Short Communication

Evaluating Municipal Solid Waste Dumps Using Geographic Information System

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Abstract

This study evaluates two existing dumpsites, namely Saggian and Mahmood Booti, regarding their inappropriate locations and related hazards. Four parameters were considered for the assessment: 1) threat to residential areas, 2) surface water bodies, 3) road network and related data, and 4) fluvial sediment sequence to groundwater depth. Geographic information system (GIS) has been used to conduct the study. Both dumping sites are unsafe for the neighboring community as 6,731 and 9,490 houses were found to lie within the hazardous region (1000 m) around Saggian and Mahmood Booti sites, respectively. Among them, 6.4% houses around Saggian dump are within 210 m of the site, while around Mahmood Booti dump the residential area starts after 210 m. It was calculated that 249.5 m^3/day and 519 m^3/day leachate is being produced by Saggian and Mahmood Booti, respectively. Saggian dumpsite is found to be more dangerous with higher co-efficient of permeability (11.37×10^{-5} m/s), high water table (18.2 m below surface), and its location along the bank of the Ravi River. However, a higher number of accidents is found near Mahmood Booti, which may be an effect of the obnoxious smell from the dumped waste.

Keywords: municipal solid waste, dumping, co-efficient of permeability, leachate, geographic information system

Introduction

The disposal of waste in a landfill is the most used and cheapest of all waste management techniques [1, 2]. The selection of a dumping site/landfill requires compliance with government regulations, and should meet economic, environmental, and social criteria [3]; otherwise it can result in serious health problems to neighboring communities, [4] have considered geology, water supply resources, land use, sensitive sites, air quality, and ground water quality as important aspects to minimize environmental damage that may be caused by these sites. Evaluation criteria such as water permeability, depth to the water table, distance from rivers, distance from roads, distance from residential areas, slope, and wind orientation were considered by Mahini and Gholamafard [5]. However, factors used may vary based on local circumstances [6], demographic constraint of the research area [7], and availability of the data [3]. After selecting suitable locations, these are properly engineered by providing a barrier to leachate percolation and a closure cover, due to which they get the name "landfill".

Developing countries are facing an even worst scenario of open dumping of waste in sites constructed without proper planning, deficient standards, and

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inadequate specifications are therefore a serious threat to human health and the environment [8, 9]. The dumping sites are exposed to natural phenomena like rain and microbial activities, leading to biological, physical, and chemical transformation of waste [10]. This exposure and transformation may pollute the environment through the atmosphere (odor and spread of diseases), the lithosphere (soil degradation), and the hydrosphere (contamination of ground as well as surface water) [9-12].

To achieve maximum protection of the environment against the hazards associated with open dumping, all potential hazards are needed to be identified and assessed properly [8, 13]. In many countries appropriate control measures are being taken at such dumps due to growing concerns about health and degradation of groundwater quality [12]. In this regard risk assessment of the existing dumping site is a starting step towards remedial measures of related hazards all over the world [13].

In Lahore the generated MSW is dumped directly on the land at many unplanned locations scattered around the city [14]. This research intends to assess existing dumping sites in Lahore for the basic requirements that a dumping site must satisfy to avoid any negative impacts on the environment. GIS had been used in the study for different analysis as it provides an easy approach to evaluate the outcomes of various management alternatives [15, 16]. The basic criteria used for the study is the same as those used by a number of studies for post assessment /optimization of landfills, but here the same parameters were used for the post-assessment.

Material and Method

Description of Study Area

Lahore lies between longitudes 74.012°E to 74.641°E and between latitudes 31.24°N to 31.751°N with an elevation range of 143 to 159 m above MSL. With an area of 1,772 square kilometers [15]; Lahore is the second largest city in Pakistan and provincial capital of the province of Punjab [17]. Lahore with a population of approximately 10 million is bounded by the Ravi river in the north and west, in the east by the Indian district of Amritsar, and in the south by the Kasur district. The climate in Lahore is hot and semi-arid with an average rainfall of 680 mm per year. In the last 10 years, average of the maximum temperature found in summer (May to September) is 40.5ºC and average of the minimum temperature found in winter (November to March) is 7ºC (Meteorological Department, Lahore).

