. Water in all boreholes are very hard, and BH1 and BH2 are the most affected boreholes by leachates from the landfill.

Heavy metals

Heavy metals analysed include lead (Pb), zinc (Zn), nickel (Ni), chromium (Cr), cadmium (Cd), and copper (Cu). The concentrations of heavy metals are shown in Table 5. The concentration of Pb in all boreholes is higher than the concentrations which reported by Abdulatif (2001). These results are also higher than the standard levels for drinking water by YMWE (1999) and WHO (2004). Pb has been known to be toxic to human. The effect of Pb on the mental development of children that causes most concern. It has been calculated that Pb can cause a reduction of between 5 to 15 per cent of a child's intelligence depending on the amount found in the water (David , 2004). This indicate that, all boreholes are contaminated with Pb and affected by the migration of leachate to the groundwater. The concentration of Zn, Cr, and Cd in all boreholes did not pose any significant water quality problems, because these concentrations are below the standard acceptable levels for drinking water by YMWE (1999) and WHO (2004).

The high concentration of Ni was found in BH1 with the value of 0.03 mg/l. This value was above the standard acceptable levels for drinking water by YMWE (1999) and WHO (2004). The reason may be due to the high concentration of Ni in leachate has migrated to the groundwater. The Ni concentrations in other boreholes however, did not pose any significant water quality problems.

The concentrations of Cu in all boreholes were significantly different. The highest concentration of Cu was recorded in BH1 with the value of 4.65 mg/l, whereas the lowest concentration of Cu was recorded in BH5 with the value of 0.16 mg/l. The results in BH1, BH2, and BH3 are also high compared to the results obtained by Yoshida *et al*. (2002). The high concentration of Cu in BH1, BH2, and BH3 are not within the standard acceptable levels for drinking water by YMWE (1999) and WHO (2004). The reason may be due to the migration of leachate to the groundwater.

Table 4: Levels of water and type of water.

Water type	Equivalent $CaCO_3$
Soft	< 60-75
Slightly hard	75-150
Hard	150-300
Very hard	> 300-350

Table 5: Concentration of heavy metals.

Parameter	Pb (mg/l)	Zn (mg/l)	Ni (mg/l)	Cr (mg/l)	Cd (mg/l)	Cu (mg/l)
BH1	0.05	1.115	0.03	0.01	0	4.652
BH2	0.044	0.18	0.012	0.009	0	1.683
BH3	0.043	1.213	0.014	0.009	0	1.497
BH4	0.04	0.011	0.011	0.01	0	0.455
BH5	0.004	0.233	0.012	0.001	0	0.159
YMWE 999	0.01	5.00	0.02	0.05	0.005	1.0
WHO 2004	0.01	3.00	0.02	0.05	0.003	1.0

CONCLUSIONS

The concentrations of Pb, Ni, Cu, Cl, Ca, Mg, NH_3, hardness and total dissolved solid (TDS) are the highest in BH1. BH2 is contaminated with Pb, Cu, Cl, Ca, Mg, NH_3, and hardness, BH3 is contaminated with Pb, Cu, Cl, Ca, Mg, and hardness whereas, BH4 is contaminated with Pb, Ca, and NH_3. These boreholes are affected by the migration of leachate from the body of the landfill to the groundwater. To prevent the pollution of groundwater, soil and plants in the neighborhood of Ibb landfill, collection of leachate to a lake basin and followed by leachate treatment is recommended.

ACKNOWLEDGEMENTS

All thanks are due to the Local Water Supply and Sanitation in Ibb city, and Yemen Standardization Metrology and Quality Control Organization for providing the research facilities throughout the study.

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Manuscript received 17 March 2008
Revised manuscript received 6 November 2008