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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

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ABSTRACT

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).
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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.

Table 4
Characterization of municipal solid waste.

Dumpsite	Organic waste (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Inert (%)	Rubber (%)	Textile (%)
Solan	57.67 ± 0.52	17.17 ± 0.75	6.33 ± 0.55	3.33 ± 0.52	1.67 ± 0.52	5.67 ± 0.52	2.67 ± 0.52	5.33 ± 0.52
Mandi	56 ± 0.63	18.17 ± 0.75	6.33 ± 0.82	3.17 ± 0.55	2.17 ± 0.55	6 ± 0.52	3.17 ± 0.41	5.67 ± 0.52
Sundernagar	52.83 ± 0.98	20.83 ± 0.75	6.67 ± 0.52	3.17 ± 0.41	2.17 ± 0.75	6 ± 0.63	3.17 ± 0.75	5.17 ± 0.75
Baddi	50.83 ± 0.75	11.5 ± 0.55	13.67 ± 0.82	3.17 ± 0.41	2 ± 0.63	9 ± 0.89	1.83 ± 0.41	8 ± 0.63

Table 5
Variations in geotechnical properties of dumpsite and natural soils from Baddi town of Himachal Pradesh.

Soil	Depth (m)	Specific gravity	Coefficient of uniformity	Coefficient of curvature	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Dumpsite soil	0.5	2	6.6	1.06	23.4	19	5
	1	2.2	–	–	24.3	19.1	5.2
	1.5	2.24	–	–	24.2	19	5.7
Natural soil		2.57	6	1.5	27.5	16.7	11

Soil	Depth (m)	OMC (%)	MDD (g/cm^3)	Angle of internal friction (°)	Cohesion (kPa)	CBR (un-soaked) (%)	CBR (soaked) (%)	Permeability (cm/s)
Dumpsite soil	0.5	12	1.78	35.79	1.67	12.34	4.52	3.4×10^{-3}
	1	12	1.85	35.75	2.67	16.69	5.35	3.2×10^{-3}
	1.5	12	1.87	34.6	3	17.42	6.7	2.7×10^{-3}
Natural soil		12	2.2	34.9	6	17.5	5.9	3×10^{-4}

Table 6
Comparisons of geotechnical properties of dumpsite and natural soils from Mandi town of Himachal Pradesh.

Soil	Depth (m)	Specific gravity	Coefficient of uniformity	Coefficient of curvature	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Dumpsite soil	0.5	2	4	1	23.5	20	5.5
	1	2	–	–	24.4	21.4	6.1
	1.5	2.1	–	–	24.2	21.8	6.2
Natural soil		2.56	4	1.5	26.6	16	12.5

Soil	Depth (m)	OMC (%)	MDD (g/cm^3)	Angle of internal friction (°)	Cohesion (kPa)	CBR (un-soaked) (%)	CBR (soaked) (%)	Permeability (cm/s)
Dumpsite soil	0.5	13.5	1.78	36.12	1	16.71	5.7	3.8×10^{-3}
	1	13	1.79	35.37	2	16.78	5.8	3.1×10^{-3}
	1.5	13	1.87	34.21	3.33	17.12	6.13	2.7×10^{-3}
Natural soil		13	2.1	34.22	4.33	18.44	6.42	3.16×10^{-4}

Table 7
Comparisons of geotechnical properties of dumpsite and natural soils from Sundernagar town of Himachal Pradesh.

Soil	Depth (m)	Specific gravity	Coefficient of uniformity	Coefficient of curvature	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Dumpsite soil	0.5	2	4.61	1.07	23.4	18.8	6.8
	1	2.1	–	–	24.2	19.45	6.85
	1.5	2.1	–	–	24.25	19.9	6.9
Natural soil		2.55	4.82	1.09	26.7	14	14

Soil	Depth (m)	OMC (%)	MDD (g/cm^3)	Angle of internal friction (°)	Cohesion (kPa)	CBR (un-soaked) (%)	CBR (soaked) (%)	Permeability (cm/s)
Dumpsite soil	0.5	10.5	1.84	34.21	1.33	16.13	4.52	3.6×10^{-3}
	1	10	1.86	32.62	3.33	16.2	4.9	3×10^{-3}
	1.5	10	1.84	34.21	1.67	16.8	6.5	3.2×10^{-3}
Natural soil		13	2.1	35.7	5	17.51	7.2	4×10^{-4}

Table 8
Comparisons of geotechnical properties of dumpsite and natural soils from Solan town of Himachal Pradesh.