Areas under the jurisdiction of Lahore produce about 5,000 tons/day of solid waste, about 60% of which is collected and disposed of in the so-called landfill sites [14]. Two dumping sites, shown in Fig. 1, were considered for this study:

1. Saggian dumping site lies between longitudes 74.266°E to 74.272°E and between latitudes 31.565°N to 31.573°N, located on the northwestern edge of the city within the flood plain of the Ravi, where dumping of waste was started in 1995.
2. Mahmood Booti dumping site lies between longitudes 74.380°E to 74.391°E and between latitudes 31.608°N to 31.612°N, and is located in the northern part of the city and in use for dumping of solid waste since 1997.

Methodology

A flow chart of the methodology for the study is shown in Fig. 2. For mapping existing landfill sites most recent high resolution imagery of Google Earth was used as it is a free source for digitization. Keeping in view the accuracy provided by Google Earth, both the sites were visited for correction of their marked boundaries. Ground coordinates of different corners were corrected using GPS with an accuracy of 3 m. These kml,s extracted from Google Earth are converted to shape files, followed by their projection to a projected coordinate system for area and perimeter measurements in the used software. ArcGIS 9.3 was used for data analysis, which provides Visual Basic Programs (VB-codes) for calculating area and perimeter of a polygon feature. These programs were used to calculate the required quantities.

For evaluating dumping sites regarding their impacts on residents, the residential area was also digitized over Google Earth, followed by all the steps discused earlier. A buffer of 1000 m around each dump site was generated and used to get residential areas in a 1000 m radius of the dumps through overlay analysis. A grid-based visual

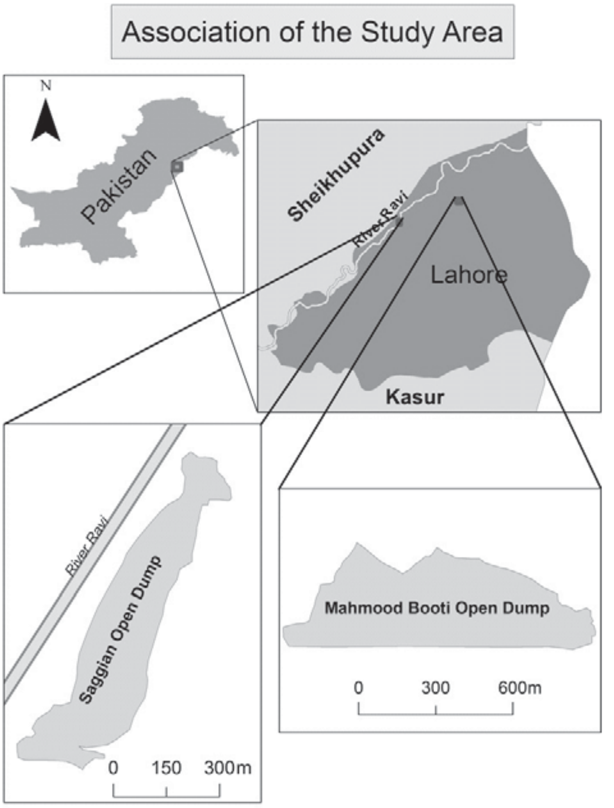

Fig. 1. Location Map of the Study Area.

