academicJournals

Vol. 8(28), pp. 1470-1480, 30 July, 2013
DOI: 10.5897/IJPS2013.3927
ISSN 1992 - 1950 © 2013 Academic Journals
http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Assessment of leachate effects to the drinking water supply units in the down slope regions of municipal solid waste (MSW) dumping sites in Lahore Pakistan

Khalid Mahmood[1], Syeda Adila Batool[1], Asim Daud Rana[1], Salman Tariq[1], Zulfiqar Ali[2,3]* and Muhammad Nawaz Chaudhry[2]

[1]Department of Space Science, University of the Punjab, Lahore, Pakistan.
[2]College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan.
[3]Nano Science and Catalysis Division, National Centre for Physics, Q.A.U Campus, Islamabad, Pakistan.

Accepted 30 July, 2013

The aim of this study was to evaluate seasonal as well as moderate temporal effects on deep groundwater quality by the dumpsites leachate in the Lahore Metropolitan with a population of about 8 million. Groundwater samples for this study ware drawn from groundwater supply units installed by local government for the provision of drinking water to the residents. The groundwater in down slope regions from municipal solid waste (MSW) dumping sites has been identified by using Inverted Watershed technique. Eleven water supply units have been spotted that fall within the identified leachate plumes. Parameters of pH, turbidity, electric conductivity, total dissolved solids (TDS) and *Escherichia coli* were determined on water samples from these identified units. The quality analysis indicates that the effect of the leachate is more prominent in the hot and dry pre-monsoon season due to the domination of base flow for recharge of the groundwater, whereas dilution observed in leachate contamination during and immediately after the monsoon rainy season is due to the recharge through seepage of the rain water which dominates the base flow. Variation in the correlation factor between electric conductivity and TDS has been used to estimate constituents of TDS contributed both by rainfall seepage and base flow. An increasing tendency, showing influence of the leachate on the deep water quality, has been observed while analyzing the correlation between distance of the tube wells from leachate sources and measurements of quality parameters.

Key words: Base flow, deep groundwater, down slope regions, landfill leachate, rainwater seepage.

INTRODUCTION

Almost 70% of the earth is covered with water but only 2.5% of this is fresh water (PCRWR, 2007; Limouzin and Maidment, 2009) is suitable for human use. Approximately 99% of fresh water is in aquifers (ESA, 2001; Gabriel and Khan, 2010) and being used as the major source of drinking water in Pakistan. Lashari et al. (2007) estimated that about 60 to 70% population of Pakistan depends directly or indirectly on groundwater for their livelihood. However, a number of locations in Punjab province of Pakistan have been reported to be contaminated by by-products of waste materials (World Bank, 2006). Therefore, qualitative and quantitative monitoring of these fresh water reservoirs is mandatory for human health.

Underlying aquifer is the main source of water for the city of Lahore like the rest of the Punjab province with a population of 80 million. The extraction of this groundwater can be categorized in three types depending

*Corresponding author. E-mail: zali1964@hotmail.com. Tel: +92301-5551014. Fax: +92-512077395.

on depths. The first category ranges in depth from 9 to 18 m depending upon the aquifer level. This serves the poor households around the dumpsites and cottage industry. The second category serves the agriculture; the water is drawn by relatively large water extraction tube wells with almost the same depth range as for the first category. The third type of extraction wells are installed by government agencies for the provision of drinking water to residents of the city. These tube wells are considered most sophisticated and deepest (150 to 180 m).

Provision of water supply to about 90% population of Lahore is the responsibility of Water and Sanitation Agency (WASA), which has installed over 450 tube wells and given over 531,336 connections in the city (Gabriel and Khan, 2006). Other agencies like Lahore Cantonment Board, Model Town Society etc. serve the remaining 10% population of Lahore. Gabriel and Khan (2006) reported that these tube wells are of varying capacity and are operated for an average duration of 16 to 18 h a day and the depth of these tube wells, varies from 150 to 180 m. Hydro-geologically, Lahore is a part of large interfluvial Bari Doab, bounded by River Ravi to the north-west and Rivers Satlej and Beas to the south-east. Its aquifer is un-confined with a thickness of about 400 m (Gabriel and Khan, 2006) and is composed predominantly of fine to medium grained sands and small lenses of silty clay.

Monitoring of underlying aquifer in the vicinity of a dumping site is mandatory for the protection of groundwater. Dumping sites provide an easy and the cheapest way for waste management all over the world (Mahini and Gholamafard, 2006; Zhang et al., 2011; Butt et al., 2008). However, without properly designed and maintained, microbial and chemical products from the dumping site may produce harmful effect to the environment (Butt and Oduyemi, 2003). Hazards associated with landfills require proper evaluation even after their construction, in order to estimate and eradicate the bad effects to environment and public health (Gorsevski et al., 2012). Contamination of the underlying aquifer by leachate from the dumping sites is the most highlighted environmental issue found in the reviewed literature (Butt and Oduyemi, 2003; Santos et al., 2006; Demitriou et al., 2008; Din et al., 2008; López et al., 2008; Singh et al., 2009; Li et al., 2012). For examples, groundwater contamination near the Ano Liosia landfill was reported in Attica region, Greece, which was unsuitable for irrigation (Feta et al., 1996). Another example is in Delaware New Castle where wells located downstream of the Llangollon landfill were found to be heavily contaminated and subsequently abandoned (Chian and DeWalle, 1976).

In 2009, the areas under the jurisdiction of Lahore city produced about 5000 tons/day of municipal solid waste (MSW), where 60% of the waste was collected and disposed of in the open dumpsites (Batool and Chohdary, 2009). Two major sites for municipal waste dumping in Lahore are located in Saggian and Mahmood Booti as shown in Figure 1. These dumping sites have neither a leachate collection system nor an impermeable liner system. The dumpsite leachate percolates through underlying sediments and contaminates the source of drinking water (Biswas et al., 2010; Li et al., 2012). Once the groundwater is contaminated, they are unable to be cleaned to a level that can meet international drinking water quality standards (Biswas et al., 2010). Horizontal spread of percolated landfill leachate is very limited (Cherry, 1990) but it moves down slope as a wide front of contamination (Lee and Lee, 1993). Municipal landfill's leachate is heavier than groundwater, therefore, after percolation through lithological cross section it will sinks to the depth where it is diluted to a level where its density becomes comparable to that of the uncontaminated groundwater (Cherry, 1991; Lee and Lee, 1993).