Soil	Depth (m)	Specific gravity	Coefficient of uniformity	Coefficient of curvature	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Dumpsite soil	0.5	1.19	4.13	1	23.4	19	5
	1	2	–	–	24.15	18.6	5.7
	1.5	2.1	–	–	24.17	19	5.7
Natural soil		2.56	4.62	1.15	26.7	16	13

Soil	Depth (m)	OMC (%)	MDD (g/cm^3)	Angle of internal friction (°)	Cohesion (kPa)	CBR (un-soaked) (%)	CBR (soaked) (%)	Permeability (cm/s)
Dumpsite soil	0.5	12	1.78	35.79	1.67	12.34	4.52	4×10^{-3}
	1	12	1.85	35.75	2.67	16.69	5.35	3.4×10^{-3}
	1.5	12	1.87	34.6	3	17.42	5.9	2×10^{-3}
Natural soil		12	2.2	34.99	6	17.88	6.2	3×10^{-4}

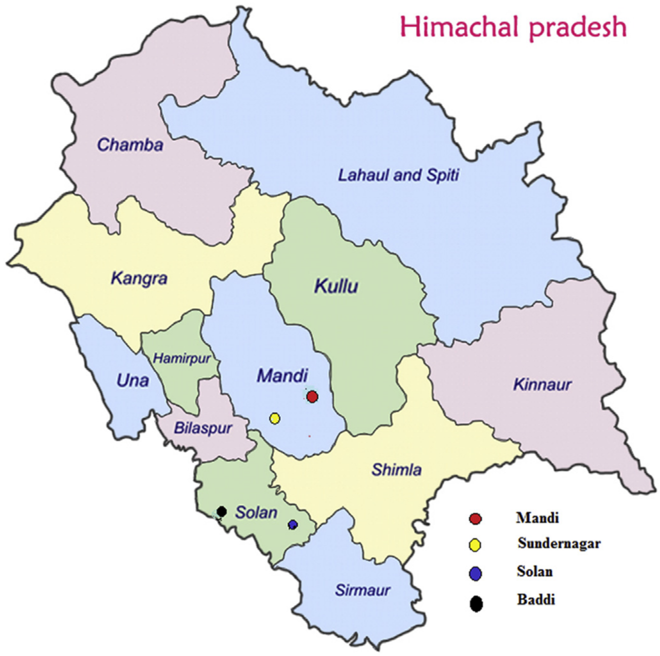


Fig. 1. Location of study areas.

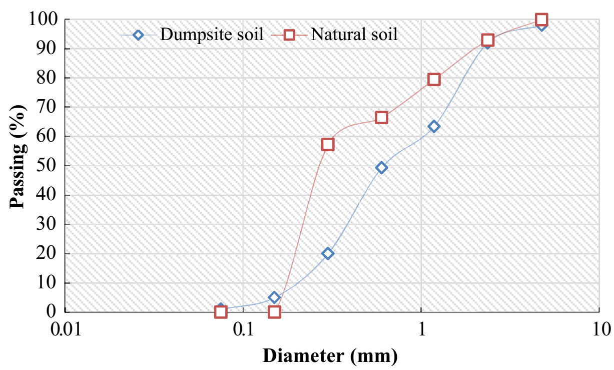


Fig. 2. Grain size analyses of dumpsite and natural soils from Baddi.

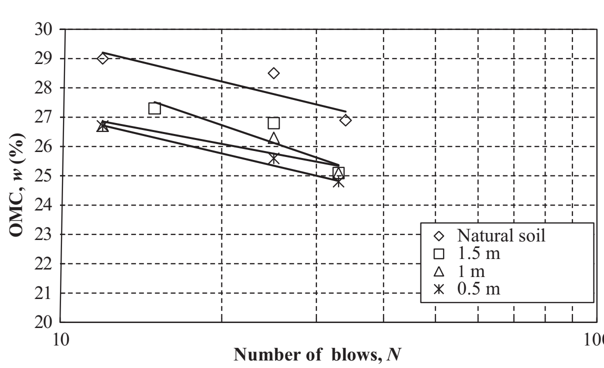


Fig. 3. Variations in optimum moisture content (OMC) with number of blows of dumpsite and natural soils from Baddi.