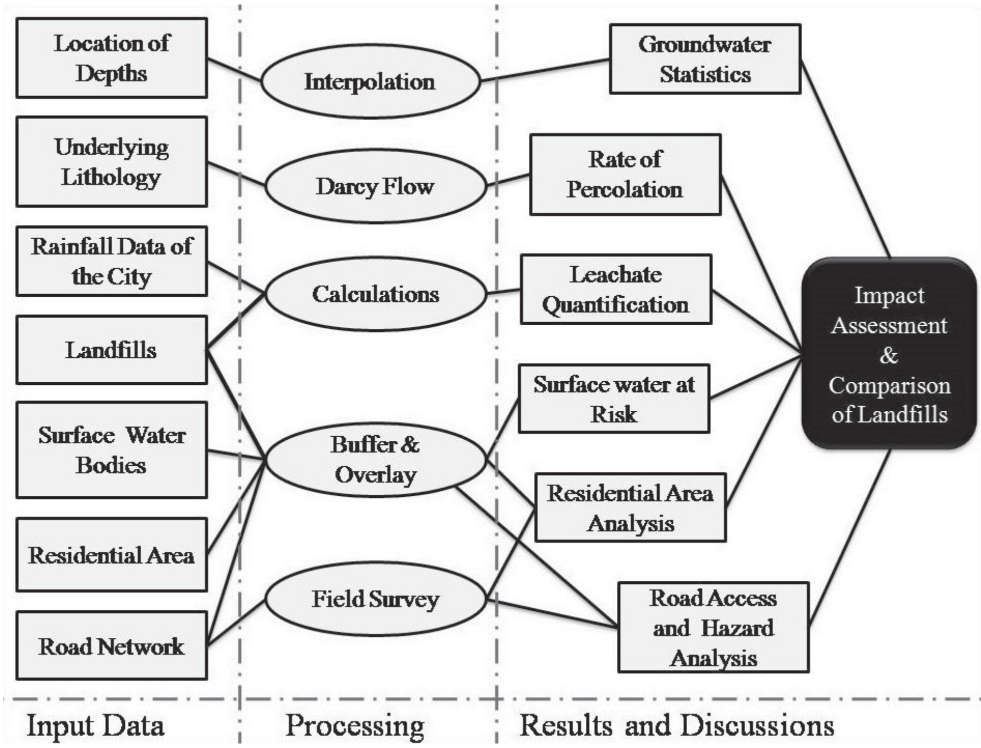

Fig. 2. Flow chart of the methodology.

analysis was performed for the house count in critical parts of the residential area. On the basis of observed house density the selected area around each of the sites was re-digitized into two categories: densely populated and sparsely populated. Two sampled boxes of 5×5 arc-seconds, over the satellite image, from each of the re-digitized categories were chosen for the house count. Grid box area (20,556 sq.m) divided by the house count in it gives an average area corresponding to one house in the box. Sampled grid boxes were averaged out with other boxes of the same category. After calculating average of the area corresponding to one house, total area covered by each of the categories had been calculated. Now the total area of densely populated house category, divided by average area for one house, gives total number of houses in this category. Similarly, the number of houses for the other category was calculated and added up with the first one to have total number of houses within the hazardous zone of each of the dumping sites. In order to verify total number of houses, a field survey based on interviews of a number of property dealers in the sampled grid cells was carried out. Population living in these houses had also been estimated using a census report stating that on average there are 7.1 persons per house in the city [18].

The minimum distance of residential area from dumping sites was measured using multi-buffer visual analysis. By the use of multiple-buffer tool, visually overlapped boundary of the residential area with the buffer ring was found. If the boundary of a residential area falls within the first ring (10 m) of the buffer the minimum distance considered was 10 m, and if it fell within the second ring (50 m) of the buffer the measured distance considered was 50 m and so on.

The reviewed literature shows that dumping sites must be at a minimum threshold distance from surface water bodies like lakes, rivers etc. This distance as found in literature must be 200 m [5]. The only surface water body around the study area is the Ravi. After mapping of the river, buffer and overlay analyses were used sequentially to mark those portions of the river that fall within the restricted zone of 200 m.

