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Identification of Possible Migration of Contaminants in Groundwater at a Landfill – A Case Study of Oman

Mahad S. Baawain[1*], Ahmed M. Al-Futaisi[2]

1. Center for Environmental Studies and Research (CESAR), Sultan Qaboos University, Muscat Oman
2. Department of Civil and Architectural Engineering, Sultan Qaboos Unviersity, Muscat, Oman

* E-mail of the corresponding author: msab@squ.edu.om

Abstract

In this study exploratory borehole drilling along with soil core sampling, chemical analysis, piezometer construction, field and laboratory hydrochemical analyses and pumping test were applied. The main aim was to understand the extent of contamination and contaminant movement in the unsaturated zone and groundwater at a dumping site in Northern part of Oman (Barka dumping site). Water samples were analyzed for inorganic, organic and biological characterization to identify any potential contamination of groundwater from Barka dumping site. Results showed elevated concentration of TDS, Na, Ca, Mg, alkalinity, chloride and total hardness. Thus, indicated that the groundwater below the dumping site is strongly affected by leachate originated from liquid lagoons located in and around the landfill. Furthermore, microbiological parameters showed that groundwater beneath Barka dumping site is largely influenced by bacterial contamination with *total coliform* and *E.coli*.

Keywords: Borehole drilling; dumping site; groundwater contamination; unsaturated zone; contaminant transport

1. Introduction

Groundwater contamination from landfills often results from leaking "leachate," water that has percolated through waste and accumulated various ions in solution. Modern sanitary landfills include clay and plastic barriers beneath the waste, as well as leachate collection and processing systems, to prevent leachate leakage. Older landfills in Europe and North America, as well as most landfills in the developing world today, have no such barriers, and allow leachate seepage into the surrounding aquifers. Identification, characterization and monitoring of contaminant plumes in the unsaturated zone and groundwater are absolutely vital for making decisions regarding the future land use at contaminated sites, and for choosing appropriate remediation measures. In addition, evaluation of contaminant concentration is necessary for the determination of natural attenuation rates of biodegrading contaminants. In general, investigation of contaminated sites, for example landfills or dumping sites, have been carried out by utilizing distinguished methods such as hydrogeological mapping, geophysical survey, exploratory borehole drilling, piezometer construction, field and laboratory hydrochemical analyses, pumping test, etc (Mack and Maus,1986; Ahmed and Sulaiman, 2001; Abu-Rukah and Al-Kofahi , 2001; Burnley, 2007; Sharma and McBean, 2007; Terzic et.al, 2007).

In this study, exploratory borehole drilling along with soil core sampling, chemical analysis, piezometer construction, field and laboratory hydrochemical analyses and pumping test were applied in a dumping site in Northern part of Oman (Barka dumping site) to understand the extent of contamination and contaminant movement in the unsaturated zone and groundwater. The term integral pumping represent the pumping test in which the contaminant concentration versus pumping time is assessed. The state of groundwater pollution can be also evaluated from the pumped-water contaminant analysis. Several investigations applied pump test for capture zone delineation, aquifer parameter determination, groundwater flow path and travel time, point concentration profile studies, identification of different water mixing, etc (Hantush, 1956; Uhl and Joshi, 1986; Bumb and Ramesh, 1992; Kamra et.al, 2002; Elliot and Younger, 2007; Ostendorf et.al, 2007). Schwarz et al. (1998) employed a method for delineating and quantifying contaminant flux from a source zone by inversion of concentration data measured during pumping test.

1.1 Study Area

Barka is located northwest of the capital city (E0589784 and N2610695), Muscat, Oman and has an area of 1,350 km2. The Sea of Oman creates a natural border in North, while watershed of Jabal Al-Akdar and Nakhal mountains limits the South, which serves as a recharge zone of the study region. The hills in the southern part of the study region have steep slopes with little soil cover and no vegetation. In general, the study area experiences dry climatic conditions with high rates of evapotranspiration. The long-term annual average air temperature is 28.5°C in the coastal area and 17.8°C in the mountains. Rainfall is extremely variable with respect to space and time.

1.2 Barka landfill

Barka landfill is a very large unregulated landfill and it is located about 8 km to the south of Barka and near to the road connecting Barka and Nakhal. It covers an area of 80 ha. Landscape of this area is flat and crossed by a wadi at one edge. Barka landfill is also locaed in the mountainous region. Geologically, the study location is underlain by the alluvial deposits of wadi alluvium and sub recent alluvial fans and terraces. Near the landfill, the depth to water table varies between 68 to 70 mbgl. The groundwater flow direction is usually from south to north. Barka landfill receives different types of wastes from three main cities: Barka, Nakhal and Wadi Al-Maawil. Disposal of liquid wastes such as domestic sewage water, chicken poultry wastewater and oil-sewage mixture produced large ponds in the landfill, and the pond water mix with other solid wastes during rainy events. About 400,000 gallon capacity wastewater treatment plant is operating in the landfill, although, the capacity is not enough to handle the entire sewage water and not equipped to handle the sewage-oil mixture and other industrial liquid wastes. Recently, the treatment plant is modified and receiving the liquid waste for treatment. Therefore, the direct disposal of sewage liquid waste in the lagoon is banned since 2006. However, the treated wastewater is still disposed in the lagoons. Solid waste dumping is active and receiving different types of waste like wood, ceramic, construction waste, poultry, meat, etc. Barka landfill is located on recharge area of major aquifer. Therefore, the groundwater below the landfill and downstream are highly susceptible to pollution by the landfill leachate and direct infiltration of liquid waste disposed in the landfill. Additionally, streams and wadies that traverse landfill can translocate the waste residues to the downstream and even to sea during the rainy season. The foremost pollutants reported by Ministry of Water Resources are heavy metals, organics, oils, grease and pathogens. Further, landfill gas emissions are another threat to the environment and nearby residents. Even though there is no settlement close to the landfill, toxic gases and smoke affect the transporters directly or indirectly in the Barka to Nakhal connecting road and occasionally reach Barka and Wadi Al-Maawil.