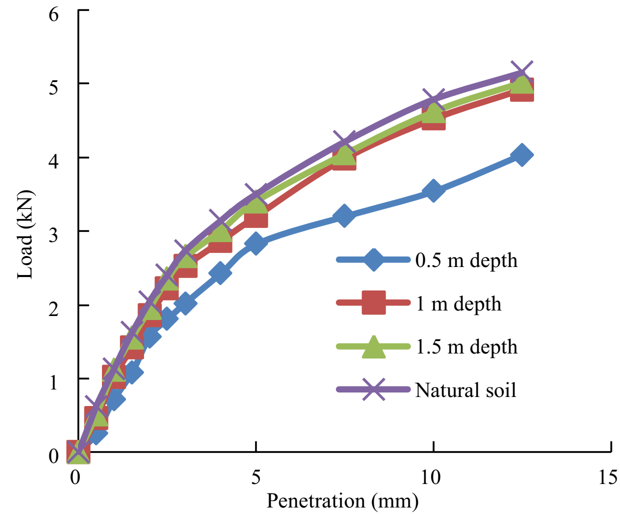


Fig. 4. Load vs. penetration curves (un-soaked) of dumpsite and natural soils from Baddi.

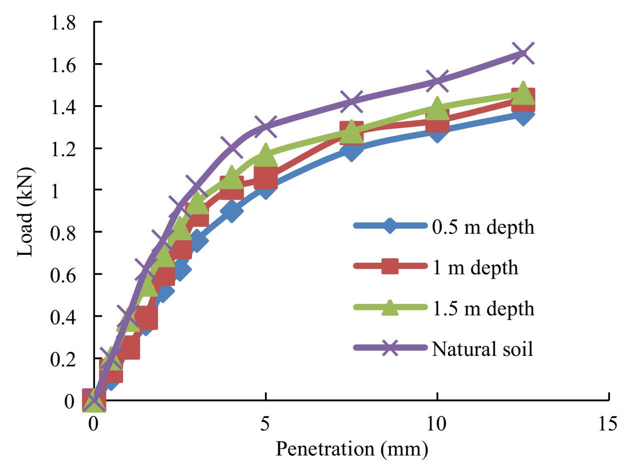


Fig. 5. Load vs. penetration curves (soaked) of dumpsite and natural soils from Baddi.

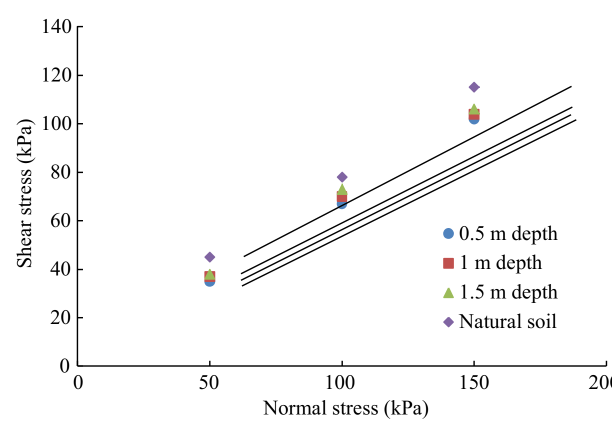


Fig. 6. Shear stress vs. normal stress curves of dumpsite and natural soils from Baddi.

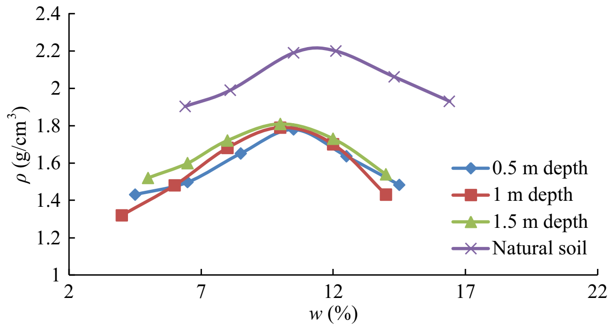


Fig. 7. Variations in maximum dry density with the optimum moisture content of dumpsite and natural soils from Baddi.