In the pre-monsoon season, lateral flow of groundwater is dominant while in the post-monsoon, vertical flow dominates the groundwater recharge. Lateral flow brings contamination to a location from its neighboring sources and the vertical flow brings contamination from the location itself. Most of the studies that analyzed the leachate hazards to the groundwater had used shallow (1 to 10 m below surface) water samples, where the effects are more pronounced (Jensen et al., 1998; Nyenje et al., 2013). This study is intended to delineate down slope groundwater regions of Mahmood Booti and Saggian dumping sites and the quality assessment of the drinking water supply tube wells that are located within the identified hazardous zones. The groundwater sampling depth ranges from 79 to 137 m from the tube wells installed by the government for the provision of drinking water. Timely detection of groundwater pollutants may lead to remedial measures for sustainability of the drinking water source. For this purpose some indirect methods have been used for the analysis of contamination caused by leachate to these depths.

MATERIALS AND METHODS

Methodology for this study has been divided into two steps. In the first step, down slope groundwater areas of each landfill have been identified and hence delineated. Afterward, in the second step tube wells falling within this area were assessed for the quality of drinking water.

Down slope area identification

WASA periodically measures the depth of groundwater on each of its tube wells installed within Lahore district. For this study, static water level (SWL) values for the months of April, July and October from 2009 to 2011 were used. Geo-referencing of the tube well sites was accomplished by a field survey identifying each tube well site using Garmin GPS map 76CSx with an accuracy of ±3 m. In order to develop water table, the point measurements had been interpolated after comparison of many techniques available for interpolation as shown in Table 1. This comparison had optimized Kriging (simple kriging) as the most suitable for the interpolation.

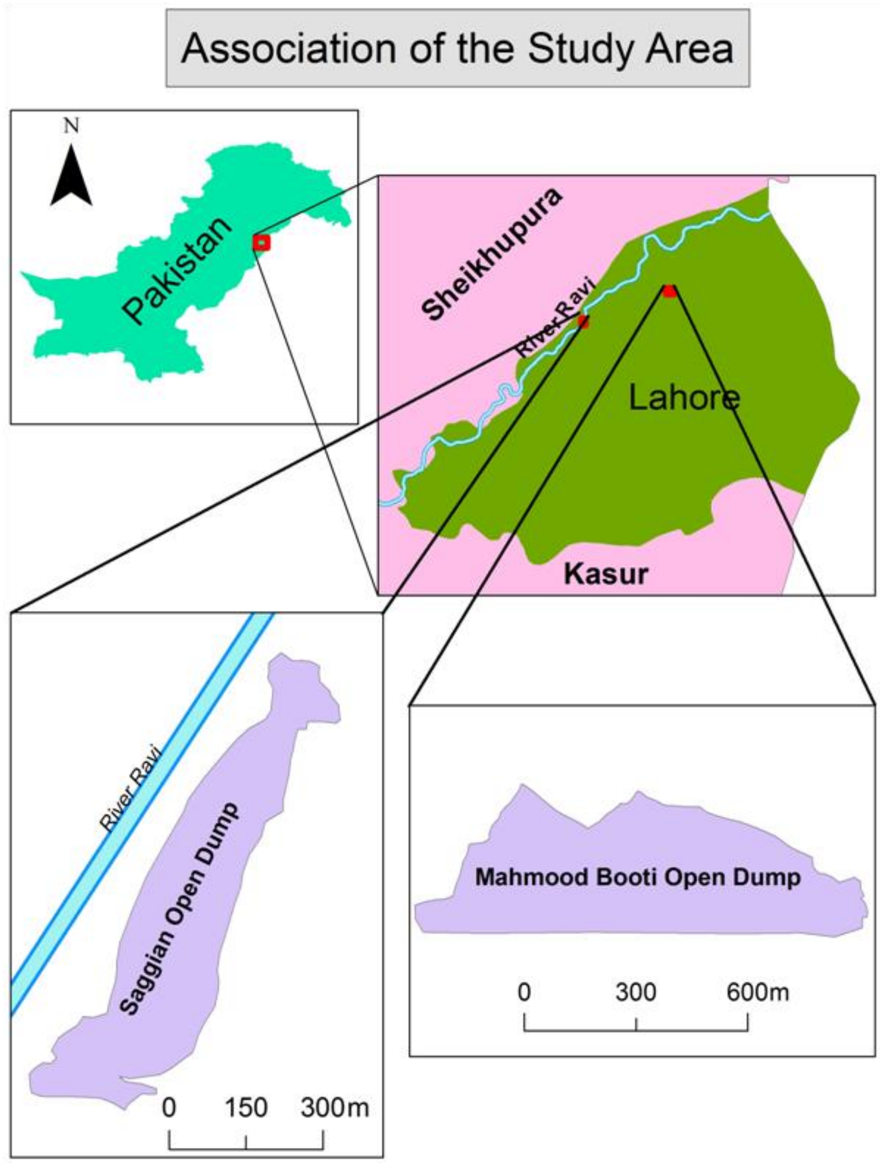

Figure 1. Dumping sites location in Lahore, Pakistan.

Table 1. Comparison of interpolation techniques.