2. Materials and Methods

2.1 Soil core sampling and analysis

In Barka dumping site, six boreholes (five piezometers and one pumping well) were constructed (Figure 1). Soil core samples were collected at different depths from five piezometer boreholes. The soil cores were wrapped in transparent plastic sheets immediately after collection to prevent evaporative water loss, and then stored in the core box and transported to the lab on same day. In addition to core sampling, soil profiles (trial pits) were excavated close to active and old liquid lagoons up to 5 m depth from surface using mechanical excavator. In total, six trial pits were excavated, and soil samples were collected at different depth directly from the horizons. Soil samples were stored in the plastic bags and transported to the lab on same day. Both core samples and soil profiles samples were air dried in the room temperature, sieved utilizing <2mm sieves and grounded to pass through a 250-mm mesh sieve for chemical analysis.

2.2 Groundwater sampling and analysis

Groundwater samples were collected from drilled piezometers from the Barka dumping site (Figure 1). After removing 3 well volumes of water from piezometers, with the help of bailers, water samples were collected for inorganic, organic and microbiological analysis. All tests were conducted according to the Standard Method for the Examination of Water and Wastewater (Eaton et al., 2005).

2.3 *Pump test*

Pump test was carried out in the newly drilled bore well. The aim of this test is to estimate the aquifer characteristics as well as monitor the contaminant concentrations with time. The pump test was conducted for 24 hours and water samples were collected every 20 minutes interval for first 6 hour then every one hour. In total, 38 samples were collected for biological, organic and inorganic analyses. During pumping, parameters such as EC, pH, Eh, temperature, dissolved oxygen and salinity were measured as a function of time in the discharged groundwater.

3. Results and Discussion

3.1 *Groundwater quality*

Groundwater quality in Barka dumping location is given in Tables 1, 2 and 3. In the newly drilled wells (P1-P5), the electric conductivity (EC) varied between 1190 μS/cm and 2532 μS/cm and total dissolved solids (TDS) ranges from 774 mg/L to 1646 mg/L (Table 1). As per the pH, groundwater samples were found slightly acidic to alkaline in nature. Piper diagram illustrates that groundwater samples collected from newly drilled wells are Ca-Mg-Cl type (Figure 2).

Among the piezometers (P1, P3, P4 & P5), P1 contains elevated concentration of TDS, Na, Ca, Mg, alkalinity, chloride and total hardness. This fact suggests that leachate originated from the liquid lagoon appears to be blending with groundwater. Moreover, P1 is located near the old liquid lagoon. Municipality wells (002/078, 212/060), existed near the boundary of the dumping site, show low EC, TDS, Ca, Mg, K, alkalinity and Cl, and high concentrations of nitrate and sulphate. This observation suggests that groundwater below the dumping site is greatly affected by leachate originated from liquid lagoons rather than solid waste disposal in the region.

Oxidation reduction potential (Eh) of the groundwater samples indicated reducing environment, which may promote decreased reactions in this aquifer. Depleted nitrate and sulphate concentrations together with a smell of hydrogen supplied have been observed during the sampling. This fact suggests the incident of reducing zone of the redox plume and indicates the likelihood of reduction reactions such as denitrification and sulphate reduction. Microbiological parameters show that groundwater beneath Barka dumping site is mostly influenced by bacterial contamination; particularly *total coliform and E.coli* (Table 2).

The dissolved oxygen (DO) contents are generally < 2 mg/L in the groundwater and suggest the reducing environment. Besides, high alkalinity observed in the piezometers and pumping well highlights impact of waste dumping activities. When the leachate mixing with groundwater, dissolved organic matter will first remove the dissolved oxygen and nitrate followed by a large amount of CO_2 output (Schwarz et al, 1998). Hence, in the dumping site, alkalinity would be anticipated from two major sources, dissolution of CO_2 generated from microbiologically mediated degradation of organic matter, and weathering of carbonate minerals, particularly calcite and dolomite. If the natural weathering of carbonate minerals is responsible for alkalinity in the groundwater, the water samples collected from the piezometers should show more or less similar alkalinity concentrations since the distance between the piezometers are not so far. But, P1 shows elevated alkalinity and major ions with low pH and DO (Tables 1 and 2). This fact reveals that leachate caused by the biological degradation of organic components mostly from liquid lagoons, which enhances mineral weathering and subsequently, increases the solute load in the groundwater. High chloride contents and bacteria recorded in the piezometers compared to the municipality wells obviously indicating the influence of surface contamination sources (Table 1).

Table 3 shows the trace metals concentrations in the groundwater samples and most of the metals are below detection limits. In the analyzed metals, Fe, Mn and Zn are presented in substantial quantity, which are sensitive to the redox reactions (Table 3). As discussed earlier, microbiological data exhibit the occurrence of reducing zone beneath the Barka dumping site. In the anaerobic environment, an iron and manganese oxide in the soil undergoes reduction and releases a large amount of Fe^{2+} and Mn^{2+} in the water (Appelo and Postma, 1994). Hence, the mixing of leachate with groundwater creates anaerobic environment, which enhances the concentrations of these metals in groundwater. In contrast, low concentrations of other metals reveal the natural attenuation process in the unsaturated zone expected organic or inorganic sorption and precipitation with carbonates or sulphates (Belevi and Baccini, 1989; Flyhammer, 1995; Erses and Onay, 2003). However, the concentrations of other metals justify the direct surface origin likely from liquid lagoons.