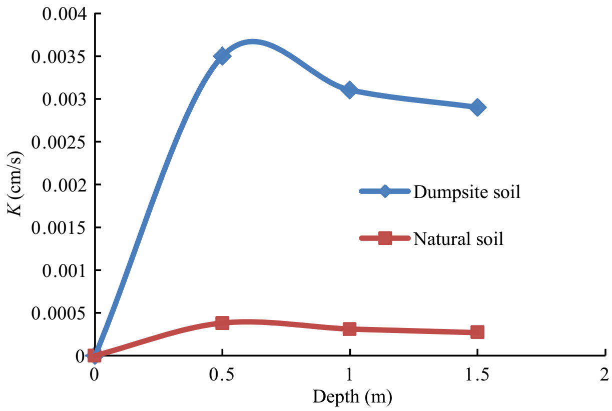


Fig. 8. Variations in permeability of natural and dumpsite soils from Baddi with depth.

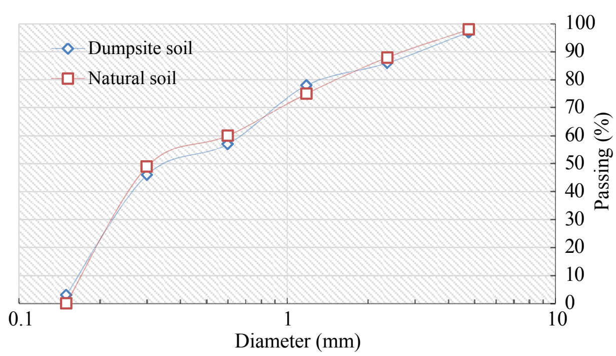


Fig. 9. Grain size analyses of dumpsite and natural soils from Mandi.

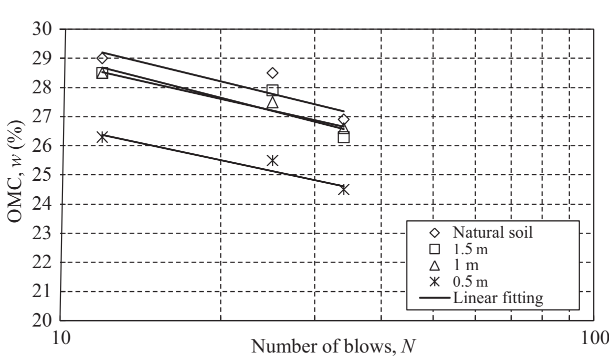


Fig. 10. Variations in optimum moisture content (OMC) with number of blows of dumpsite and natural soils from Mandi.

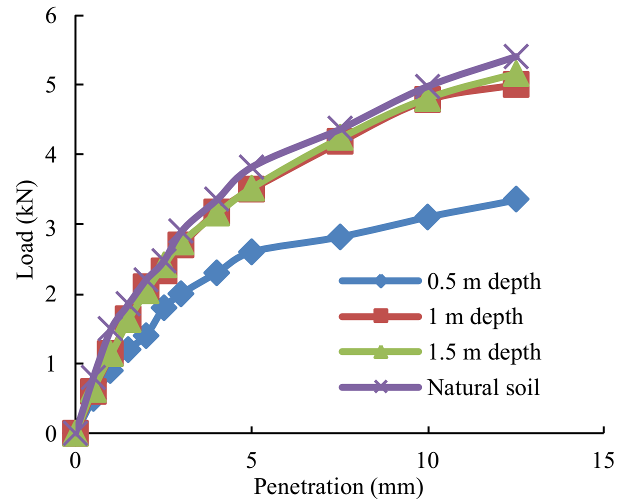


Fig. 11. Load vs. penetration curves (un-soaked) of dumpsite and natural soils from Mandi.

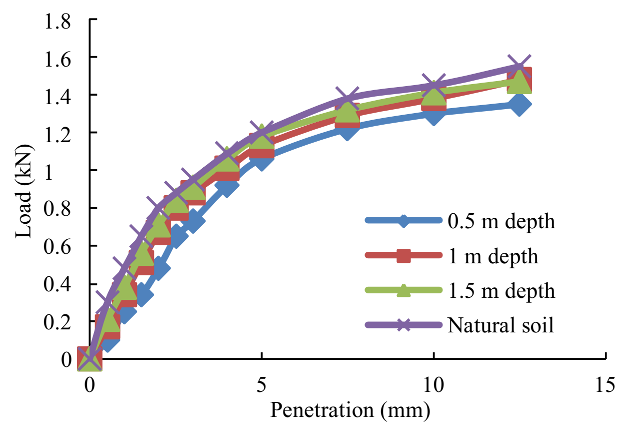


Fig. 12. Load vs. penetration curves (soaked) of dumpsite and natural soils from Mandi.