Dumping sites were also evaluated for the road network in their neighboring vicinity. This parameter was analyzed from two different perspectives. One of them was based on the facility that provides access to the site so that waste could easily be transported. The second perspective was based on the hazards of landfill to the road users, e.g. odor, accidents, etc. For this purpose major and frequently used roads of Lahore passing close to the dumping sites were mapped. Buffering and overlay analysis was used in the same way as for the residential area and surface water bodies to identify all the road segments that fall within 100 m of any of the sites. The data about number and types of vehicles traveling through the identified road segments was taken from the Transport Planning Unit, Transport Department, and government of Punjab, Pakistan, and road accident count was taken from the Punjab Emergency Service, Lahore Division.

For assessing risk of groundwater contamination by leachate, fluvial sediment cross-sections under both the sites were taken from the Water and Sanitation Agency (WASA), Lahore. The used models for soil classification were ASTMD-2487 and ASTMD-2488; whereas ASTMD-422 (Sieve analysis + Hydrometery) was used for soil texture analysis. The measured point

Table 1. Measured hazardous parameters for dumpsite comparison.

Dumping Site	Risk to residential areas (a)			
	Distance from residential area (m)	Risk-prone residential area (Sq. m)	Risk-pone houses	Risk-prone population
Saggian	10	1279473	6731	47790
Mahmood Booti	210	1662011	9490	67379
	Groundwater statistics beneath the sites (b)			
	Average depth (m)	Maximum depth (m)	Minimum depth (m)	Variation in depth (m)
Saggian	18.29	20.12	16.46	3.66
Mahmood Booti	26.21	31.7	21.03	10.67
	Leachate generation and its access to groundwater (c)			
	Water table depth (m)	Co-efficient of permeability (m/s)	Time to reach water table (days)	Amount of leachate (m^3/ day)
Saggian	18.2	11.37×10^{-5}	1.85	249.5
Mahmood Booti	26.2	4.26×10^{-5}	7.12	519

