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Impact of Leachate Percolation on Groundwater Quality near the Municipal Open Dumpsite (Jam Chakro): A Case Study of Surjani Town, Karachi, Pakistan

Adnan Khan[1*], Sumaira Asif Khan[1], Zubaid Saeed[2], Bisma Naz[1]

[1]Department of Geology, University of Karachi, Pakistan

[2]Department of Geology, Federal Urdu University of Arts Science and Technology, Karachi Campus, Pakistan

*Corresponding author Email: adkhan@uok.edu.pk

Abstract: Present study is aimed at assessment of landfill leachate migration impact on groundwater quality of Surjani Town. Groundwater samples (n=28) were collected at various depths (35-220m) and analyzed for various physicochemical characteristics. Data revealed that groundwater pH is highly fluctuating (ranges= 6.5 - 7.6; mean: 7.0) where about one third of total samples are acidic (range= 6.5 – 6.91). Remarkably high TDS content (range: 609 - 28100 mg/l; mean: 11946 mg/l) is reported. Major cations and anions vary in the order of Na (7293mg/l) > Ca (1049 mg/l) > Mg (998 mg/l) > K (44 mg/l) and Cl (5513 mg/l) > SO_4 (2942 mg/l) > HCO_3 (1408 mg/l) > NO_3 (17 mg/l) respectively. Results of principal component analysis suggest landfill leachate percolation and mixing followed by water rock interaction in groundwater of study area. Extremely high concentration of measured parameters concluded that groundwater of Surjani Town is subjected to anthropogenic pollution by leaching of contaminants from Jam Chakro landfill site.

Keywords: Landfill, leachate, Jam Chakro, groundwater pollution, Surjani Town.

Introduction

Water is one of the most essential components of the ecosystem. It is a renewable natural resource required for socio-economic development of any nation (Chima, et al., 2007) which is available on the earth as surface and groundwater respectively (Sarada and Bhushanavathi, 2015). Usually, groundwater is used for domestic, industrial water supply and irrigation all over the world (Ramakrishnaiah, et al., 2009) if available in sufficient quantity with acceptable quality (Khattak and Khattak, 2013). However, due to rapid urbanization, the quality of groundwater deteriorates due to overexploitation, sewage and improper solid waste disposal (Ramakrishnaiah, et al., 2009). Municipal solid waste management is highly negligible factor of environmental management in all low and most middle-income countries (Murtaza, et al., 2000). Moreover, waste storage is still the most common practice of municipal waste management in the world (Laner, et al. 2012). Inappropriate management of urban solid waste not only increases the pollution in environment, but also threatens human health through its collection, transfer and disposal processes (Dong, et al., 2001). As a result, developing countries face serious threat in managing municipal solid waste (Shahid, et al., 2014). Similarly, due to improper waste management strategy, Pakistan is also facing critical health and environmental problems (Muhammad and Zhonghua, 2014). It is well established that, groundwater located near the landfill or dumpsites is considered highly polluted due to leachate percolation from nearby waste disposal site (Kamble and Saxena., 2017; Mor, et al., 2006). Dumped solid waste gradually releases its initial interstitial water and some of its decomposition by-products (leachate) that simultaneously get into water moving through the waste deposit (Mor, et al., 2006). Besides, leachate constitutes a complex matrix of various toxic chemical substances, including dissolved organic matter, inorganic salts, organic trace impurities and heavy metals. These chemicals are present in different concentrations due to the physical, chemical, and microbiological processes taking place in the deposited waste (Aziz, et al. 2010). In general, presence of toxic substances in groundwater ultimately deteriorate the groundwater chemistry making it unfit for human health and natural environment (Kamble and Saxena., 2017). According to WHO (1993), about 80% diseases in humans are caused by consuming contaminated or toxic water which causes waterborne diseases. On the other hand, several studies have been carried out worldwide to study the impact of leachate on groundwater quality (Longe and Balogun, 2010; Vasanthi, et al., 2008; Sabahi, et al., 2009; Jhamnani and Singh, 2009).