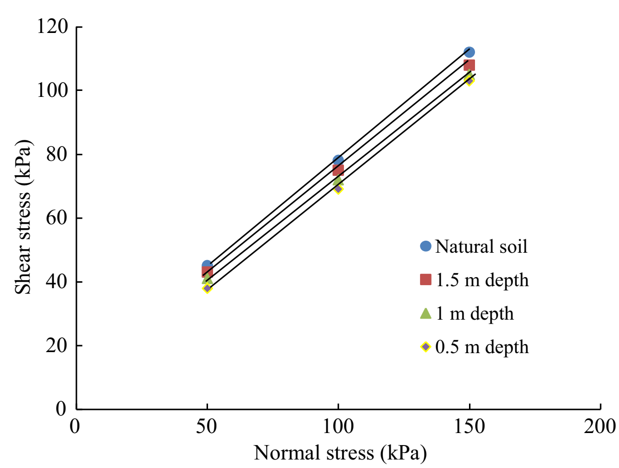


Fig. 13. Shear stress vs. normal stress curves of dumpsite and natural soils from Mandi.

Three of the soil samples were collected at the centre and corners of the dumpsites in low-lying areas and one sample from the surrounding area within 1 km outside the periphery of dump area.

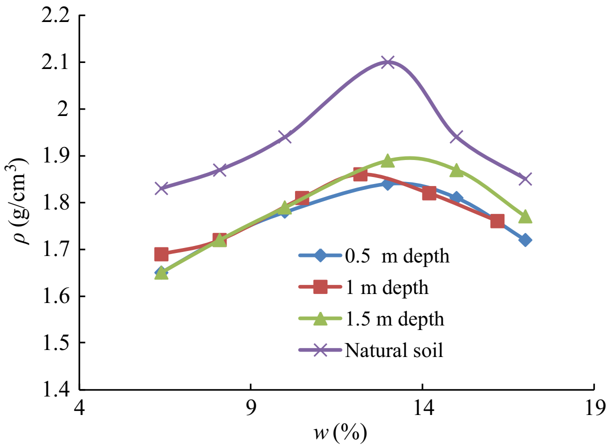


Fig. 14. Variations in maximum dry density with the optimum moisture content of dumpsite and natural soils from Mandi.

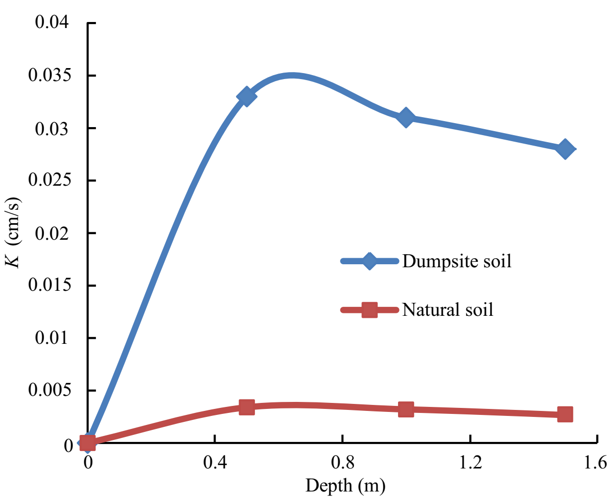


Fig. 15. Variations in hydraulic conductivity with depth of natural and dumpsite soils from Mandi.

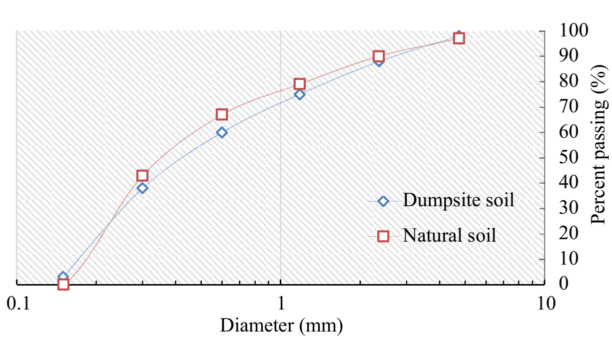


Fig. 16. Grain size analyses of dumpsite and natural soils from Sundernagar.