Method	RMSE	Correlation	Mean
IDW	3.492	0.890536	0.1231
Spline	3.399	0.897549	0.1748
Kriging	3.37	0.898589	0.02551

For the down slope area identification some of the geographic information systems (GIS) software only facilitates in finding down slope trajectories for individual pixels; whereas, one of the objectives of the study was to delineate all the area that receives water after passing through the landfills, therefore an indirect approach has been applied for this purpose. The method devised in this study for the down slope area identification is an inverse watershed technique. In this technique, the water table surface is inverted to get its reflection surface which shows higher areas at low levels and vice versa. The down slope areas in the actual raster surface will appear to be up slope areas or in other words, watersheds, in the output surface. The process of inversion of water

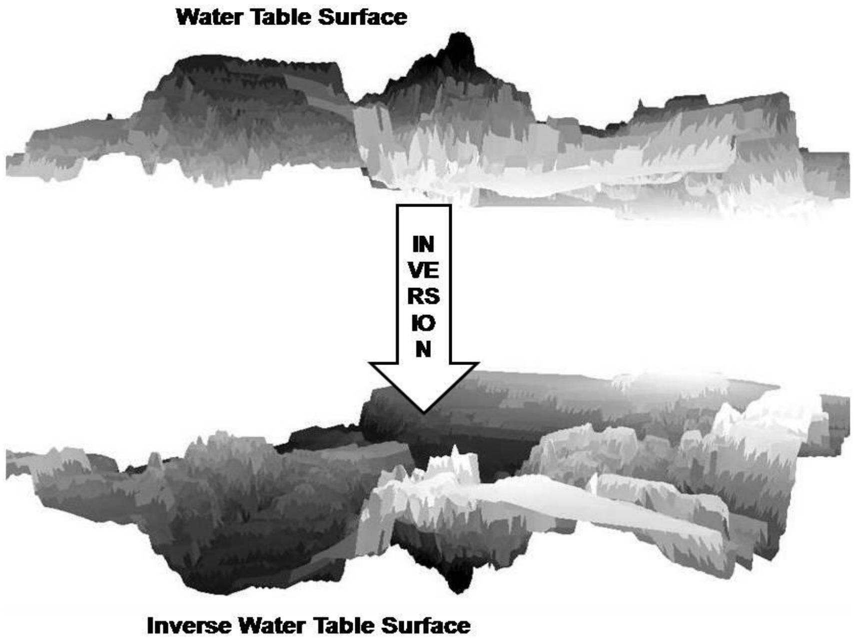

Figure 2. Inversion of groundwater surface.

table surface is shown in Figure 2.

Both landfills were used as target feature for delineating watersheds based on the inverted water table surface. This watershed gives the required down slope regions of the groundwater from landfills. To incorporate possible variations in the down slope area a time series of water table surfaces consisting of nine datasets spanning from April, 2009 to October, 2011 were used in this study. Groundwater surface changes with time as a consequence of rates and position of water extraction and recharge, the combined output of all down slope regions is shown in Figures 3 and 4 for Mahmood Booti and Saggian landfills, respectively. As a hypothesis, the estimated down slope areas from various input surfaces must overlap as they belong to the same region. Therefore, in the final down slope region only those areas which overlapped by at least two of the datasets were selected. The outputs of all the overlapping datasets are united for the demarcation of the down slope areas of both the dumping sites.

Quality assessment of risk prone tube wells

The final down slope area for each of the dumping sites identifies the possible hazardous region prone to leachate contamination. Tube wells installed by WASA, Lahore for drinking water supply were identified in this study. After identification of expected risk prone water supply units, an assessment was performed to check the water quality of these tube wells. The qualitative report of expected risk prone tube wells for pre-monsoon 2010 was taken from WASA, Lahore. The other data set for the water quality assessment was acquired especially for this study in post-monsoon 2012. The available datasets made it possible to provide both seasonal as well as moderate temporal changes in the drinking water quality. This time gap provided a fair chance to evaluate the impacts of leachate, having a slow lateral movement (Cherry, 1990), even at the farthest tube well identified. Water samples of the tube wells were collected in neat, airtight and sterilized polyethylene 500 ml bottles. Samples were immediately brought to laboratory for the analysis of selected water quality parameters.

In the pre-monsoon season, lateral flow of ground water is more dominant, whereas in the post-monsoon season, vertical flow dominates the groundwater recharge. Both seasons were taken into account to determine the influence of lateral as well as vertical flow of recharge to water quality. In order to highlight the influence of landfill leachate to water quality parameters a basic principle of likelihood has been used by virtue of which any effect caused by a source is inversely related to the distance (Nyenje et al., 2013). A correlation of each quality parameter with distance from dumping site was established. The distance from the dumping site had been taken, keeping in view, both the filter depth of tube wells and its ground distance from the dumping sites as shown in Figure 5.

RESULTS AND DISCUSSION

The delineated down slope regions for both municipal dumpsites show a general trend of groundwater flow from dumping sites towards the residential area of the city as shown in Figure 6. The extracted down slope regions using inverse watershed technique are verified by the cited literature, as explained in the following points:

1) It is a fact that almost all the extraction of groundwater for livelihood is made in central portions of the city leading to a depression zone as mentioned by a number of studies (Mahmood et al., 2013). So, in order to maintain surface level, water flows from outer boundaries, beneath municipal dumpsites, to inner regions of the city.

