THE ENVIRONMENTAL IMPACT OF AL-AZRAQAIN LANDFILL ON THE QUALITY OF THE SURROUNDING GROUNDWATER, SANA'A CITY, YEMEN

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Abstract:

Al-Azraqin landfill, located to the north of Sana'a city, the capital of the Republic of Yemen, is a waste disposal site constructed without following scientific standards. The landfill might present a major pollution threat causing ground water quality deterioration, as it is located on an area characterized by intensive geological structures and vulnerable aquifers. This study was conducted to evaluate the water quality of surrounding wells used for drinking and irrigation purposes. The Quaternary alluvial, Tertiary volcanic and Cretaceous Tawilah sandstone aquifers are the main aquifer systems which were delineated in the research area. Groundwater flows from south west to north east. In eight out of twelve representative groundwater samples, Cd, Cr, Pb, and F exceeded WHO standards for drinking water quality. All wells were contaminated with *fecal* and/ *total coliforms.* The contamination concentrates east to the landfill which could be an indication of leachate migration through groundwater.

Résumé

Le secteur d' Al-Azraqain ; est situé au nord de la ville de Sana'a ; République de Yémen , et constitue une vaste zone construite sans aucune norme scientifique. Cette zone présente une source importante de pollution et détérioration de la qualité de l'eau de consommation courante ,de plus elle est situé dans une endroit caractérisé par des activités géologique intensif et une nappe phréatique fragile. Cette étude a été conduite afin d évaluer la qualité de l'eau des puits aux alentour ; utilisés comme source de l'eau potable et d'irrigation de la terre . Le quaternaire Alluvial, tertiaire volcanique et nappe phréatique de Tawilah Cretaceous Sablonneux sont le principaux systèmes de nappe phréatique qui ont été délimitées pour cette étude. Les fléaux des eaux souterraine se font de Sud -West vers le Nord- Est .Dans douze échantillons représentatives ; le teneur en Cd, Cr, Fe, Pb, Ni et F excède les normes de l' OMS en ce qui concerne la qualité de l'eau de consommation . Tous les puits sont contaminés par les Coliformes . la contamination se concentre à l'Est de la zone étudiée ; ceci indique probablement une migration à travers les eaux souterraine .

Key Words: drinking water – aquifers – contamination – water analysis – baseline - lechate
Mots clé : Eau potable – nappes phréatique – contamination – analyse de l'eau –ligne de base) - Résidu des poubelles .

INTRODUCTION

Al-Azraqain landfill, covering an area of 3 km^2, is located near fertile agriculture lands and residential areas, 16.5 km north west of Sana'a City (Fig. 1). The dump site was constructed in 1978 on a sensitive area, characterized by intense geological structures and vulnerable aquifers. The selection of the site, its construction and development was not based on scientific criteria. Approximately 269 tons of hazardous wastes are dumped at a height of 15 - 20 m (Al-Mikhlafi *et al.,* 2008). The dumped non separated solid and liquid waste includes domestic wastes (kitchen waste, paper, plastic, glass, cardboard, clothes,….etc), construction and demolition wastes consisting of sand, bricks, concrete blocks, empty unclean paint and pesticide containers, metal pipes, all types of batteries, electronic and electrical devices, wastes from poultries, fish markets, slaughter houses in addition to toxic and radioactive hospital and industrial wastes which have in general limited or no units for primary treatment. The leachate produced from the decomposition of these wastes under weathering conditions, may migrate into groundwater. Private wells surrounding the landfill are used for drinking and irrigation might become a risk factor for several diseases. No comprehensive studies were carried out in Yemen on landfill and their environmental, social, economical and health impacts except (Al-Mikhlafi *et al* 2008) on solid waste management in Sana'a city. However, only scattered unpublished studies were dealing with water quality in Sana'a Basin. This study was carried out to assess the water quality of private wells around Al-Azraqain landfill and to set up a database for future impacts.