Karachi is the largest and densely populated city of Pakistan, where 12,000 tons per day municipal solid waste is generated which is about 4.4 million tons per year (Ahmed, 2017). About 60% of total waste is dumped at the landfill site and the 40% remains on the streets, which is not collected properly (Shahid, et al., 2014). There are two official landfill sites i.e. Jam Chakro (near Surjani Town) and Gond Pass (near Hub river). Municipal waste of 11 towns of Karachi is dumped at Jam Chakro landfill site where it is brought through uncovered vehicles and openly dumped without proper planning and segregation (Shahid, et al., 2014).

Surjani town is newly developed area where lower to middle class is being accommodated due to availability of relatively low-cost land. On the other hand, municipally supplied water is not available in sufficient quantity. Hence, dwellers are stressed for switching to other water sources like hydrants or groundwater. Since, Jam Chakro landfill site is located in the proximity of Surjani Town, it is believed that groundwater of study area is under threat of contamination from landfill site which is serving as point source of water contamination. A study with limited number of groundwater samples has been carried out in the vicinity of landfill sites to assess the impact of municipal solid waste on groundwater which showed that the groundwater was found contaminated with the leachate derived from Jam Chakro landfill site (Shahid, et al., 2014). Therefore, present study is aimed at detailed assessment of groundwater quality of Surjani Town to understand the relationship between leachate transport from landfill site and mixing with groundwater of study area.

Materials and Methods

Study area

Study area is located in the northwest of Karachi city which lies between 25.00942 ^{0}N to 67.417 ^{0}E (Fig. 1). Geologically, Surjani Town is resting on Gaj Formation of Miocene age which mainly comprises clastic sediments (sandstone and shale) with subordinate limestone. Jam Chakro landfill site is located in the proximity of Surjani Town (Fig. 2) which is 30 to 35 km away from the city center (Shahid, et al., 2014). The residents of study area are highly dependent on the groundwater for domestic purpose and extract either through hand pumps or electrically pumped bore wells.

Sample collection

Ground water samples (n= 28) were collected from both shallow and deep wells at a depth range of 35-220m through hand pump or electrically pumped wells. Well water was pumped for 2-3 minutes to get representative samples. Plastic bottles of 1000 ml capacity were used for sample collection to determine all physicochemical parameters. Bottles of 100 ml capacity were also used for nitrate determination in which about 1ml of boric acid solution (1%) was added to cease any further reaction. Sample bottles were thoroughly washed with distilled water and rinsed properly with well water. The field coordinates of sample locations were noted by using GPS (Global Positioning System) and plotted on the google image (Fig. 1).