2) The River Ravi exists as one of the major recharge sources of Lahore’s groundwater at northern and western edges of the city (Basharat and Rizvi, 2011; Mahmood et al., 2013). Since the leachate producing bodies are

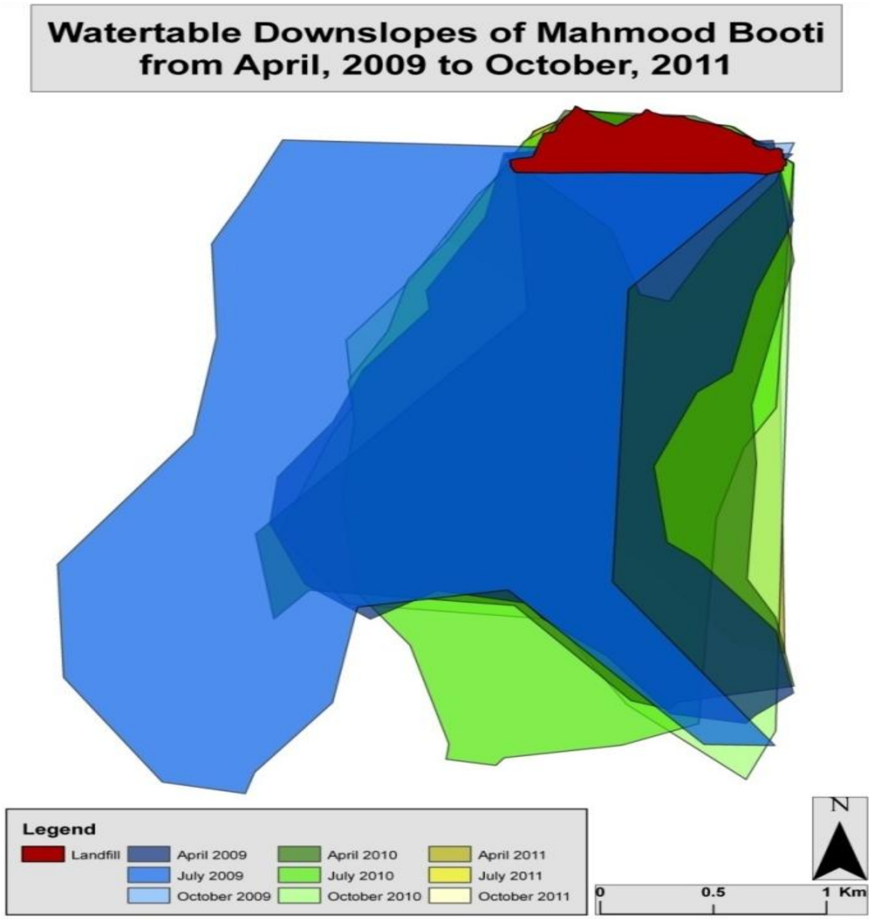

Figure 3. Time series of Water table down slopes of Mahmood Booti dumping site.

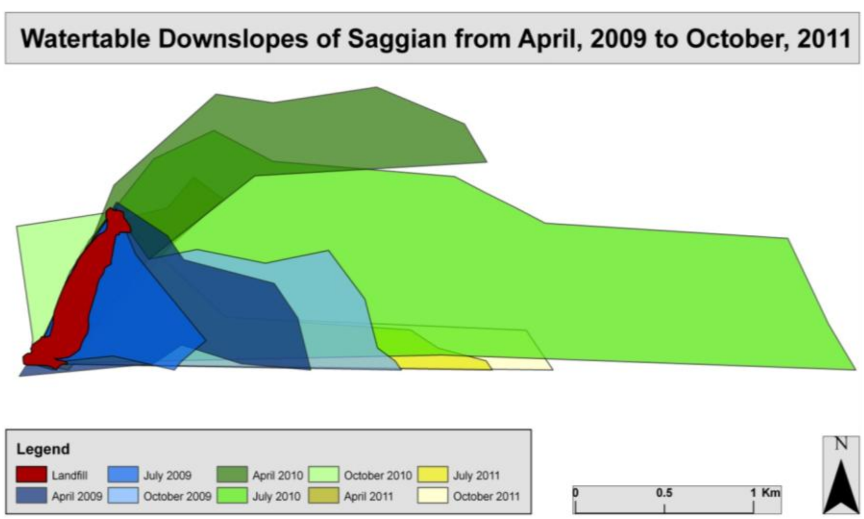

Figure 4. Time series of Water table down slopes of Saggian dumping site.

situated away from River Ravi to the residential part of the city, therefore, flow of the water for recharging the underlying aquifer is from dumpsites to central city. In this way, leachate contaminates that part of the groundwater

