Journal of Rock Mechanics and Geotechnical Engineering xxx (2018) 1–15

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Impact of open dumping of municipal solid waste on soil properties in mountainous region

Anchal Sharma, Ashok Kumar Gupta*, Rajiv Ganguly

Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, 173234, India

A R T I C L E I N F O

Article history:
Received 29 August 2017
Received in revised form
7 December 2017
Accepted 14 December 2017
Available online xxx

Keywords:
Municipal solid waste (MSW)
Physical characterization
Soil pollution
Open dumping
Scanning electron microscopy (SEM)
Energy disperse X-ray spectroscopy (EDS)

A B S T R A C T

This paper presents the effect of open dumping of municipal solid waste (MSW) on soil characteristics in the mountainous region of Himachal Pradesh, India. The solid waste of dumpsite contains various complex characteristics with organic fractions of the highest proportions. As leachate percolates into the soil, it migrates contaminants into the soil and affects soil stability and strength. The study includes the geotechnical investigation of dump soil characteristics and its comparison with the natural soil samples taken from outside the proximity of dumpsites. The geochemical analysis of dumpsite soil samples was also carried out by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). Visual inspection revealed that the MSW consists of high fraction of organics, followed by paper. The soil samples were collected from five trial pits in the dumpsites at depths of 0.5 m, 1 m and 1.5 m. Then the collected soil samples were subjected to specific gravity test, grain size analysis, Atterberg's limit test, compaction test, direct shear test, California bearing ratio (CBR) test and permeability analysis. The study indicated that the dumpsite soils from four study regions show decreasing trends in the values of maximum dry density (MDD), specific gravity, cohesion and CBR, and increasing permeability as compared to the natural soil. The results show that the geotechnical properties of the soils at all four study locations have been severely hampered due to contamination induced by open dumping of waste.

1. Introduction

Rapid growth in industrialization and urbanization in India has led to increasing generation of municipal solid waste (MSW). The amount of MSW is expected to increase significantly in the future due to rapid population explosion and economical potential of cities (CPCB, 2000; Sharma and Shah, 2005; Hazra and Goel, 2009). The waste generation in India is more than 42 million tons annually and the rate of solid waste generation varies from 0.2 kg/d to 0.8 kg/d (Sharholy et al., 2008; Ogwueleka, 2009; Rana et al., 2015). It is reported from the literature study that the increase in MSW generation in India is around 5% annually (Sharholy et al., 2008; Kumar et al., 2009). It was estimated that the MSW generation is 127,486 tonnes per day (TPD) in India in 2011 (Rana et al., 2017). Out of the total waste generated in India, 89,334 TPD of MSW was collected and 15,881 TPD was recycled (TERI, 2015). At present, about 960 million tonnes of solid waste is being generated annually as by-products during municipal, industrial, mining, agricultural and other processes in India. Out of this, 350 million tonnes is organic waste from agricultural sources, 290 million tonnes is inorganic waste of industrial and mining sectors, and 4.5 million tonnes is hazardous in nature (Pappu et al., 2007). Metro cities in India generate approximately 30,000 tonnes of solid waste every day, and Class 1 cities generate about 50,000 tonnes every day (Sujatha et al., 2013).

Lack of proper management of solid waste in Indian cities is very common with the absence of appropriate data including volume of generation, collection, transportation and disposal of solid wastes generated (Shekdar, 2009). In India, the current status of MSW management is not very satisfactory. For example, a matrix method of evaluation of Tricity showed the efficiency of less than 40% for the existing system (Rana et al., 2015, 2017). The generation of MSW in Himachal Pradesh, India, was reported to be 360 TPD in 2015 (Sharma et al., 2017). For the hazardous waste in Himachal Pradesh, 84.27% is landfillable, 5.33% is incinerable, and 10.3% is recyclable (Sharma et al., 2017). The waste generated per capita in Himachal Pradesh is around 0.413 kg/d. The

* Corresponding author.
E-mail address: ashok.gupta@juit.ac.in (A.K. Gupta).

Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

https://doi.org/10.1016/j.jrmge.2017.12.009

estimated waste generation in Himachal Pradesh in the years 2011, 2021, 2031 and 2041 are reported in Table 1. The waste generation in Himachal Pradesh is significantly lower as compared to that in India (Table 2).

Generally, MSW is disposed of in low-lying areas without taking any precautions or operational controls, being the major cause of soil and groundwater pollution (Nayak et al., 2007; Amadi et al., 2012). Therefore, MSW management is one of the major environmental problems for Indian cities. When rainfall occurs, rain comes in contact with solid waste and forms leachate which finds its way to percolate into aquifers and soil strata. Leachate may contain a large amount of organic content, heavy metals and inorganic salts (Renou et al., 2008; Aziz et al., 2010; Aziz and Maulood, 2015; Mojiri et al., 2016). Unscientific disposal causes an adverse impact on all components of the environment and human health (Jha et al., 2003; Sharholy et al., 2008). The waste disposal sites and landfills that are neither properly designed nor constructed become point sources for pollution of aquifers and soils. MSW disposal is at a critical stage of development in India. There is a dire need to develop facilities for the disposal of drastically increased amount of MSW. More than 90% of the waste in India is believed to be dumped in an unsatisfactory manner. It is reported from the literature study that an area of approximately 1400 km^2 was occupied by waste dumps in 1997 and it is expected to increase substantially in the near future (Goswami and Sarma, 2008; Sharholy et al., 2008). In this context, it is suggested to construct properly engineered waste disposal facilities to improve public health and prevent environmental resources including surface water, groundwater, air and soil from being polluted (Nanda et al., 2011; Musa, 2012).