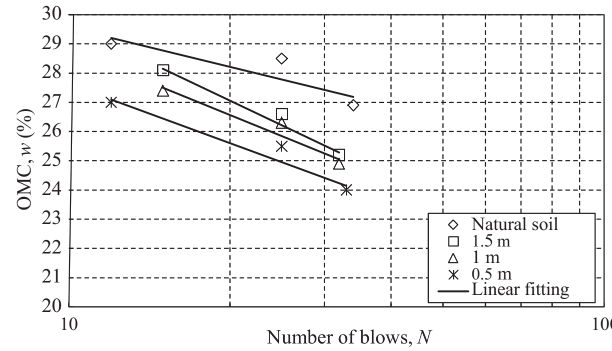


Fig. 17. Variations in optimum moisture content with number of blows of dumpsite and natural soils from Sundernagar.

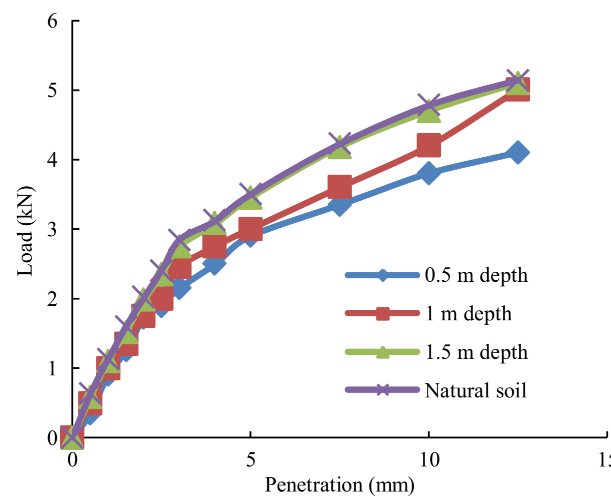


Fig. 18. Load vs. penetration curves (un-soaked) of dumpsite and natural soils from Sundernagar.

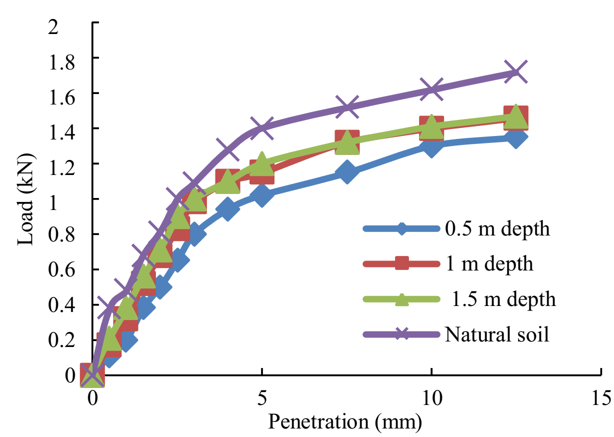


Fig. 19. Load vs. penetration curves (soaked) of dumpsite and natural soils from Sundernagar.

2.4. Laboratory investigation

The geotechnical properties of dumpsite soil in the study regions were used to measure the characteristics of the solid waste. The geotechnical properties determined include specific gravity, particle size gradation, liquid limit, plastic limit, plasticity index, maximum dry density (MDD), cohesion, angle of internal friction and permeability. Tests were performed as per Indian standard codal provision for compaction characteristics (IS 2720: Part 7, 1980), direct shear test (IS 2720: Part 13, 1986), particle size distribution (IS 2720: Part 4, 1985), Atterberg's limit (IS 2720: Part 4, 1985), and California bearing ratio (CBR) (IS 2720: Part 7, 1980).

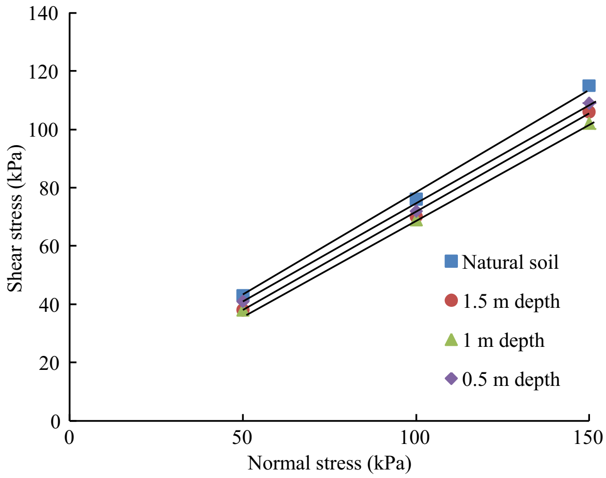


Fig. 20. Shear stress vs. normal stress curves of dumpsite and natural soils from Sundernagar.