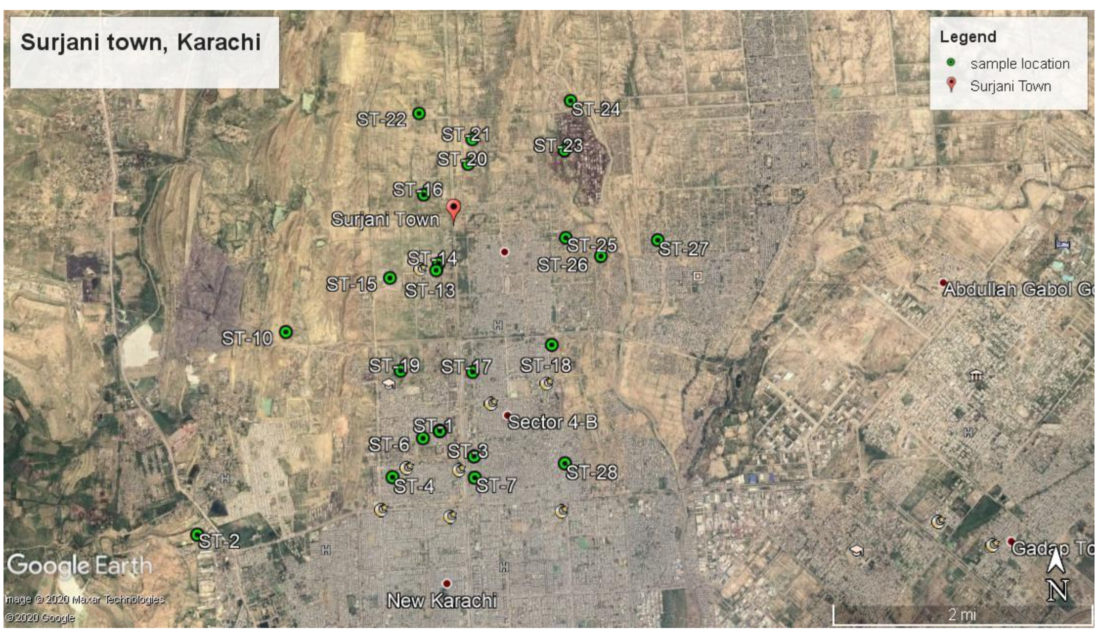

Fig. 1 Map showing samples locations of Surjani Town, Karachi.

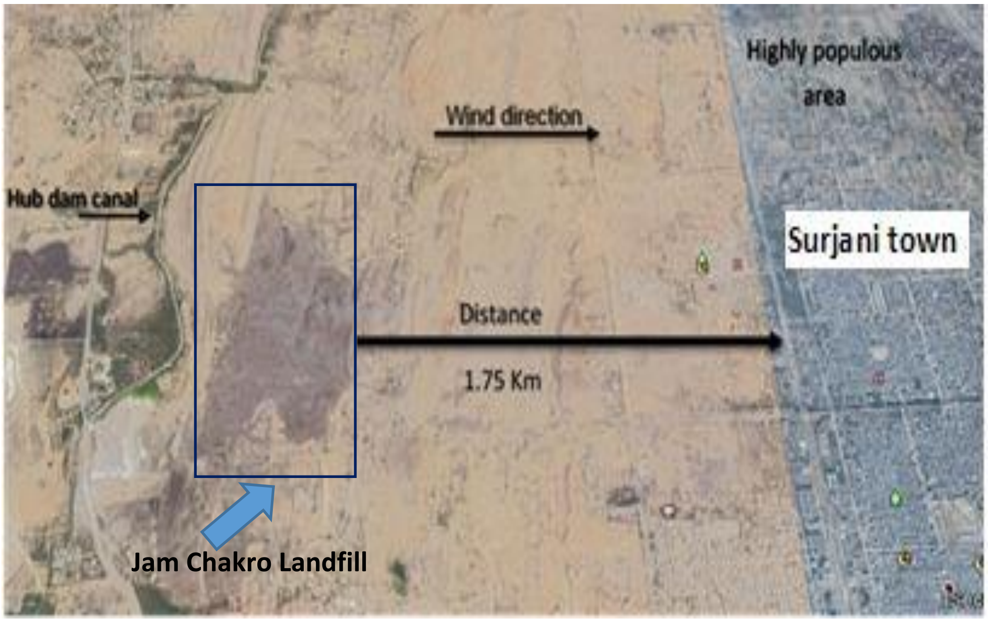

Fig. 2 Image showing Jam Chakro landfill site (left) and Surjani Town (right). The bed rocks are dipping toward study area.

Sample Analysis

The quality of analytical data was ensured through careful standardization, repeating analysis and procedural measurements. The pH of collected groundwater samples was measured with pH meter (JENCO 6230N). TDS and EC were measured with the help of EC meter (Eutech Cyber Scan CON 11). Sodium and potassium concentrations were determined by using flame photometer (Model No. Jenway PFP7). Calcium was determined by EDTA titration method while Mg concentration was derived from standard formula using difference between Ca concentration and hardness content. Sulphate content was determined by gravimetric method and chloride was measured by standard titration method using silver nitrate. Similarly, HCO_3 was also estimated by standard titration method. Groundwater samples preserved in the boric acid were analyzed to determine the nitrate concentrations by Cadmium Reduction method (HACH-8171) by spectrophotometer.