3.2 *Effect of pumping on groundwater quality*

Tables 4 and 5 along with Figures 3, 4, 5, 6, and 7 shows the groundwater quality variation during pumping period. The electrical conductivity (EC) varied from 2110 to 2395 µS/cm with a mean value of 2312 µS/cm and pH ranges from 6.96 to 7.3. Large variations were observed in the standard deviations of EC, TDS, Na, alkalinity, chloride, total hardness (TH) and bacteria. This fact reveals that these elements are highly fluctuated during pumping and possibly drawn from diverse formation waters. Figure 3 illustrates that EC rapidly increases while pumping and reaches steady state after 14 hours. Further, pH and Eh show that initially both are high and then stabilized after 9 hours. Microbiological parameters showed high fluctuations in the first 6 hours during pumping (Figure 4). Dissolved oxygen content indicated reducing environment throughout the period of pumping and fluctuates between 0.8 mg/L and 1.34 mg/L. Other parameters such as COD, BOD and bacteria also indicate that peak concentrations are recorded within few hours (< 8 hours) and then, mostly unchanging. Similar results were observed in main ions (Figures 5 and 6). As mentioned earlier, redox plume appears to be present in this aquifer due to mixing of leachate originated from liquid lagoon. The Eh value also shows strong reducing environment and it varies from -22.8 mv to -2.4 mv. Hence, during pumping, existing and contaminated water appears to be discharged in the first couple of hours followed by the fresh water representing the aquifer.

Figure 7 illustrates the variation of metal contents during pumping period. The metals have variable times of peak concentrations and Cu, Ni, Cd and Cr display multiple peaks throughout the course of pumping. Further, Fe and Zn exhibit high concentrations at zero hour. High standard deviation in the concentrations of Ni, Zn and Fe reflected the variation during pumping (Table 5). Several factors such as different adsorption characteristics, natural heterogeneity, etc decide the concentrations of metals in groundwater.

The variation in chloride concentration during pumping period causes uncertainty about the origin whether from dumping site or seawater upconing process. Regional water level circulation indicates that the groundwater-seawater interface seem to be appeared beside the Barka dumping site (Figure 3). The ionic ratio such as total cation/chloride (TC/Cl) and mBr/Cl may be useful to differentiate the source of origin. The TC/Cl ratio varies from 1.65 to 1.95 with a mean value of 1.76 and higher than the seawater ratio (1.12). Similarly, mBr/Cl ratio ranges from 0.00294 to 0.00434 with a mean value of 0.00396 and greater than seawater (0.0035) (Figure 6). According to Murad and Krishnamurthy (2004), animal waste comprises a substantial amount of bromide (28.5 mg/kg). These facts reveal that salinity and most of the contaminants originated from dumping sites rather than seawater upconing.

4. Conclusion

Groundwater samples were collected from the aquifer that exists beneath Barka dumping site using drilled piezometers and a pumping well. Water samples were analyzed for inorganic, organic and biological characterization. It was observed that the well P1, which is close to the lagoons, comprises increased concentration of TDS, Na, Ca, Mg, alkalinity, chloride and total hardness. This observation suggests that groundwater below the dumping site is highly influenced by leachate originated from liquid lagoons located within the landfill.

Depleted nitrate and sulphate concentrations together with a stink of hydrogen sulphide, observed during the sampling, strongly suggest the occurrence of reducing zone of the redox plume and possibility of reduction reactions such as denitrification and sulphate reduction. Microbiological parameters show that groundwater beneath Barka dumping site is largely influenced by bacterial contamination with total coliform and E.coli. The concentrations of trace metals in the groundwater samples of this study are below detection limits. This low concentration of metals reveals that the natural attenuation process in the unsaturated zone expected to have organic or inorganic sorption and precipitation with soils before reaching groundwater.

A functional structure made up of holons is called holarchy. The holons, in coordination with the local environment, function as autonomous wholes in supra-ordination to their parts, while as dependent parts in subordination to their higher level controllers. When setting up the WOZIP, holonic attributes such as autonomy and cooperation must have been integrated into its relevant components. The computational scheme for WOZIP is novel as it makes use of several manufacturing parameters: utilisation, disturbance, and idleness. These variables were at first separately forecasted by means of exponential smoothing, and then conjointly formulated with two constant parameters, namely the number of machines and their maximum utilisation. As validated through mock-up data analysis, the practicability of WOZIP is encouraging and promising.

Suggested future works include developing a software package to facilitate the WOZIP data input and conversion processes, exploring the use of WOZIP in the other forms of labour-intensive manufacturing (e.g. flow-line production and work-cell assembly), and attaching a costing framework to determine the specific cost of each resource or to help minimise the aggregate cost of production.