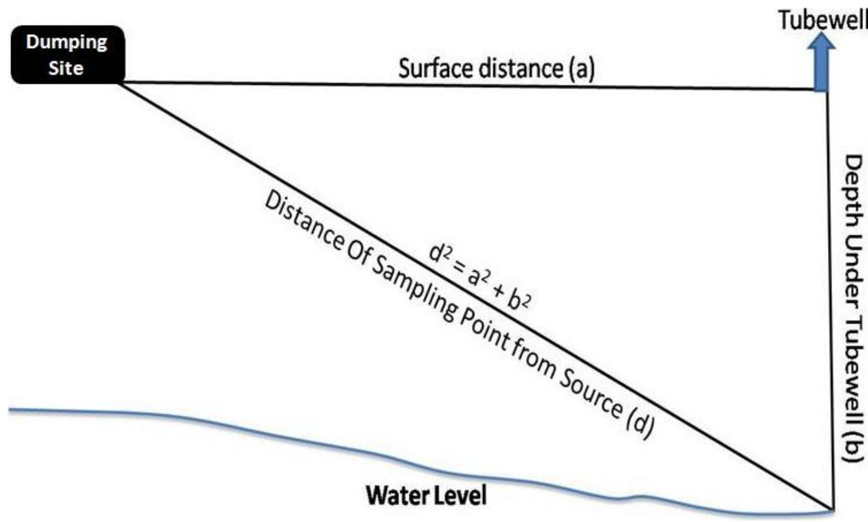

Figure 5. Distance from dumping site to tube well filter

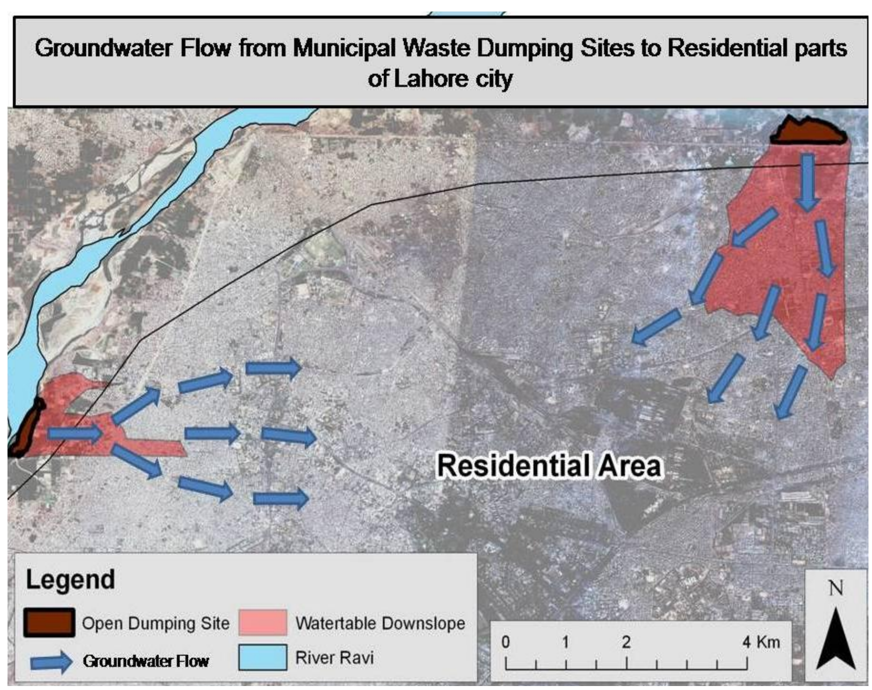

Figure 6. Groundwater flow to the Lahore city.

which has to be ultimately extracted for human usage.

Effects on the drinking water supply units/tube wells

Table 2 lists the details of risk prone tube wells identified in this study. Nine tube wells were located within contamination reaches in Mahmood Booti dumping site (Figure 7) and two tube wells were in the Saggian dumpsite (Figure 8).

The quality parameters for the risk prone tube wells are shown in Table 3. The landfill leachate contains acidic substances that cause decrease in pH value of the leachate (Kareem et al., 2010) which further tends to decrease pH of the ground water if it gets mixed with it. Keeping in view this effect to the pH parameter, Table 3 shows the average measured pH of groundwater is more acidic in the pre-monsoon season than the post-monsoon

Table 2. Tube wells at risk along the dumping sites.

S/N	Serving area	Effecting dumping site	Design capacity (Cusecs)	Distance from landfill (m)	Water depth Nov, 2011(m)	Water sampling depth (m)
1	Madho Lal Hussain	Mahmood Booti	0.112	2565	39.62	137
2	Dy. Yaqoob Colony	Mahmood Booti	0.112	2049	32.92	137
3	Aliya Town	Mahmood Booti	0.112	548	32.69	137
4	Gulshan-e-Shalimar	Mahmood Booti	0.112	1148	32.5	137
5	Angoori Bagh SchemeNo.1	Mahmood Booti	0.056	3172	39.5	137
6	Gosha-e-Angoori	Mahmood Booti	0.112	3190	39.1	137
7	Kotli Pir, Abdul Rehman	Mahmood Booti	0.112	3328	39.8	137
8	Naseer Abad, Pakistan Mint	Mahmood Booti	0.112	2595	39.5	137
9	Mahmood Booti Well Center 3	Mahmood Booti	0.112	50	32.55	137
10	Rafi Abad Darbar	Saggian	0.056	987	23.71	79
11	Islam Pura	Saggian	0.112	2095	25	79

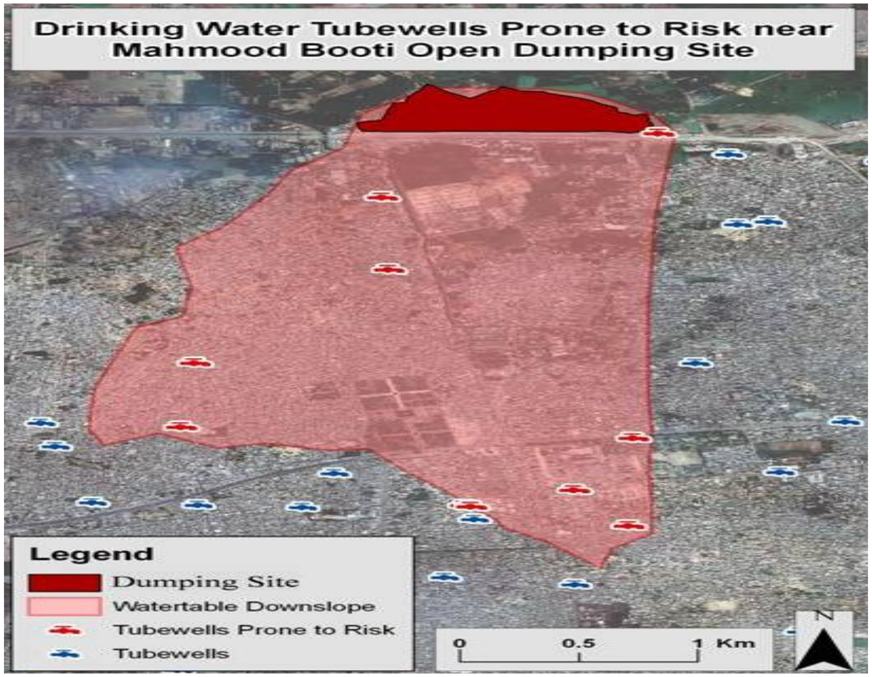

Figure 7. Drinking Water at risk around Mahmood Booti.