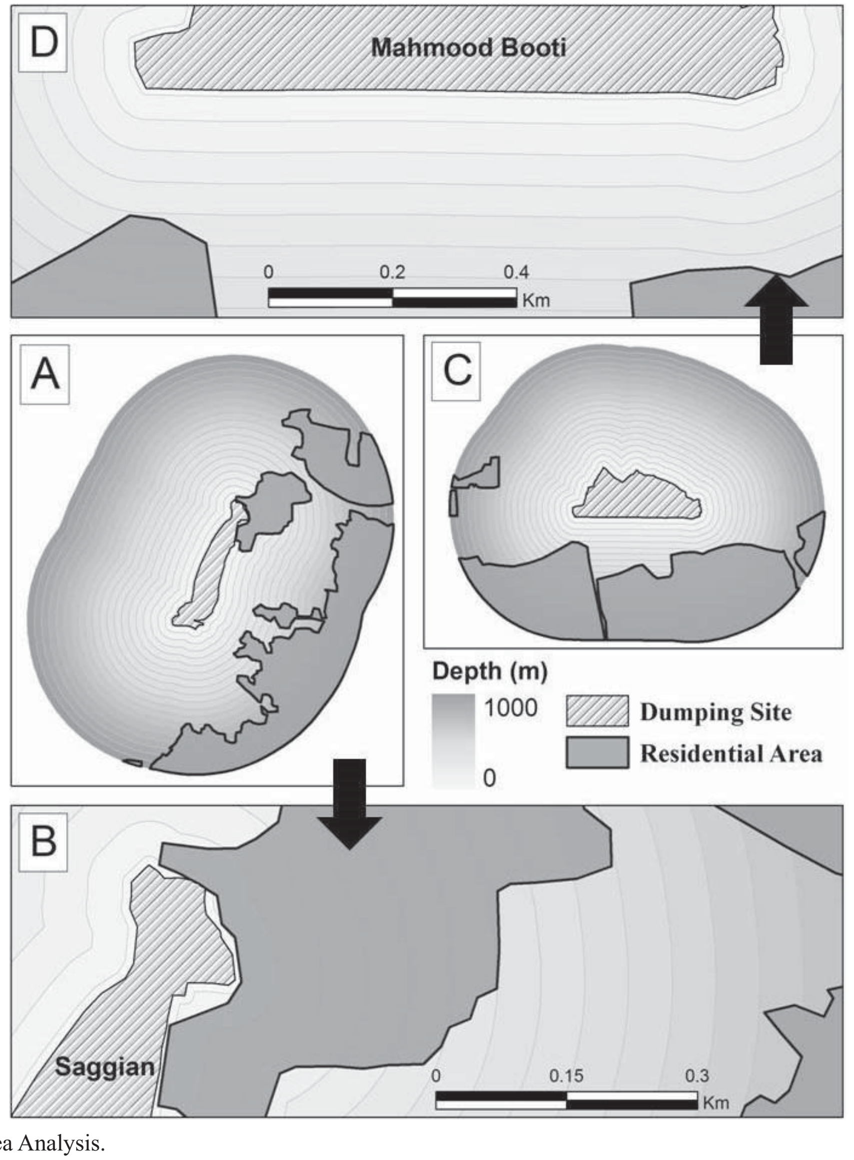

Fig. 3. Residential Area Analysis.

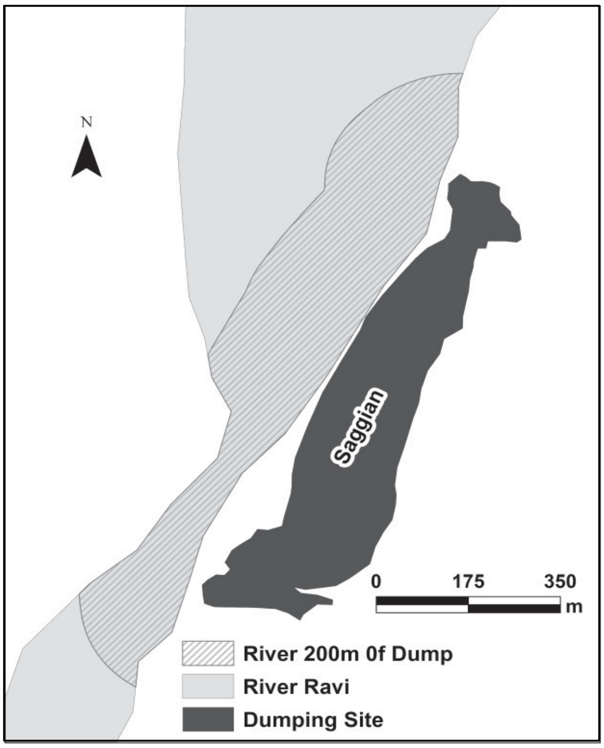

Fig. 4. Surface water under threat by Saggian dumping.

data for groundwater depth also had been taken from WASA, Lahore, and then location of these points was spotted using GPS. All the sampled points that lie within 1,500 m of the dump sites were chosen to estimate the water table depth under each of the landfills. Seven of the sampled points around Mahmood Booti and three around Saggian dumping sites were found in this way. These point measurements of groundwater depth were interpolated to get depth surfaces under the sites using simple kriging interpolation as suggested by Mahmood et al. for the study area [19]. Later on the 'zonal statistics' tool of the Spatial Analyst toolbox was used to find statistics of water table depth under each of the dumping sites. These data sets obtained from WASA, Lahore, were then ultimately used to calculate time taken by leachate to reach the groundwater using Darcy law for each of the sites. Thickness time permeability of the materials was added to calculate coefficient of permeability. Amount of leachate generated by each of the landfills was measured

Table 2. Types of vehicle and their frequency over the ring road at Mahmood Booti.