5. Acknowledgement

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Dr. Mahad S Baawain (First Author) Mahad Baawain is Director at the Center for Environmental Studies and Research and an Associate Professor in the Department of Civil and Architectural Engineering, Sultan Qaboos University, Oman. He obtained his BSc in Civil Engineering from Oman in 1998. Then he continued his postgraduate studies in the area of Environmental Engineering where he obtained MSc from UK in 2000 and PhD from Canada in 2007. His research interest covers several areas among environmental engineering including fundamentals of water and wastewater treatment processes, advanced oxidation processes, water and wastewater reactors modeling, nanotechnology applications for water and wastewater treatment, groundwater assessment and contaminant transport, solid waste management and air pollution modeling and management.
Dr. Ahmed Al-Futaisi (Second Author) Ahmed Al-Futaisi received his University Degree in Civil Engineering in 1994; he earned his MSc and PhD in Environmental Engineering from USA in 1997 and 2002, respectively. His research interest covers several areas among environmental engineering including applied environmental geosciences, physically-based pore-scale modeling, Mmultiphase flow in porous media, hydrogeology and hydroinformatics, contaminant fate and transport, soil sorption to organics and heavy metals.

List of Tables

Table 1. Groundwater quality of piezometer wells in Barka dumping site

	P1	PW2	P3	P4	P5	002/078	212/060	Domestic/Drinking water standard		
								OSTD		EPA
								Min	Max	
Depth	75	90	75	75	75	NA	NA			
WL	70.1	72	68.5	70.6	72.8	59.3	NA			
Temp	36.0	34.7	34.0	34.9	36.4	33.4	35.0			
EC	2532	2110	1875	1500	1190	940	1044			
TDS	1646	1308	1219	975	774	611	679	800	1500	500
pH	6.7	7.3	7.4	7.3	8.6	9.0	7.6	6.5	9.0	8.50
Eh	-14.8	-22.8	-29.7	-25.0	-102	NA	NA			
Na	149	262	107	85	95	108	94	200	400	
Ca	126	124	82	88	44	16	52			
Mg	132	68	106	74	36	41	65			
K	10	7	9	8	31	3	3			
Alk	400	305	299	218	330	154	278			
SO4	28	106	46	110	10	34	109	250	400	250
Cl	628	471	428	314	206	235	143	250	600	250
NO3	2.00	16.8	1.50	2.00	1.50	0.00	10.59		50.0	45
Silica	6.4	NA	6.00	7.20	2.60	6.00	26.0			
NO2	BDL	BDL	BDL	BDL	BDL	BDL	BDL		3	3.3
PO4--	NA	0.11	NA	NA	NA	NA	NA			
F	NA	0.39	NA	NA	NA	NA	NA		1.5	2
Br-	NA	1.69	NA	NA	NA	NA	NA			
TH as CaCO3	856	590	640	523	258	207	396	200	500	

- Unit – mg/l except pH, Eh (mV), EC (µS/cm), Temp (°C), Depth (m) and Water level (WL) (m bgl).

Table 2. Statistical summary of microbiological parameters of piezometer wells of Barka Dumping site

	P1	PW2	P3	P4	P5	002/078	212/060	Domestic/Drinking water standard		
								OSTD		EPA
								Min	Max	
DO (mg/l)	0.76	0.94	1.64	1.07	1.34	1.08	3.30			
BOD (mg/l)	12.0	1.12	8.00	10.0	8.00	NA	NA			
COD (mg/l)	NA	7.6	NA	NA	NA	32	0			
T.Coli (MPN/100ml)	8000	2.00	6000	5000	3000	3.2	19.2			Nil
E.Coli (MPN/100ml)	1000	1.00	900	700	400	3.2	0			Nil

Table 3. Groundwater quality in Barka dumping site – Trace elements (µg/l)

	P1	PW2	P3	P4	P5	002/078	212/060	Domestic/Drinking water standard		
								OSTD		EPA
								Min	Max	
Ni	BDL	154	BDL	BDL	BDL	BDL	BDL		20	
Cu	BDL	13	BDL	BDL	BDL	NA	NA	1000	1500	1000
Zn	300	9393	1800	1800	400	NA	NA	3000	5000	5000
Cd	BDL	0	BDL	BDL	BDL	BDL	BDL		3	5
Mn	1000	60	300	400	20	NA	NA	100	500	50
Cr	BDL	BDL	BDL	BDL	BDL	29.0	BDL		50	100
Co	BDL	NA	BDL	BDL	BDL	BDL	BDL			
Fe	13000	996	5000	8900	900	NA	NA	300	1000	300
Ba	BDL	NA	BDL	BDL	BDL	21.0	104		700	2000
Pb	BDL	BDL	BDL	BDL	BDL	40.9	7.82		10	15
Ar	BDL	NA	BDL	BDL	BDL	NA	NA			
Se	BDL	NA	BDL	BDL	BDL	NA	NA			
Hg	BDL	NA	BDL	BDL	BDL	NA	NA			

- BDL – Below Detectable Level

Table 4. Effect of pumping on groundwater quality in Barka dumping site

	Min	Max	Mean	Median	STD	Count	Domestic/Drinking water standard		
							OSTD		EPA
							Min	Max	
Temp	26.7	35.6	33.1	34.7	2.7	38			
EC	2110	2395	2312	2333	75.1	38			
TDS	1372	1557	1503	1516	48.8	38	800	1500	500
pH	6.96	7.3	7.02	7.00	0.06	38	6.5	9.0	8.50
Eh	-22.8	-2.4	-5.94	-5.2	3.42	38			
Na	260	313	284	282	13.5	38	200	400	
Ca	120	140	128	130	5.65	38			
Mg	65.5	80.1	73.6	72.8	3.35	38			
K	6.6	8.4	7.16	7.15	0.32	38			
Alk	280	315	297	298	7.35	38			
SO4	88.0	114	93.4	91.0	6.66	24	250	400	250
Cl	422	565	496	495	33.7	24	250	600	250
NO3	16.8	30.3	23.5	23.5	2.29	24		50.0	45
Silica	NA	NA	NA	NA	NA	NA			
NO2	6.38	6.38	6.38	6.38	-	1		3	3.3
PO4--	0.11	0.11	0.11	0.11	-	1			
F	0.21	0.54	0.42	0.43	0.09	21		1.5	2
Br-	1.43	2.43	1.95	1.97	0.28	21			
TH as CaCO3	590	640	623	620	16.1	38	200	500	
DO	0.8	1.34	1.05	1.07	0.13	38			
BOD	0.58	10.6	1.92	1.26	1.87	35			
COD	1.9	24.6	10.9	9.50	6.55	38			
T.Coli	0.1	250	28.2	4.20	55.6	38			Nil
E.Coli	0.1	165	6.40	0.10	27.3	38			Nil