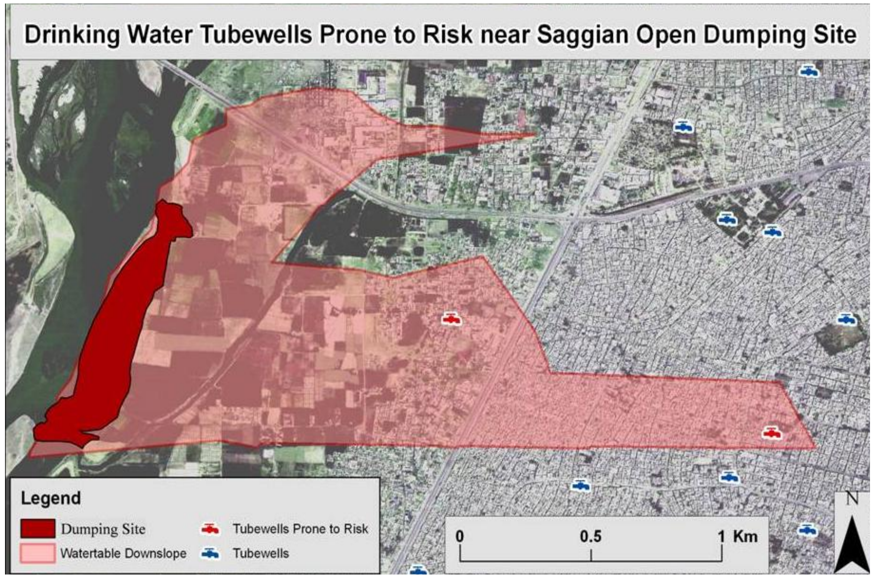

Figure 8. Drinking Water at Risk around Saggian

Table 3. Quality degradation chart of the risk prone tube wells.

S/N	Location	PH		Turbidity (NTU)		Conductivity (ms/cm)		TDS (ppm)		*E. coli*	
		Pre MS*	Post MS*	Pre MS*	Post MS*	Pre MS*	Post MS*	Pre MS*	Post MS*	Pre MS*	Post MS*
1	Madho Lal Hussain	7.6	8.4	0.59	0.08	526	430	331.3	290	Absent	Present
2	Dy. Yaqoob Colony	8.1	8.5	0.16	0.09	518	410	236.3	290	Absent	Present
3	Aliya Town	7.5	8.2	1.07	0.13	514	390	323.8	380	Absent	Present
4	Gulshan -e-Shalimar	8.6	8.6	3.44	0.18	886	380	558.1	390	Absent	Present
5	Angoori Bagh SchemeNo.1	7.5	7.9	1.85	0.15	921	1010	580.2	465	Absent	Present
6	Gosha-e-Angoori	7.8	7.9	3.8	0.15	621	1010	391.2	465	Absent	Present
7	Kotli Pir, Abdul Rehman	7.9	8.2	2.02	0.16	560	560	352.8	390	Absent	Present
8	Naseer Abad, Pakistan Mint	7.9	8.1	1.94	0.21	574	530	361.6	359	Absent	Present
9	Mahmood Booti Well Center 3	7.9	8.1	1.97	0.15	380	450	239.4	310	Absent	Present
10	Rafi Abad Darbar	8	8.8	0.57	0.15	321	260	202.2	285	Absent	Present
11	Islam Pura	7.7	8.5	1.67	0.18	392	290	246.9	210	Absent	Present
Averages		7.8	8.2	1.73	0.15	564.8	520	347.6	348.5	Absent	Present

*MS- Monsoon.

Table 4. Change in co-relation (Pearson's r test) among quality parameters.

Correlation between	Pre-monsoon	Post-monsoon
Electric conductivity/TDS	0.97638	0.82374
Electric conductivity/Turbidity	0.511273	0.05530
TDS/Turbidity	0.589632	0.16959
Electric conductivity/pH	0.316727	0.82572
TDS/pH	0.316727	0.68812

measurement. This trend shows the effect of leachate intrusion to be more prominent in pre-monsoon season. As mentioned earlier, the groundwater recharge of the Lahore district is contributed by two main sources; one is the River Ravi and the other is rainfall. The measurement of pH in the pre-monsoon season is more influenced by base flow which carries the effects of the leachate to the groundwater down slope. In the monsoon season groundwater gets the dominant share of its recharge from rainwater that seeps down. In this way, quality of the groundwater is more influenced by the local circumstances. High value of pH in post-monsoon analysis indicates that the decreased value of pH in the pre-monsoon could possibly be due to the leachate, which is diluted in post-monsoon, affecting the increase in pH because of the local influence.

A similar trend is observed in the measurements of turbidity which shows an average decrease from 1.73 to 0.15 NTU. Landfill leachate tends to increase electrical conductivity (Kareem et al., 2010), therefore its value must be higher in the pre-monsoon as compared to the post-monsoon. The measurements (Table 3) agree with the hypothesis, though the effect has not been found as prominent as it was in the cases of pH and turbidity parameters. According to the cited literature, wherever hydrocarbon degradation takes place, it tends to increase total dissolved solids (TDS) (Atekwana et al., 2004). Kareem et al. (2010) has measured high concentration of TDS in the leachate for the same study area. With reference to his study, pre-monsoon measurement of TDS should be higher than the post-monsoon measurements as in this season effect of leachate is diluted considerably as found for other quality parameters, whereas, behavior of TDS is found somewhat variant from the expected, as it has shown an increasing trend from 347.62 to 348.54 ppm.

This anomaly may also be the result of the local geochemical heterogeneity which is more prominent in the post-monsoon season. However, another interesting behavior has been identified in the relation between electrical conductivity and the amount of TDS. Noways's electric conductivity is used as a proxy for the measurement of TDS in the water (Post, 2012), based on the assumption that almost all TDS constituent participate in increasing conductivity of the groundwater (Atekwana et al., 2004). In fact, the groundwater contains both the charged and the uncharged species in proportions that may vary depending upon geochemical heterogeneity. For example, dissolved silica (H_4SiO_4) and organic substances do not contribute to increase electric conductivity (Post, 2012). Any increase in uncharged substances disturbs the correlation between the two quantities. Therefore, electric conductivity cannot be directly used for the measurement of TDS, but it only gives a good approximation of the TDS through the relation given by Lloyd and Heathcote (1985):

$$TDS = K_c \times EC$$

Where EC is electrical conductivity and K_c is correlation factor that may vary depending upon proportion of charged and uncharged constituents (Atekwana et al., 2004).