METHODOLOGY

Three types of lithostratigraphic units have been delineated in and around the landfill and a geological map has been constructed. The groundwater aquifer in the area has been delineated along east-west subsurface cross-section using previous borehole litholog data of seven deep wells available around the landfill (WEC, 2001). Twelve groundwater samples were collected from sampling stations at well depths ranging between 130 and 300 m, within 1 km distance around Al-Azraqin landfill, for physical, chemical and microbiological analysis (pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{2-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, PO_4^{3-}, Cd, Cr, Cu, Pb, Ni, Mn and F, and *total* and *fecal coliforms*). The analyses were carried out at the Sana'a Water & Sanitation Local Corporation (SWSLC) laboratory following the procedures described by APHA et al, 1989. The pH and EC were examined in the field using a 720 inolab WTW pH meter with a reference electrode at 25ºC and a HACH sension 5 conductivity meter with a reference electrode at 25Cº. The maps have been constructed using Arc GIS 9.2 software.

RESULTS AND DISCUSSION

A review of literature (Italconsult, 1973; Abu-Khadrah, 1982; El-Anbaawy, 1985; Selkhospromexport, 1985; Al-Subbary, 1995; El-Nakhal, 1998; GAF, 2005) indicated that Sana'a Basin has been subjected to intense structural activities. The geological field survey revealed that the landfill site is located in a geological sensitive area. The constructed geological map for the landfill and surrounding area indicated that the lithology of this area is represented by the Cretaceous Tawilah sandstone, Tertiary and Quaternary volcanic and the Quaternary alluvial sediments. The field survey indicated also that the geological structures around Al-Azraqin landfill are of two types. North westerly faults: they are of almost north-south directions and run parallel to the Red Sea fault system. East westerly faults: two normal faults of almost east-west trends have been delineated forming the faulted Wadi Dhahr that is one of the most important Wadis in Sana'a Basin. According to the geological and structural setting of the study area, it is clear that the area has been subjected to structural activities and hence is sensitive for pollution which might percolates downward and reaches the groundwater level.

The geometry, thickness, extent of the different aquifers and the subsurface geological structures around the landfill, have been delineated by constructing 3 subsurface geological cross-sections (Fig. 1). One of these cross-sections extends from west to east passing through the landfill site (Fig. 2). It provides a localized picture of the sub-surface extent of the different aquifers in and around the landfill. The Tawilah Sandstone aquifer has a variable thickness and is present at different depths from the surface, followed by the volcanic aquifer. The volcanic aquifer also has variable thickness, reaching its maximum below the landfill site.

The Quaternary alluvial aquifer is present at the top with varying thickness. The other two cross sections confirm these results.

Water quality analysis revealed that ph values of all samples were slightly alkaline, ranging from 7.24 to 8.02. The EC varied between 522 and 687 µs/cm. According to Ongreths water classification for TDS, the entire analyzed samples are considered to be GOOD (between 300 – 600 mg/l). All samples are considered hard (TH values fall in the range between 150 – 300 mg/L. The differences in hardness may be attributed to the type of aquifer lithology. The analysis results of Ca, Mg, Na, K, HCO_3, CO_3, Cl, SO_4, NO_3, PO_4, Ni, Mn and Fe were all within the limits of WHO guidelines for drinking water quality (WHO, 2008).