- Unit – mg/l except pH, Eh (mV), EC (µS/cm), Temp (°C), *E.coli* (MPN/100ml) and *T.coli* (MPN/100ml)
-

Table 5. Effect of pumping on groundwater quality in Barka dumping site – Trace elements (µg/l)

	Min	Max	Mean	Median	STD	Count	Domestic/Drinking water standard		
							OSTD		EPA
							Min	Max	
Ni	BDL	1002	135	110	172	38		20	
Cu	5	67	36	36	18	38	1000	1500	1000
Zn	373	9393	660	435	1455	38	3000	5000	5000
Cd	15	84	39	36	18	38		3	5
Mn	6	129	22	18	20	38	100	500	50
Cr	23	34	30	31	5	38		50	100
Fe	24	996	215	188	173	38	300	1000	300
Pb	BDL	BDL	BDL	BDL	BDL	38		10	15

- BDL – Below Detectable Level

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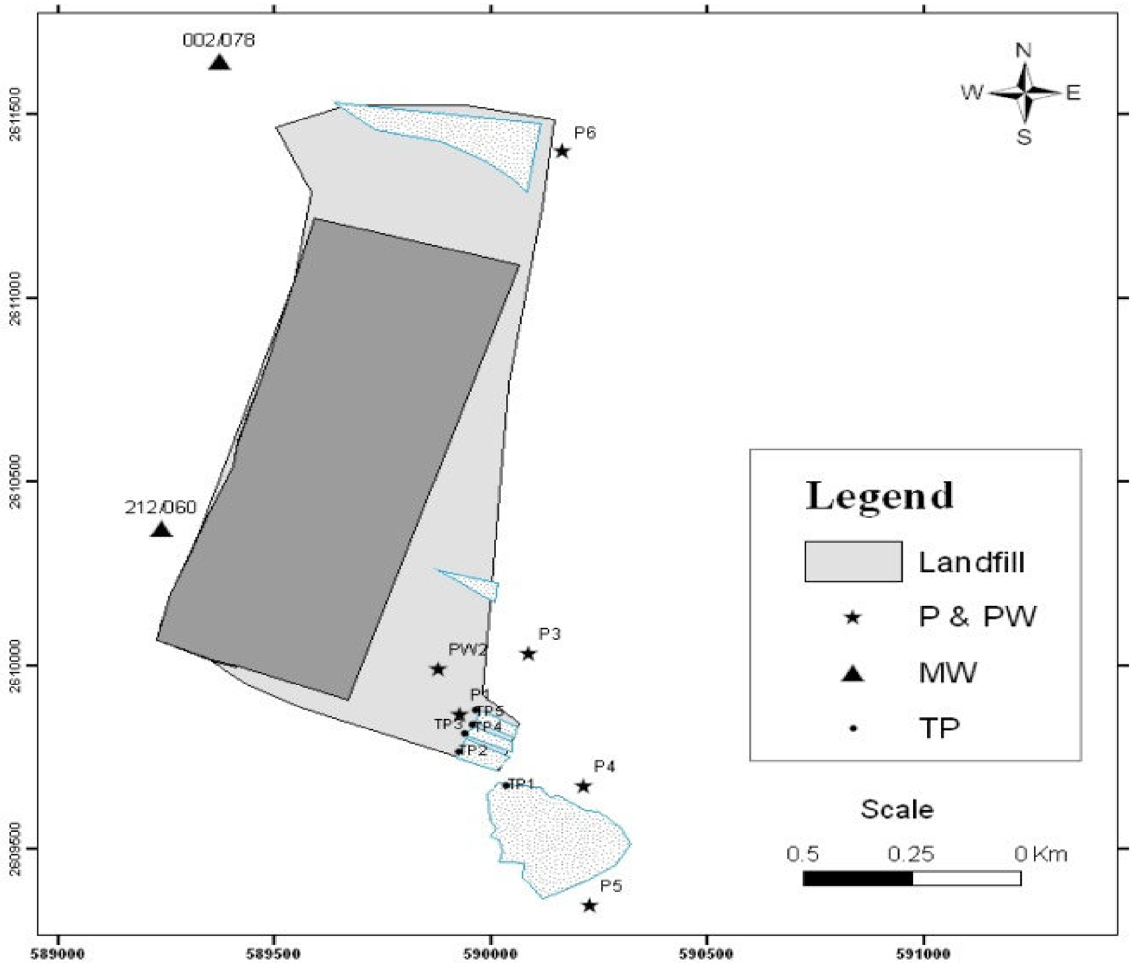

Figure 1. Map shows the Barka dumping site and locations of piezometers (P), pumping well (PW) and trial pits (TP)