Decrease in the correlation between electrical conductivity and TDS in the post-monsoon season as shown in Table 4, indicates that base flow contribution to the TDS are dominated by charged species for the contributing leachate (Kareem et al., 2010). Whereas decrease in correlation factor and increased TDS in the post-monsoon season reflect that contribution of local influences to TDS is dominated by uncharged species. The charged species may include inorganic substances which may also contain metals for groundwater pollution (Rivett et al., 2011). Changes in the correlation may also be used as an indicator of raising the metal contents in groundwater due to intrusion of the leachate which is one of the serious issues of groundwater contamination (Jensen et al., 1998; Baumann et al., 2006; Malana and Khosa, 2011).

Increase in the effects of leachate to groundwater has also been assessed in terms of correlation of the measured parameters with distance of sampling depths from dumping sites as shown in Table 5.

With reference to Table 5 almost all the parameters had shown increase in the leachate influence over the time except turbidity. The smallest rise is found in the correlation of TDS with the distance, it may be the result of TDS contribution by factors other than the leachate, which already had been explained. Looking at the influential trends over pH and electric conductivity, the effect is almost doubled in the time gap of sampling. Here, it is very important to keep in mind that the samples

Table 5. Changes in influence of leachate over water quality.

S/N	Quality parameter	2010	2012
1	pH	0.25382	0.41689
2	Turbidity	0.20550	0.02893
3	Conductivity	0.39163	0.63782
4	TDS	0.37129	0.38575

Table 6. Additional water quality parameters.

S/N	Location	T.H	Ca	Mg	Cl	HCO_3
1	Madho Lal Hussain	140	35.2	12.4	18	156
2	Dy. Yaqoob Colony	140	35.2	22.4	19	144
3	Aliya Town	176	40	18.2	16	154
4	Gulshan -e-Shalimar	102	19.2	12.9	70	100
5	Angoori Bagh SchemeNo.1	250	48.8	30.7	42	246
6	Gosha-e-Angoori	120	24	14.4	27	172
7	Kotli Pir, Abdul Rehman	140	26.4	17.7	30	188
8	Naseer Abad, Pakistan Mint	120	24.8	15.3	21	166
9	Mahmood Booti Well Center 3	136	28.8	15.3	14	122
10	Rafi Abad Darbar	140	27.2	17.2	10	92
11	Islam Pura	124	24.8	14.8	18	130
Averages		144.36	30.4	17.39	25.91	151.82
Correlation with distance		0.1811	0.10047	0.2589	0.16906	0.72278

in 2012 had been taken after monsoon that had diluted the effects of base flow but the results are still alarming. Other parameters like total hardness (TH), Calcium (Ca), Magnesium (Mg), Chlorine (Cl), and Bicarbonates (HCO_3) can also be used for groundwater quality measurement (Malana and Khosa, 2011) and their source may also be associated with dumping of MSW (Xing et al., 2013). These parameters had also been analyzed in the first dataset taken from WASA, Lahore and are given in Table 6.

Regarding these additional water quality parameters two observations are important to note. The first one is the tube well installed at Angoori Bagh Scheme No. 1 with comparatively high values of all quality parameters. At the second place, the correlation of bicarbonates (HCO_3) with distance from dumping site is high, which shows contribution of leachate to this quality parameter.

CONCLUSION AND RECOMMENDATION

The Inverse Watershed technique had been found fruitful for the identification of contamination plume under Municipal Waste Dumping sites as the results agree with the reviewed literature. Flow of groundwater under both sites is found towards the residential part of the city, which proves unsuitability of locations of the dumping sites. The groundwater in the down slope region around Mahmood Booti has nine tube wells that are being used for the provision of drinking water to residents. Similarly, the leachate plume detected around Saggian dump contains two tube wells of the same kind.

Hazardous effects of landfill leachate to groundwater has been identified which are more prominent in the pre monsoon season and diluted by the intrusion of rainfall water to it in the post monsoon season. The variation in the correlation factor between electrical conductivity and TDS may possibly be due to the intrusion of metals to the groundwater by the leachate. The quality parameters are well within the range of the drinking water standards for these deep tube wells but the increasing influence of leachate in the down slope regions may turn out to be a big issue in the near future.

Therefore, in future, drinking water supply tube wells should be installed at opposite sides of the groundwater down slope directions for the landfills. As the shallow water is more prone to these risks, so shallow bores in the area for drinking water need to be banned.

ACKNOWLEDGEMENTS

We would like to acknowledge and extend our heartfelt gratitude to Mr. Arif Butt, Director Hydrology, WASA, Lahore for providing data. We also acknowledge Nano Science and Catalysis Division, National Centre for Physics, Quaid-i-Azam University Islamabad, Pakistan and College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan, for providing us technical and analytical facilities.

REFERENCES

Atekwana EA, Rowe RS, Warkema DD, Legall FD (2004). The Realtionship of total dissolved solid measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbons. J. Appl. Geophys. 56:281-294.

Basharat M, Rizvi SA (2011). Groundwater extraction and waste water disposal regulations – Is Lahore aquifer at stake with as usual approach. Pakistan Engineering congress, World Water Day. pp. 112-134.

Batool SA, Chohdary MN, (2009). Municipal solid waste management in Lahore City District, Pakistan. Waste manage. 29:1971-1981.

Baumann T, Frushtorfer P, Klein T, Niessner R (2006). Colloid and heavy metal transport at landfill sites in direct contact with groundwater. Water Res. 40:2776-2786.

Biswas AK, Kumar S, Babu SS, Bhattaacharyya JK, Chakrabarti T (2010). Studies of Environmental Quality in and around municipal solid waste dumpsite. Resour. Conserv. Recycling. pp. 129-134.