This paper presents the assessment of geotechnical properties of soils within four dumpsites and their comparison with those of the natural soil to evaluate the impact of pollution potential of open dumping on soil in the region of Himachal Pradesh, India. The geochemical analysis of the soil samples from respective study regions is done with scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) to understand the morphology and element composition of the dumpsite soils, respectively. The study also aims at encouraging authorities/researchers to work towards the improvement of the present scenario of open dumping of waste through some recommendations. Hence, the construction of landfill demands the use of soils with suitable geotechnical properties to ensure adequate engineering design and construction of a landfill.

2. Methodology

2.1. Site locations

Sundernagar town is located at the coordinates of 31.5332°N and 76.8923°E with a population of 24,344 (Census of India, 2011). The daily waste generation rate is 20 TPD and the collection efficiency of MSW is reported as 60%, which is disposed in an open land in the periphery of the town.

Mandi town is situated at 31.5892°N and 76.9182°E with a reported population of 26,422 (Census of India, 2011). The daily waste generation rate is 21 TPD, out of which 60% (12.6 TPD) is directly disposed of in open landfills.

Solan town stands at 30.9045°N and 77.0967°E, having a population of 39,256 (Census of India, 2011) and the total MSW generation of 22 TPD, out of which 13.2 TPD is directly disposed of in open landfills.

Baddi town is located at 30.9578°N and 76.7914°E, having the population of 29,911 according to Census of India (2011). The total waste generation of the town is 18 TPD, of which 11 TPD (60% collection) is disposed of in non-engineered landfills. Detailed description of dumpsites of study regions (Fig. 1) are given in Table 3.

Table 1
Estimated waste generation rate in Himachal Pradesh (HPSPCB, 2012).

No.	Year	Waste generated per capita (kg/d)	Waste generated (TPD)
1	2011	0.413	304.3
2	2021	0.478	416.6
3	2031	0.538	550.9
4	2041	0.614	709.6

Table 2
Estimated waste generation rate in projected years in India (CPCB, 2000).

No.	Year	Waste generated per capita (kg/d)	Waste generated (TPD)
1	2011	0.356	127,458.1
2	2021	0.406	17,728,107
3	2031	0.463	239,240
4	2041	0.529	313,839.7

2.2. Sampling of municipal solid waste

Sampling was performed according to the guidelines prescribed in ASTM D5231-92(2008) (2008). Dumpsites in four study regions (Solan, Sundernagar, Mandi and Baddi) were investigated. According to the method prescribed in ASTM D5231-92(2008) (2008), MSW was collected from waste transporting vehicles while unloading the waste at the dumpsites. Solid waste samples of around 1000 kg were collected from the trucks/tippers/dumpers. The material was spread on the plastic sheet and all the waste was mixed using the shovel in order to obtain the homogeneous mixture of the sample. Out of the total waste of 1000 kg, the waste samples of 100 kg were extricated randomly throughout 10 d sampling period in order to acquire representative waste samples. In the sampling procedure, the total number of samples was kept at 40 ($n = 10$ for each of the four sites). The waste samples thus obtained were segregated manually with the help of rag pickers and workers hired by the respective municipal councils of the study regions.

2.3. Collection of soil samples

Four open dumpsites were selected in the above-mentioned four regions of Himachal Pradesh. The soil samples were collected within the dumping ground and from 1 km outside the periphery of dumpsites in the selected regions. Each dumpsite consists of mix waste including municipal, institutional, residential, industrial, and commercial waste. The depth and approximate area of the dumpsites were 10–15 m and 50–150 km^2, respectively. Sample collections were carried out in the months of February and March prior to rainy season so that the measured parameters were not affected by the rainwater.

Soil samples taken from six trial pits of each dumpsite in the study regions at depths of 0.5 m, 1 m and 1.5 m were used for investigation.

Table 3
Description of the dumpsites in the study regions of Himachal Pradesh, India.

No.	Location of dumpsite	Distance from town (km)	Depth of dumpsite (m)	Area of dumpsite (acre)	Daily dumping of MSW (TPD)
1	Solan	10	13	22	22
2	Sundernagar	6	10	20	20
3	Mandi	8	15	20	21
4	Baddi	12	12	22	18

Note: 1 acre = 4046.856 m^2.

Please cite this article in press as: Sharma A, et al., Impact of open dumping of municipal solid waste on soil properties in mountainous region, Journal of Rock Mechanics and Geotechnical Engineering (2018), https://doi.org/10.1016/j.jrmge.2017.12.009