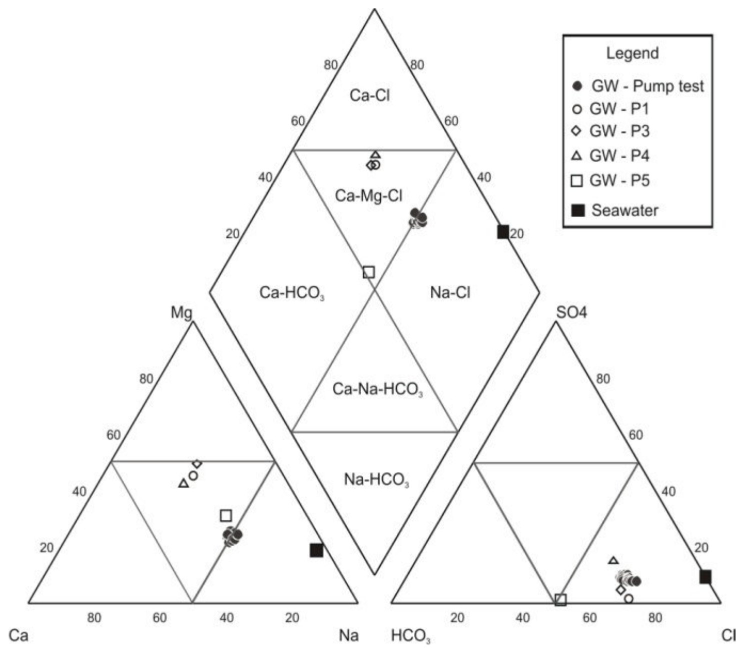

Figure 2. Groundwater quality in the newly drilled wells in Barka dumping site.

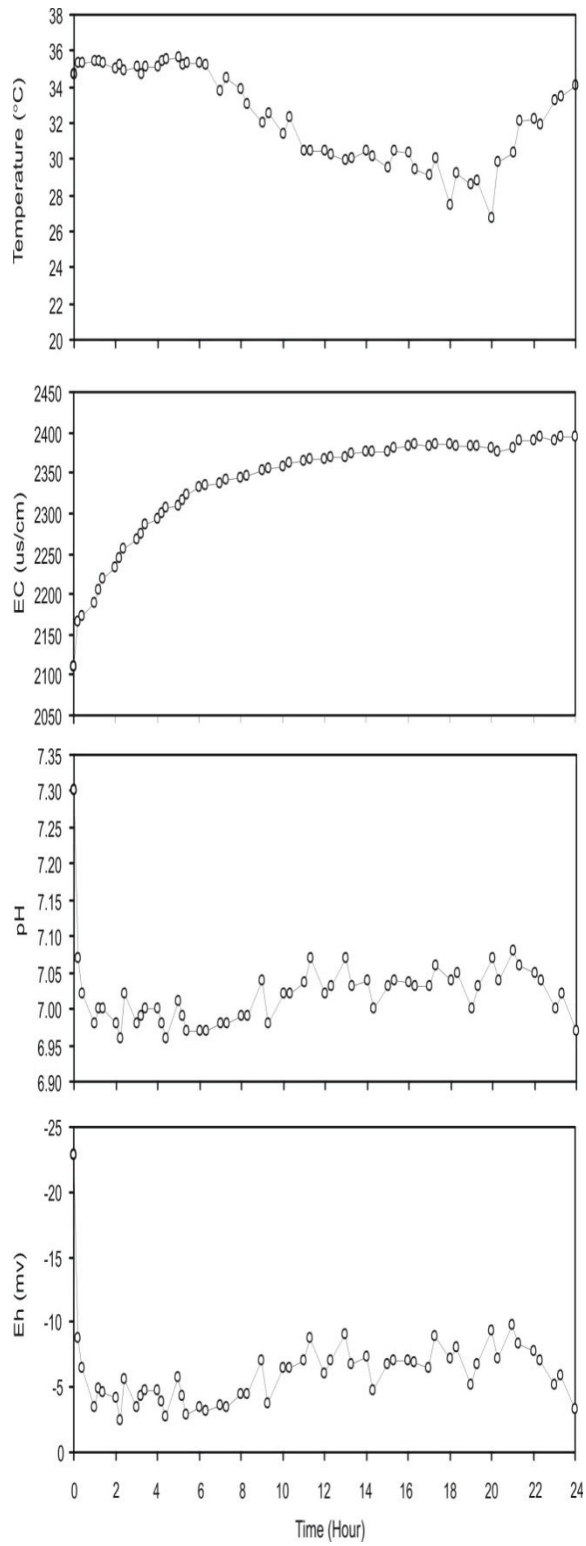

Figure 3. Variation of *in situ* parameters during pumping test in the newly drilled well in Barka dumping site.