Results and Discussion

Physicochemical Characteristics

Results of physicochemical characteristics of collected samples (n=28) are given in Table 1. Data reveal that groundwater pH is highly fluctuating which varies between acidic to alkaline (ranges= 6.5 - 7.6; mean: 7.0). About half of the collected samples (n=14) are slightly alkaline (range= 7.04 – 7.6) which is attributed to the impact of leachate percolation from nearby landfill site of Jam Chakro (Shahid, et al., 2014). Whereas, rest of the samples show acidic pH (range= 6.5 - 6.9). TDS content ranges between 609 - 28100 mg/l with a mean of 11946 mg/l (Table 1). About one third samples are reported to contain slight to moderate TDS concentration (range= 1260 – 8260 mg/l) whereas more than one third samples (n=13) show remarkably high TDS content (range= 10800 – 28100 mg/l) which are greatly exceeding the permissible limit of both WHO (500 mg/l) and Pakistan Environmental Protection Agency (1000 mg/L). Conversely, only three wells (ST-3, ST- 4 and ST- 14) are reported to contain acceptable TDS concentration (range= 609 – 847 mg/l). High TDS content may be associated with the leaching of various pollutants into the groundwater (Mor, et al., 2006). According to Olaniya and Saxena (1977), groundwater pollution from solid waste in the vicinity of the dumping sites are primarily detected through increased TDS concentration of water. Therefore, extremely high TDS concentration in groundwater of study area is due to the proximity of Surjani Town with landfill site (Jam Chakro).

Water Solute Chemistry

Major Cations

Concentration of sodium (range: 118-22,700 mg/l; mean 7293.678 mg/l) and potassium (range: 20-80 mg/l; mean 44 mg/l) are highly variable in the groundwater of Surjani Town (Table 1). Data revealed that only four wells have sodium concentration < 300mg/l while others have exceptionally high Na content (range: 3300 - 22700 mg/l). About two third of total samples have K concentration < 50mg/l while one third have above 50mg/l. None of the samples has K concentration within the permissible limit of WHO (12mg/l) for drinking purpose. Both these cations (Na^+ and K^+) in groundwater are mainly attributed to weathering of sodic plagioclase (albite) and muscovite. It is due to the fact that feldspars and micas are more susceptible to weathering and alteration than quartz among silicate rocks (Ahmed, and Clark, 2016). However, excessively high amount of Na and K is associated with anthropogenic input instead of weathering from rocks and minerals. Calcium and magnesium contents also fluctuate between highly variable extremes where the mean concentration of both ions is found to be ± 1000 mg/l. In general, the concentration of calcium in groundwater ranges from 10 to 100 mg/l (Nag, 2009). Except three, all samples contain moderate to high calcium concentration up to 5,600 mg/l. On the other hand, more than half of the collected samples show very high concentration of Mg (up to 3000 mg/l) where the mean value is 22 times higher than normal concentration (250 mg/l). Ca and Mg ions mainly occur due to carbonate rocks dissolution such as limestones and dolomites. It is consistent with the fact that dolomitic limestone (Talawa limestone of Gaj Formation) is cropping out in study area. Elevated concentration of major solutes in the groundwater of study area may be associated with anthropogenic input. The occurrence of landfill site in the proximity of study area seems responsible for contamination. It is well established that high concentration of salts in groundwater of urban areas is associated with landfill leachate from nearby waste disposal site (Singh and Hasnain, 1999; Ellis, 1980).

Major Anions

Chloride is major anion which is extremely variable in its concentration (range: 106 - 15035 mg/l). About one third of total samples show exceptionally high chloride content (range: 5885 – 15035 mg/l). Usually, high chloride concentration serves as an indicator of pollution from wastewater or leachate (Bjerg, et al., 2003). Moreover, groundwater containing high chloride concentration (usually >1000 mg/l) is associated with high temperature and less rainfall (Ramakrishnaiah, et al., 2009). The occurrence of high chloride content in the groundwater of study area is consistent with the fact that Jam Chakro landfill site occurs in the proximity of study area and city enjoys arid climate where the mean temperature is > 25^0C and annual rainfall 5 – 10 inches (Khan and Hassan, 2019).

Table 1 Physico-chemical characteristics of ground water of Surjani Town, Karachi.