Vehicle Type	Number per day
Private Vehicles	21,437
Public Vehicles	9,136
Goods Vehicle / non-motorized	5,723
Rikshaw / Qingqi	2,324
Total	38,620

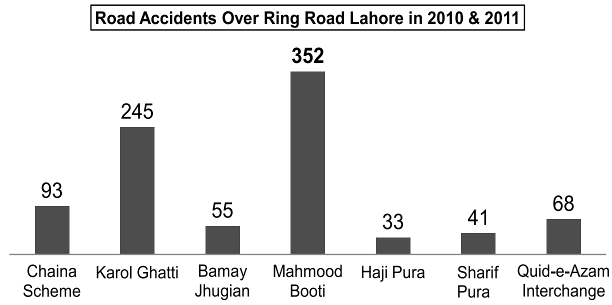

Fig. 5. Comparison of road accidents at and around Mahmood Booti.

by calculating volume (area × height) and weight of the waste in the landfill and annual rainfall. Rainfall data was taken from the Meteorological Department, Lahore.

Results and Discussion

It was estimated that currently 1,248,296 and 7,417,467 tons of waste has been dumped in Saggian and Mahmood Booti, respectively. The amount of waste has been estimated by considering the area of landfill sites, height of piles of waste, and density of waste. The major portion of the composition of waste is organic (67%) and the re-cycleables include paper (5.04%), glass (2.19%), Fe (0.02%), non Fe (0.47%), film plastic (12.94%), rigid plastic (5.55%), textile (1%), and others (5.77%) [14]. Both the dumpsites pose a serious threat to nearby communities and for the whole city as well. The results of assessment are given below.

Residential Area

As per literature reviewed there must no population living within 1000 m of a landfill site. Sites considered for this study have large residential areas in their immediate vicinity, as shown in Table 1(a). Refer to Fig. 3(b), a distance of just 10 m between residential areas and Saggian

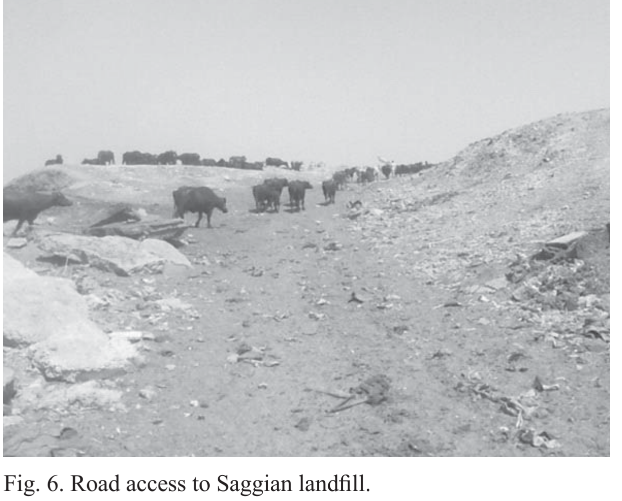

Fig. 6. Road access to Saggian landfill.

dump site shows the severity of danger to the residents and livestock, which is one of the main sources of income for their livelihood. Although the impact of Mahmood Booti is not as severe as that of Saggian, a large residential area within its hazardous zone increases the number of at risk families. Although Mahmood Booti has a large residential area within its hazardous range, Saggian has a more severe danger to residents as it contain 81,482 m^2 of residential area (corresponding to 428 houses and 3,044 humans living here), or about 6.4% of the total affected area within its immediate vicinity of 210 m, and in contrast no house was found within the same range around Mahmood Booti as shown in Fig. 3(d).

Surface Water Bodies

An area of about 18,303 m^2 of the Ravi falls within the hazardous zone (200 m) of Saggian as shown in Fig. 4. As the Ravi is one of the major sources for groundwater recharge of Lahore [19, 20], if any part of the river is being contaminated by the landfill then ultimately this contamination goes to the groundwater under the city. That's why people living in immediate the vicinity of Saggian claim unavailability of clean drinking water. It was reported that a tube well (182.88 m deep) installed in 2009 in Karim Park (i.e. about 2 km from the river) is now contaminated. This means that contamination has been spreading and is really a big threat to the community. The shallow groundwater from which people living near to these sites draw water for drinking and domestic usage is also reported to be contaminated [21].