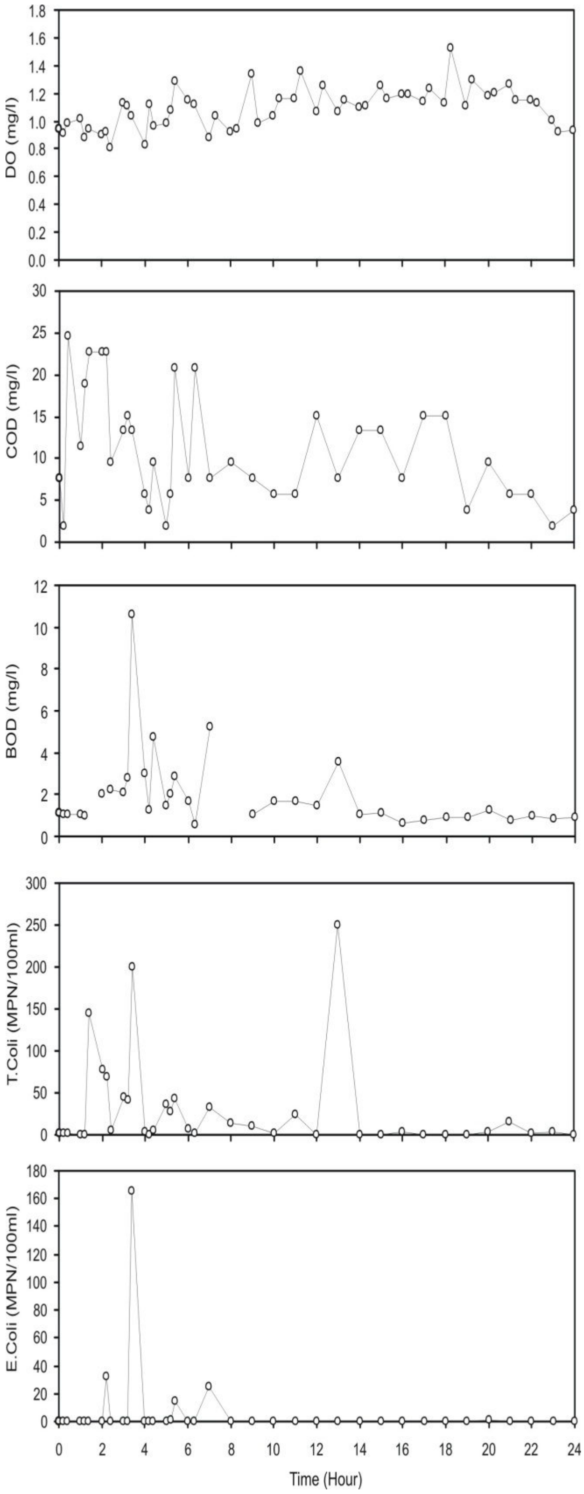

Figure 4. Variation of microbiological parameters during pumping test in the newly drilled well in Barka dumping site.

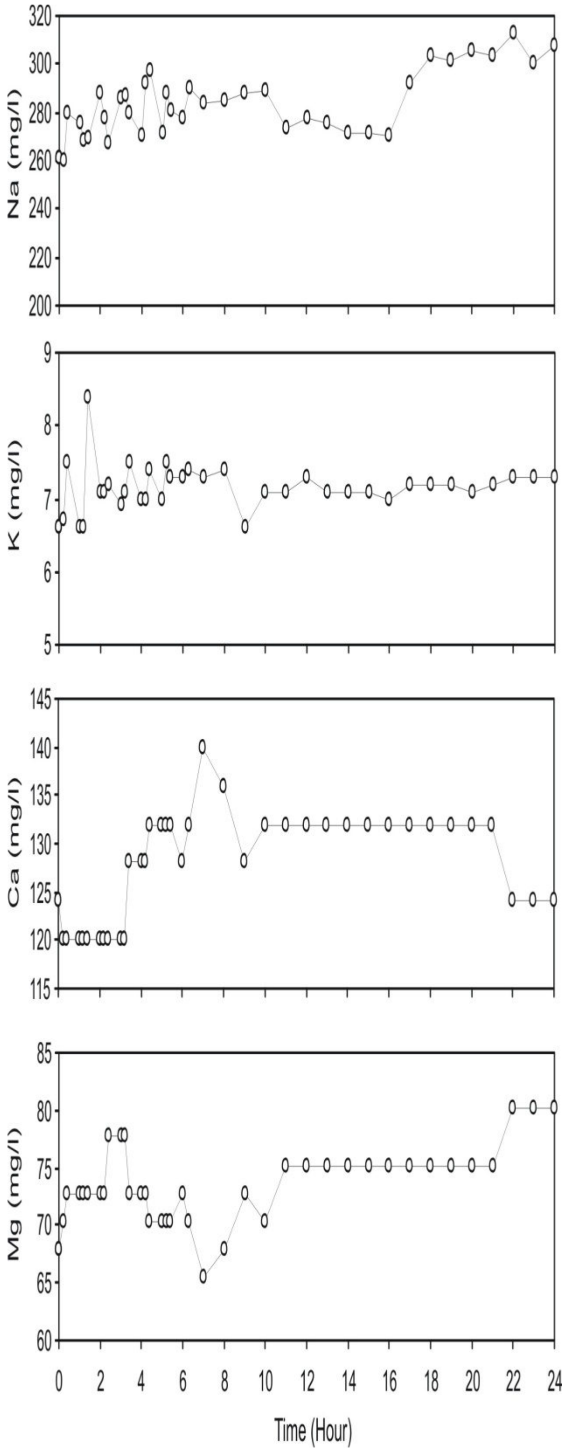

Figure 5. Variation in the major cations during pumping test in the newly drilled well in Barka dumping site.