Trace element analysis revealed higher concentrations of Cd, Cr, F, and Pb in some groundwater samples (table 1). The highest number of trace elements (Cd, F, and Pb) was found in well M-113 followed by M-112 and M-115. The concentration of Cd in M-113 (0.0054 mg/l), south east to the landfill (table 1, Fig. 3) exceeded the limit of WHO guidelines for drinking water quality (WHO, 2008). Common sources of Cd in drinking water may be referred to galvanized pipes and runoff from waste batteries and paints, and may lead to kidney damage on long term exposure (US EPA, 2009). The higher Cr concentration recorded in wells M-111, M-112 and M-115, north east to the landfill (table 1, fig. 4), might be referred to decomposed waste materials such as alloys and pigments and may cause allergic dermatitis (US EPA, 2009). The concentration of fluoride in M-112 (1.98 mg/l) and M-113 (1.66 mg/l) south east to the landfill is slightly higher than the maximum recommended WHO guidelines for drinking water quality (WHO, 2008) of 1.5 mg/l (table1, Fig. 5). Fluorine is a common element that is widely distributed in the earth's crust and exists in the form of fluorides in a number of minerals, such as fluorspar, cryolite and fluorapatite. Probable pollution might come from infiltrated rainwater mixed with F contaminated landfill leachate. Higher fluoride concentrations may cause dental flourosis (tooth mottling) and more seriously skeletal flourosis. Lead was the element most frequently found (in 6 wells) with the highest value of 0.018 mg/l in well M-115 east to the landfill (table 1, Fig. 6). Its average abundance in groundwater is generally less than 0.1 mg/l (APHA, 1989). Lead is obtained chiefly from galena (PbS) and used in batteries, ammunition, solder, piping, alloys, pigments, and insecticides. According to WHO guideline limits of 0.01 mg/l (WHO, 2008), water from these wells is not suitable for drinking purposes. Exposure above the Maximum Concentration Limit (MCL) delays physical or mental development in infants and children and kidney problems and high blood pressure in adults (US EPA, 2009).

It is remarkable that wells west to the landfill have lower concentrations of trace elements than wells east to it. Accordingly, it cannot be excluded that groundwater flow might partially be an evidence of leachate migration into groundwater, particularly in rainy seasons. Direct contact of leachate with storm water and a surface runoff towards the south might have a direct effect on the direction of groundwater flow from south west to north east. A common source of trace element contamination in drinking water might come from erosion of natural deposits.

Total and fecal *coliforms* were found in almost all wells with critical concentrations in wells M-112 and M-116 (table 1) and whose presence indicates contamination with human or animal wastes. This might be referred to lack in awareness about personal hygiene among the settled population dealing with the wells and exposed daily to an unhealthy environment as the landfill. Disease-causing pathogens may pose a special health risk, particularly diarrhea, for infants, young children, and people with severely compromised immune systems, (US EPA, 2009).

CONCLUSION

It can be concluded that all wells except well M-110, 114, 117 and 121 are containing trace elements (Cd, Cr, F, Pb) exceeding WHO standards. Wells M-112, M-113 and M-115 located east to south east to the landfill were found to be the most polluted groundwater wells. Main proposed reasons might be referred to the surface flow of leachate towards the south, followed by its infiltration into soil, particularly after rainy seasons. Pollutants might migrate with the groundwater flow from south west to north east. However, pollution might also be caused by natural composition of rocks. There is no evidence about an increase in the concentrations of analyzed chemicals since the construction of Al-Azraqain landfill due to the lack of previous studies about groundwater quality. It is therefore highly recommended to monitor water quality of these wells over a longer period.

Table 1. Trace element and microbiological analysis of groundwater samples

	Element				Fecal Coliform (CFU/100ml)	Total Coliform (CFU/100ml)
	Cd (mg/l)	Cr (mg/l)	F (mg/l)	Pb (mg/l)		
Well No.	**WHO Guidelines**					
	0.003	0.05	0.5-1.5	0.01	Nil	0
M- 110	0.0021	0.024	0.68	0.002	9	43
M- 111	0.0014	0.069	0.06	0.007	Nil	4
M- 112	0.0013	0.055	1.98	0.010	T.N.T.C	T.N.T.C
M- 113	0.0054	0.037	1.66	0.014	5	17
M- 114	0.0021	0.031	0.88	0.010	8	23
M- 115	0.0010	0.080	0.74	0.018	20	52
M- 116	0.0013	0.017	1.44	0.013	T.N.T.C	T.N.T.C
M- 117	0.0018	0.026	1.15	0.005	22	87
M- 118	0.0010	0.013	0.54	0.014	4	16
M- 119	0.0020	0.015	0.18	0.011	2	7
M- 120	0.0010	0.021	0.15	0.012	1	4
M- 121	0.0015	0.042	0.41	0.007	24	56