Road Network

No highway is located in the immediate vicinity of the Saggian site but a newly constructed ring road for the city passes adjacent to the Mahmood Booti. It is a three-lane highway with a length of 1,165 m, within 100 m of Mahmood Booti. The frequency and types of vehicles over this segment of the road is given in Table 2. It is a very busy road with almost all types of vehicles. This dump site therefore has the potential to affect a large number of road users over the neighboring road segment through inhalation of bioaerosols. Any kind of disease caused by dumped waste is out of the scope of this study. However, road accident data had been used to evaluate the impact of this landfill site.

Although the same frequency of road user was found at Mahmood Booti and its surrounding segments of the ring road, the frequency of road accidents is not the same. For comparison, three segments from each side of Mahmood Booti were chosen and among all these seven locations of the same road, the highest road accident count in two years was found over the Mahmood Booti region as shown in Fig. 5. The dumped waste served as food for a number of animals, and disturbance caused by the movement of these animals in surrounding regions of the dump may result in road accidents. The obnoxious smell arising from open waste dumps may also be responsible for road accidents as it can divert a driver's attention.

The joining passage from main road to dump site must be a concrete and stable structure, such that this passage can easily be used to transport the waste to the designated

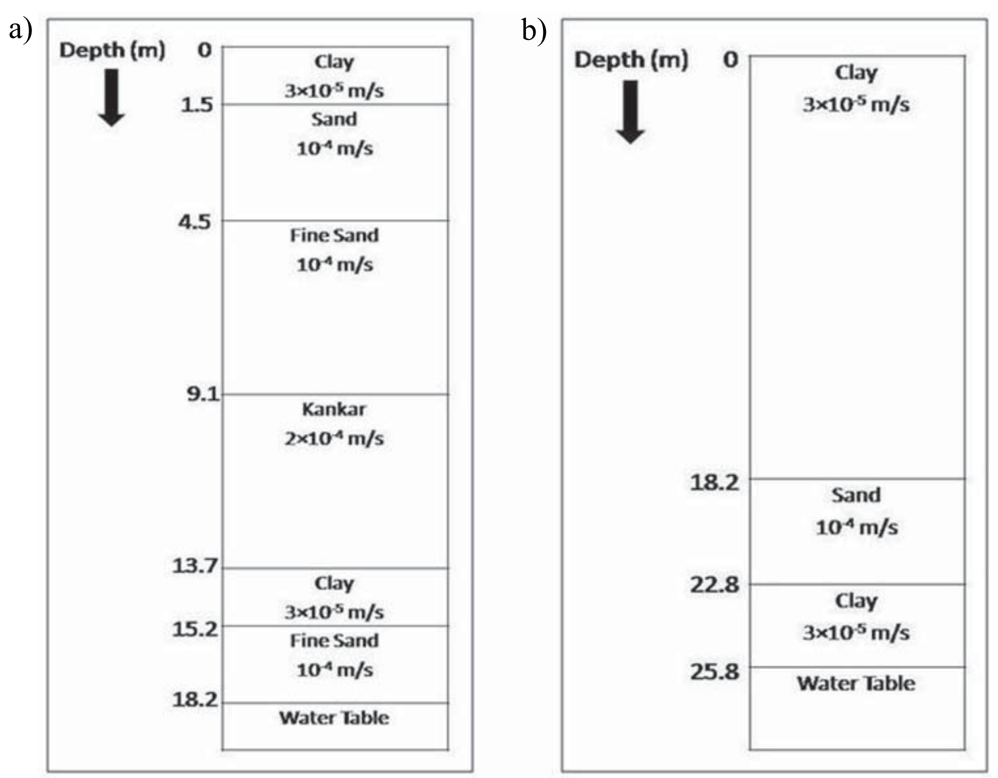

Fig. 7. Sediment Sequence of Saggian (a) and Mahmood Booti (b): source: WASA, Lahore.

sites. Otherwise, waste-carrying truck can't reach the site and dispose of their carriage close to or even within residential areas. The survey to both sites showed the absence of such access to the Saggian dump; the provided path is 1.3 km from the highway, is made up of pulverized mud, and is very hard to drive over during the rainy season (a part of it is shown in Fig. 6). As a result, the waste piles up within the residential area. As Mahmood Booti lies adjacent to the ring road, no such problem had been seen.