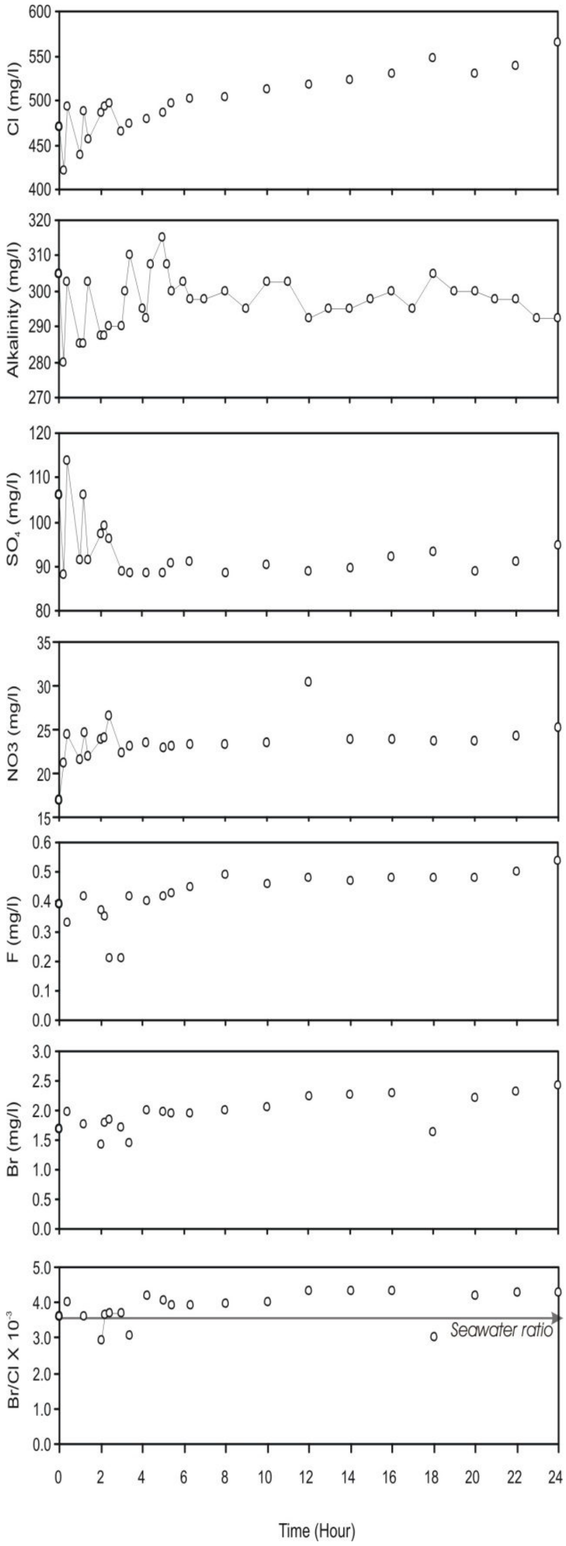

Figure 6. Variation in the major anions during pumping test in the newly drilled well in Barka dumping site.

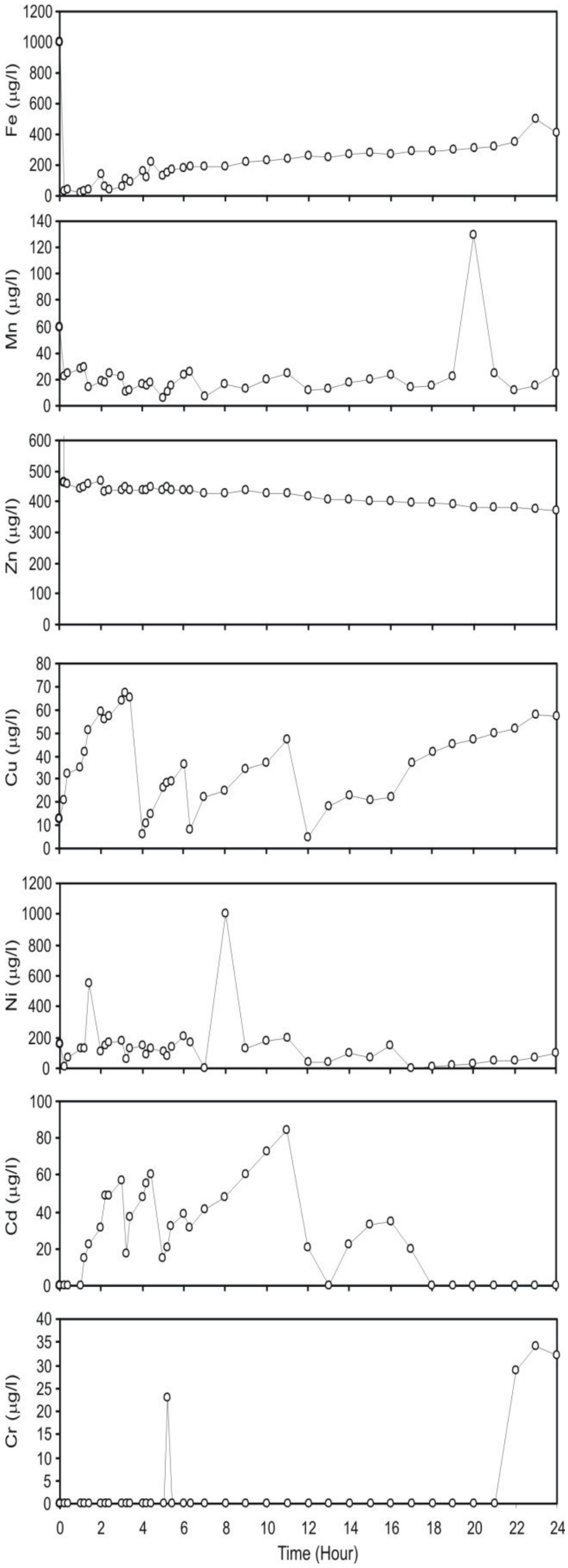

Figure 7. Variation in the trace metals during pumping test in the newly drilled well

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