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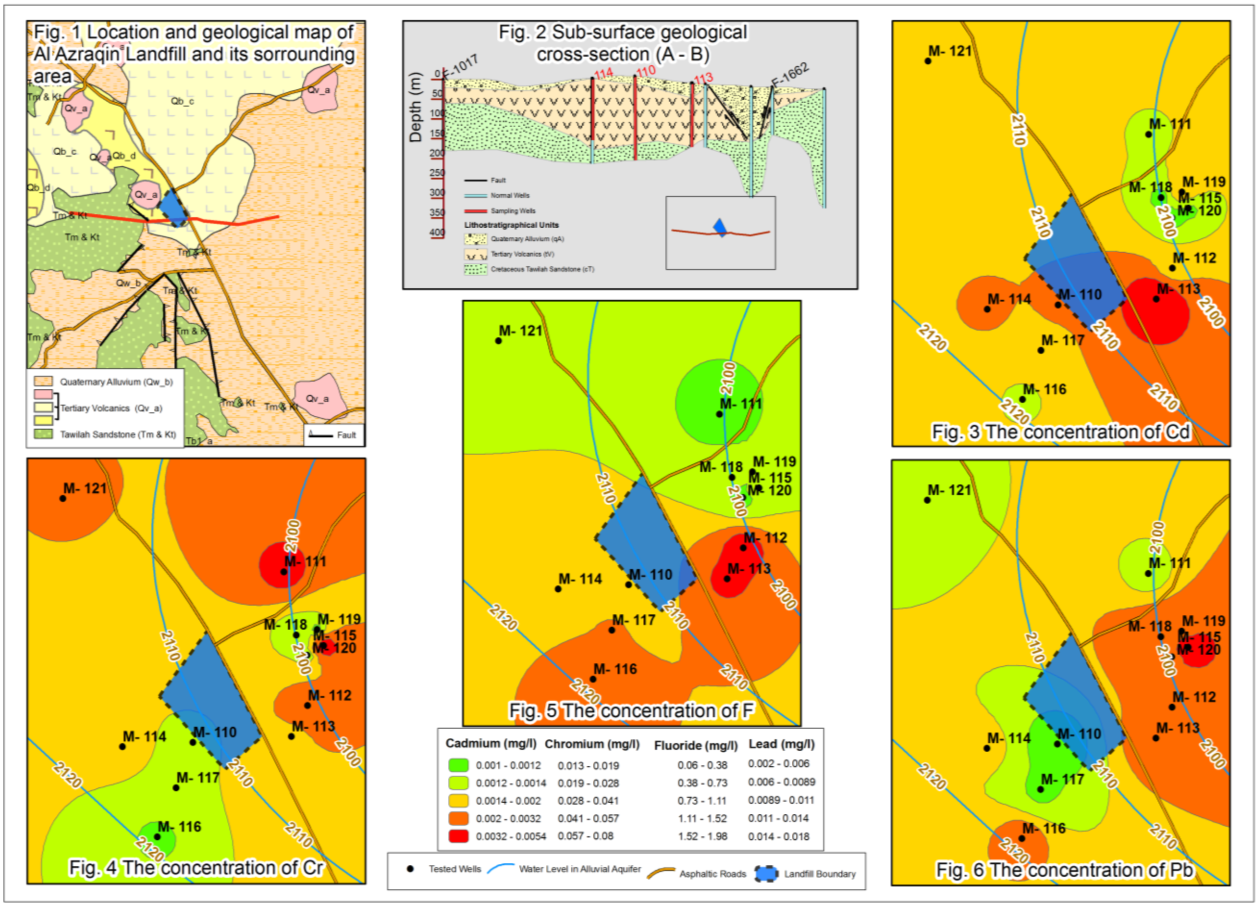

Fig. 1 Location and geological map of Al Azraqin Landfill and its surrounding area

Fig. 2 Sub-surface geological cross-section (A - B)

Fig. 3 The concentration of Cd

Fig. 4 The concentration of Cr

Fig. 5 The concentration of F

Fig. 6 The concentration of Pb