Butt TE, Lockley E, Oduyemi KOK (2008). Risk assessment of landfill disposal sites- State of the art. Waste Manage. 28:952-964.

Butt TE, Oduyemi KOK (2003). A holistic approach to Concentration Assessment of Hazards in the risk assessment of landfill leachate. Environ. Int. 28:597-608.

Cherry J (1990). Groundwater Monitoring: Some Deficiencies and Opportunities. Hazardous Waste Site Investigationns; Towards Better decision, Proceedings of 10th ORNL Life sciences symposium Gatlinberg, TN, May 1990, Lewis publishers.

Cherry J (1991). Waterloo Center for Ground Water research. University of Waterloo, Ontario, Canada, Personal Communication.

Chian SK, DeWalle FB (1976). Sanitary landfill leachate and their treatment. J. Environ. Eng. 102:411-431.

Demitriou E, Karaozas I, Saratakos K, Zacharias I, Bogdanos K, Diapoulis A (2008). Groundwater risk assessment at a heavily industrialized catchment and the associated impacts on a peri-urban wetland. J. Environ. Manage. 988:526-538.

Din MAM, Jaafar WZW, Obot RMM, Hussain WMAW (2008). How GIS can be a Useful Tool to Deal with Landfill Site Selection. International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Scinces.

ESA (2001). Water in a Changing World. Ecological Society of America. J. Issues Ecol. Vol. 9.

Feta D, Pabadopoulos A, Loizidou M (1996). A study on the landfill leachate and its impact on the ground water quality of the greater area. Environ. Geochem. Health. 21:175-190.

Gabriel HF, Khan S (2006). Policy Options for Sustainable Urban Water Cycle Management in Lahore, Pakistan. Proceedings of ERSEC Water Workshop 2006 Beijing, China. pp. 180-202.

Gabriel HF, Khan S (2010). Climate Responsive Urban Groundwater Management Options in a Stressed Aquifer System. IAHS Publications, 338:166-168. ISSN 0144-7815.

Gorsevski PV, Donevska KR, Mitrovski CD, Frizado JP (2012). Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered weighted average. Waste Manage. 32:287-296.

Jensen DL, Ledin A, Christensen TH (1998). Specification of heavy metals in landfill leachate polluted groundwater. Water Resour. 33(11):2642-2650.

Kareem S, Chaudhry MN, Ahmad K, Batool SA (2010). Impact of Solid Waste Leachate on Groundwater and Surface water. General Chem. Soc. Pak. 32(5):606-612.

Lashari B, McKay J, Villholth K (2007). Institutional and Legal Groundwater Management Framework: Lessons Learnt from South Australia for Pakistan. Int. J. Environ. Dev. 4(1):45-59.

Lee GF, Lee AJ (1993). Groundwater Quality Monitoring at lined landfills: Adequacy of Subtitle D Approaches. Report of G. Fred Lee & Associates, El Macero, CA.

Li Y, Li J, Chen S, Diao W (2012). Establishing indices for groundwater contamination risk assessment in the vicinity of hazardous waste landfills in China. Environ. Pollut. 165:77-90.

Limouzin M, Maidment D (2009). Water Scarcity is an Indicator of Poverty in the World. A term project of University of Taxas at Austin.

Lloyd JW, Heathcote JA (1985). Natural in organic Hydro-Chemistry in realtion to groundwater. Clarendon Press, Oxford, England.

López JAR, Hernández JR, Mancilla OL, Diazconti CC, Garrido ML (2008). Assessment of groundwater contamination by landfill leachate: A case in México. Waste Manage. 28:33-39.

Mahini SA, Gholamafard M (2006). Siting MSW Landfills with a Weighted Linear combination Methodology in a GIS Environment. Int. J. Environ. Sci. Technol. 3(4):435-445.

Mahmood K, Rana AD, Tariq S, Kanwal S, Ali R, ALI AH, Tahseen T (2013). Groundwater Levels susceptibility to degradation in Lahore Metropolitan. Sci. Int. 25:123-126.

Malana MA, Khosa MA (2011). Groundwater Pollution with special focus on arsenic, Dera Ghazi Khan-Pakistan. J. Saudi Chem. Soc. 15:39-47.

Nyenje PM, Foppen JW, Muwanga R, Uhlenbrook S (2013). Nutrient Pollution in shallow aquifers underlying pit latrines and domestic solid waste dumps in urban slums. J. Environ. Manage. 122:15-24.

PCRWR (2007). Water quality Monitoring Report (2005-6). ISBN 978-696-8469-18-4, Pakistan Council of Research in Water Resources (PCRWR), www.pcrwr.gov.pk.

Post VEA (2012). Electrical Conductivity as proxy for ground water density in coastal aquifers. Ground Water. 50(5):785-792.

Rivett MO, Ellis PA, Mackay R (2011). Urban groundwater baseflow influence upon inorganic river-water quality: The river tame headwaters catchment in the city of Birmingham, UK. J. Hydrol. 400:206-222.

Santos FAM, Mateus A, Figueiras J, Gonçalves MA (2006). Mapping groundwater contamination around a landfill facility using the VLF-EM method — A case study. J. Appl. Geophys. 60:115-125.

Singh RK, Datta M, Nema AK (2009). A new system for groundwater contamination hazard rating of landfills. J. Environ. Manage. 91:344-357.

World Bank (2006). Pakistan Strategic Country Environment Assessment. Main Report (Volume 1), 36946-PK.

Xing W, Lu W, Zhao Y, Zhang X, Deng W, Christensen TH (2013). Environmental impact assessment of leachate recirculation in landfill of municipal solid waste by comparing with evaporation and discharge (EASEWASTE). Waste Manage. 33:382-389.

Zhang H, Zhang DQ, Jin TF, He PJ, Shao ZH, Shao LM (2011). Environmental and economic Assessment of combined biostabilization and landfill for municipal solid waste. J. Environ. Manage. 92:2533-2538.