Sample Code	Physical parameter				Chemical parameter							
					Major Cation				Major Anion			
	pH	TDS ppm	EC (ms/cm)	Hardness (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)
ST-1	6.7	21800	43.7	6900	8500	49	1400	826.2	925	15035	2897.84	1.09
ST-2	6.5	16700	33.5	8500	7080	68	1740	1008.45	1050	9394	2653.64	0.16
ST-3	7.5	802	1600	760	240	28	68	143.37	1475	195	211.64	0.98
ST-4	7.14	609	1216	670	118	33	108	97.2	850	106	122.1	3.72
ST-5	7.49	6490	12.98	1220	4700	37	164	196.83	450	2399	18445.24	0.78
ST-6	7.41	1270	2.5	1180	420	27	112	218.7	1000	372	301.18	2.33
ST-7	6.9	24600	49.2	10000	9500	52	1400	1579.5	2725	7302	927.96	12.06
ST-8	7.18	7070	15.36	3500	5000	41	324	653.67	775	2630	3191	17.22
ST-9	7	20750	5.47	3000	3300	25	284	556.47	3050	744	830	27.66
ST-10	7.07	10800	21.5	6350	6000	61	792	1061.91	1025	3704	3053	28.89
ST-11	6.91	17500	35	8250	7800	53	1100	1336.5	625	4183	3077	46.75
ST-12	7.6	5100	10.2	3000	3500	46	276	561.33	1325	850	1498	6.65
ST-13	7.16	2640	5.28	4750	3300	50	494	854.145	925	762	521	55.93
ST-14	6.7	847	1697	2300	265	25	64	520.02	2125	159	8067	23.16
ST-15	6.84	1660	33.1	7500	12000	56	1200	1093.5	675	8543	2979	26.88
ST-16	7.34	25400	50.8	9500	11000	80	1100	1640.25	625	13577	2271	6.69
ST-17	7.07	22000	45.6	9450	9500	30	2000	1081.35	725	14304	4005	3.34
ST-18	7.04	1260	75	5350	8500	52	1080	643.95	875	4874	2922	44.4
ST-19	7.02	24500	80	10100	9300	49	2100	1178.55	275	13187	2824	26.22
ST-20	6.65	28100	118	12500	10000	56	2000	1822.5	1125	8330	3402	0.41
ST-21	6.87	3180	91	12500	14000	45	90	2982.825	1400	2658	3834	5.33
ST-22	6.51	3400	105	19750	22700	46	5600	1397.25	300	9926	2613	0.3
ST-23	6.8	6660	785	4900	4200	32	420	935.55	1875	2871	993	14.97
ST-24	7.09	6390	59	4400	5500	20	460	789.75	3375	1595	627	5.06
ST-25	6.9	19700	114	9500	8000	49	1760	1239.3	525	9571	1457	19.02
ST-26	7.3	8260	58	4700	6800	35	396	901.53	3450	921	1009	8.37
ST-27	6.7	26200	75	9500	13000	40	1400	1458	2900	10280	5275	23.04
ST-28	6.8	20800	95	8500	10000	47	1440	1190.7	3000	5884	2377	76.32
Max	7.6	28100	1697	19750	22700	80	5600	2982.825	3450	15035	18445	76.3
Min	6.5	609	2.5	670	118	20	64	97.2	275	106	122	0.16
Mean	**7.006**	**11946**	**233.292**	**6733.214**	**7293.678**	**44**	**1049**	**998.903**	**1409**	**5513**	**2942**	**17.4**
S.D	0.295	239.5	475.5	4337.8	4920.8	13.9	1119	601	988.8	4871	3491.8	19.2
WHO limit	**6.5-8.5**	**500 ppm**	--------	**500**	**200 mg/l**	**12 mg/l**	**200 mg/l**	**150 mg/l**	**300 mg/l**	**250 mg/l**	**500 mg/l**	**10 mg/l**

Sulfate content of groundwater fluctuates within the range of 122 – 18445 mg/l with a mean of 2942 mg/l (Table 1). Extremely high SO_4 content (18445 mg/l) is reported in ST-