The depth to water table is one of the controlling factors of groundwater contamination from leachate produced in the dumped waste. In general the water table must be deep enough and sediments must have very low permeability at such places so that the leachate faces maximum resistance to reach and then pollute the underlaying aquifer.

Water Table

Ground water is 16.46 m deep under the Saggian site, which renders the water table under these regions more vulnerable to contamination risk. On the other hand, Mahmood Booti has a water table depth of 26.21 m on average, with a variation of 10.67 m between the minimum and maximum depths. This makes it comparatively better than the Saggian, but the movement of groundwater beneath both sites is to the residential part of the city, which contains a number of tube wells that are in use for drinking water [22].

Underlying Sediments

Sediment log sections of both landfills are shown in Fig. 7. Both sites have layers of clay, which is a very resistive material for leachate to percolate. Mahmood Booti has two layers of clay, one with a thickness of 18.2 m and other of 3 m, so the total thickness of the clay between surface and water table is 21.2 m. As far as Saggian is concerned, the top layer of fluvial sediments in the Ravi flood plain is composed of up to 3.5 m thick horizon of clay and silt, which is underlain by 12.2 m thick channel belt of fine to medium sands and kankar. That is why the time taken by leachate to reach the water table for Mahmood Booti is about 4 times greater than the Saggian site.

One of the suitability parameters for a dumping site is the higher value of the coefficient of permeability, and often this requirement is achieved by clay-lining [23]. Both dumping sites here are un-engineered so no artificial arrangement has been made that can provide a suitably higher coefficient of permeability. Therefore, the comparison can only be made for naturally existing lenses of the clay, which is higher for Mahmood Booti as shown in Table 1(c).

Conclusions

Both the dump sites are potentially hazardous to neighboring residents. However, the overlaping boundary of Saggian dump and its neighboring residence has greatly increased the intensity with which the dump can act as a hazard to the community. 6.4% of the total 6,731 houses in the hazardous region around Saggian were found within 210 m of the site, while around Mahmood Booti dump the residential area starts after 210 m. Existence of 1.3 km muddy road access to Saggian dump has made it unsuitable even for transportation. No such transportation problem is associated with the Mahmood Booti dump, but its location over the Ring road, with high road user frequency, may be the root cause of increased accidents found the area. A length of 1,165 m of the three-lane ring road of the city with 38,620 vehicles per day falls within 100 m of Mahmood Booti dump and had a large number of accidents as compared to their surrounding regions. Although no surface water body is found within 200 m of Mahmood Booti dump, an area of 1.83 km^2 of the Ravi is situated within hazardous reaches of Saggian dump. Groundwater is shallow under both landfills as compared to other areas of the city, making it more vulnerable to leachate contamination.

An overall comparison of both sites has shown that the Saggian dumping site is more dangerous to nearby communities, as it is very close to the residential area and is also responsible for surface as well as shallow groundwater contamination due to its nature of sediment sequence and location along the banks of the Ravi. On the other hand, the Mahmood Booti site, because of thick layers of clay, comparatively deep groundwater, and no surface water body in its immediate neighborhood, is more suitable for municipal waste dumping.

This study concludes that the Saggian dump site should be cleared of all kind of wastes in order to protect the environment and neighboring communities. The Mahmood Booti dumpsite may be used but with the immediate actions like application of cover material to dumpsite to reduce the abundance of dogs, birds, and odor to reduce accidents, which are highest in the vicinity of Mahmood Booti.

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