5 well. Generally, high concentrations of SO_4 occurs in shallow, unconfined aquifers that receive large inputs of sulfate from atmosphere which may be anthropogenic sources and industrial process as well (Mostafa, et al. 2017). Nitrate concentration varied between 0.16 – 76.3 mg/l with a mean of 17.4 mg/l (Table 1). About two third of total samples have objectionable concentration up to 76.3 mg/l. In general, nitrate in groundwater is derived from anthropogenic sources such as domestic sewage, leaching from solid waste disposal and agricultural activity. According to Jawad et al. (1998), groundwater containing increased NO_3 content indicates the contribution through landfill leachate (Ali, et al., 1998).

Concentration of bicarbonate is also highly variable (range: 275-3450 mg/l; mean: 1409 mg/l) in the groundwater of study area (Table 1). Data revealed that about 50% of the samples show extremely elevated HCO_3 content (range: 1000 – 3450 mg/l) which is seven times greater than the permissible limit of 300 mg/l in drinking water (WHO, 2004). Whereas, one third wells are fluctuating within the range of 450 – 925 mg/l. It is well established that very high bicarbonate alkalinity may be attributed to the anthropogenic activity, dissolution of carbonate mineral and decomposition of organic matter. In addition, potential source of bicarbonate in groundwater is associated with anthropogenic CO_2 gas, emanating from municipal wastes within unlined landfill sites (Mor et al., 2005) and oxidation of organic materials leaked from old latrines and sewage systems in the downtown area (Mor, et al., 2006). Furthermore, the fermentation of organic matter generates gas and acidic condition which are highly reactive and ultimately responsible for the dissolution of limestone (Shugg, 2014). Hence, solid waste disposal sites of Jam Chakro seemed as a point source for elevated bicarbonate alkalinity and subsequent dissolution of limestone.

Ionic interrelationship

Strong negative correlation of pH is observed with total hardness (r= -0.64), Na (r= -0.54), Ca (r= -0.57) and Mg (r= -0.48) which is consistent with the fact that, at acidic pH, high rate of rock water interaction leads to the leaching of these ions in groundwater (Table 2). Strong positive correlation of TDS with Cl (r= 0.69) indicates high mobility of chloride ions (Mor, et al., 2006) and it is responsible for high TDS content in groundwater of Surjani Town.

On the other hand, total hardness shows strong correlation with Ca (r=0.85), Mg (r=0.8), Cl (r=0.67) and Na (r=0.93). It indicates that the increasing trend of hardness in groundwater is mainly due to these major ions. Additionally, strong correlation of chlorides with alkaline earth metals (Ca^{+2} and Mg^{+2}) also support the leachate percolation from nearby landfill site (Kumar and Alappat, 2005).

Table 2 Correlation matrix of collected samples in the study area.

Correlation matrix													
	Depth	pH	TDS	EC	Hardness	Na	K	Ca	Mg	HCO3	Cl	SO4	NO3
Depth	1.00												
pH	-.39*	1.00											
TDS	-.07	-.33	1.00										
EC	-.11	.03	-.40*	1.00									
Hardness	.45*	-.64**	.45*	-.40*	1.00								
Na	.57**	-.54**	.34	-.48**	.93**	1.00							
K	.21	-.22	.39*	-.42*	.49**	.45*	1.00						
Ca	.53**	-.57**	.33	-.29	.85**	.80**	.34	1.00					
Mg	.19	-.48*	.42*	-.38*	.80**	.72**	.48*	.35	1.00				
HCO3	-.25	-.06	.12	.08	-.19	-.14	-.43*	-.30	.01	1.00			
Cl	.44*	-.45*	.69**	-.38*	.67**	.65**	.53**	.66**	.43*	-.34	1.00		
SO4	-.13	.04	-.02	-.02	-.08	.05	-.03	-.05	-.07	-.20	.04	1.00	
NO3	-.02	-.13	.06	-.14	-.02	.00	.15	-.06	.04	.15	-.11	-.10	1.00

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Principal Component Analysis

Results of PCA applied to the data of physicochemical variables and major ions in groundwater have been summarized in Table 3. Four components were found significant. The first component (PC-1) describes about 41.01% of its total variance and has both positive and negative loadings. Total dissolved salts, Na+, Cl^-, Ca^{+2}, Mg^{+2}, K^+, hardness and depth have high positive loadings with pH (-0.645) in first component. Strong loadings of these variables suggest that the processes that impact these variables, their concentrations and variability in the groundwater are similar (Iranmanesh, et al., 2014). Negative association of pH with ions show intense water rock interaction which is consistent with the fact that acidic pH is responsible for dissolution of minerals and simultaneous leaching of ions in the groundwater. Significant positive association of TDS (0.565) with Na+ (0.916) and Cl- (0.825) suggests that these ions are responsible for relatively higher salinity which is derived from water rock interaction and gets enriched in the groundwater due to their high solubility (Rao, et al., 2006). Whereas, high load of Na+ and K+ may be due to weathering of rock and different ion-exchange process in groundwater system near landfill (Drever, 1997, Srivastava and Ramanathan, 2008). Further, strong correlation of chlorides with alkaline earth metals (Ca^{+2} and Mg^{+2}) also indicate leachate percolation from nearby landfill site (Kumar and Alappat, 2005b). Hence, anthropogenic pollution is considered as point source for concentration of these ions in groundwater (Rao, et al., 2006).

The second component (PC-2) accounts for 11.98% of variability. The concentration of TDS (0.493), HCO_3 (0.72) and NO_3 (0.488) show negative loading with Depth (-0.449). It is clearly indicating that the source is near surface. The concentration of NO_3 in the groundwater is obviously related to the influence of anthropogenic origin (Rao, et al., 2006). Moreover, the association of HCO_3 and NO_3 ions is an indication of the hydrogeochemical effect of runoff leakage on the groundwater (Wang and Tma, 2001). The third component (PC-3) accounts for 10.8% of variability and positively correlated with pH (0.46), K^+(0.46) and SO_4 (0.4) whereas negatively correlated with EC (-0.457), HCO3 (-.424) and depth (-.421). Moderate positive loadings of K and SO_4 may indicate continuous release of leachate from landfill site (Kumar and Alappat, 2005a) while negative correlation of bicarbonate with depth suggests that source is present near surface. The fourth component (PC-4) described the 8.3% of total variance with high negative loading of nitrate (-0.65) and moderate positive loading of SO_4 (0.416) which suggests anthropogenic contamination from nearby municipal landfill leachate (Kumar and Alappat, 2005b).

Table 3 Principal component analysis of groundwater of Surjani Town, Karachi.

	Component			
	PC 1	PC 2	PC 3	PC 4
Hardness	**.948**	.021	-.145	.071
Na	**.916**	-.055	-.131	.029
Cl	**.825**	-.103	.203	.159
Ca	**.823**	-.249	-.210	.040
Mg	**.731**	.318	-.017	.078
pH	**-.645**	-.117	**.465**	-.134
K	**.628**	.008	**.460**	-.376
TDS	**.565**	**.493**	.325	.321
Depth	**.538**	**-.449**	**-.421**	-.278
EC	-.512	-.272	**-.457**	.183
HCO3	-.265	**.723**	**-.424**	.272
SO4	-.036	-.295	**.435**	**.416**
NO3	.025	**.488**	-.036	**-.653**
Eigen value	5.382	1.558	1.413	1.085
% of Variance	41.401	11.987	10.871	8.350
Cumulative %	41.401	53.387	64.258	72.608

Conclusion

It is concluded from the present study that groundwater of Surjani Town is extremely contaminated in terms of its major chemical constituents. Beside natural attenuation of ions, mobilization from anthropogenic source is also imprinted in groundwater of study area. Dip direction of bedrocks towards study area strongly support the contaminant transport from landfill site towards Surjani Town. Further investigations are required in terms of microbiological and heavy metal determination to establish a connection between contaminants leaching and transport from Jam Chakro landfill site to the groundwater of Surjani Town.

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