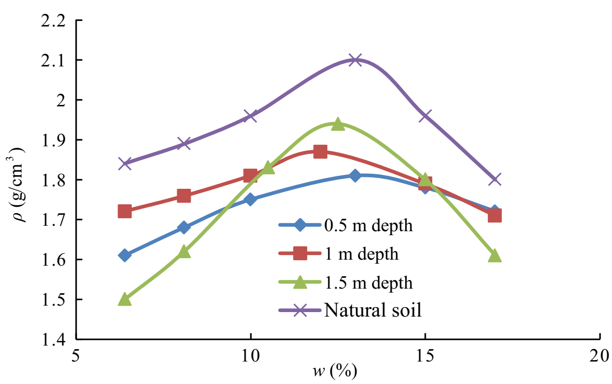


Fig. 21. Variations in maximum dry density with the optimum moisture content of dumpsite and natural soils from Sundernagar.

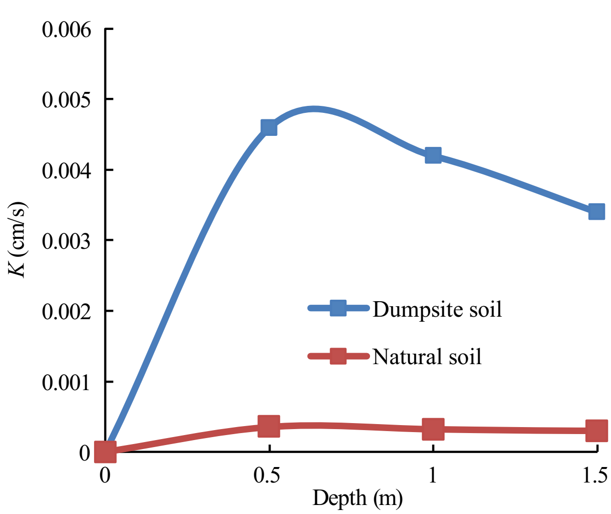


Fig. 22. Variations in hydraulic conductivity with depth of natural and dumpsite soils from Sundernagar.

2.5. Mineral composition

SEM provides high-resolution images of solid material by focusing an electron beam across the surface and hence detects

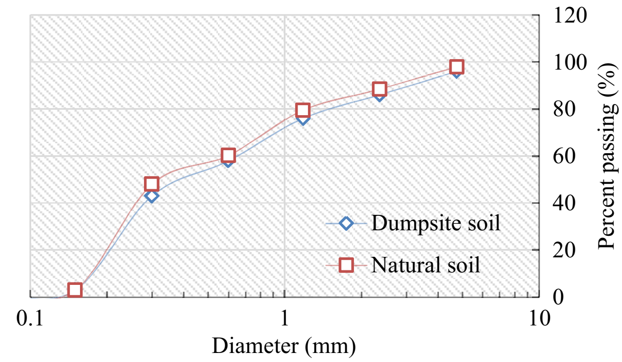


Fig. 23. Grain size analyses of dumpsite and natural soils from Solan.

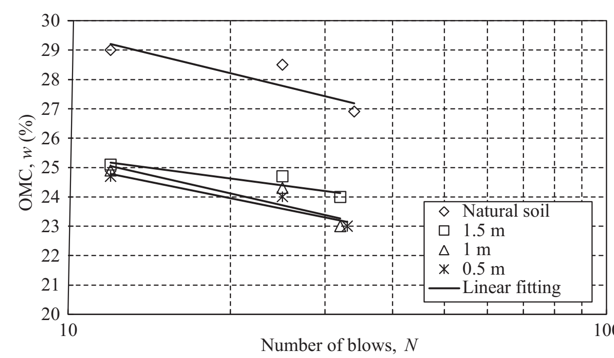


Fig. 24. Variations in optimum moisture content with number of blows of dumpsite and natural soils from Solan.

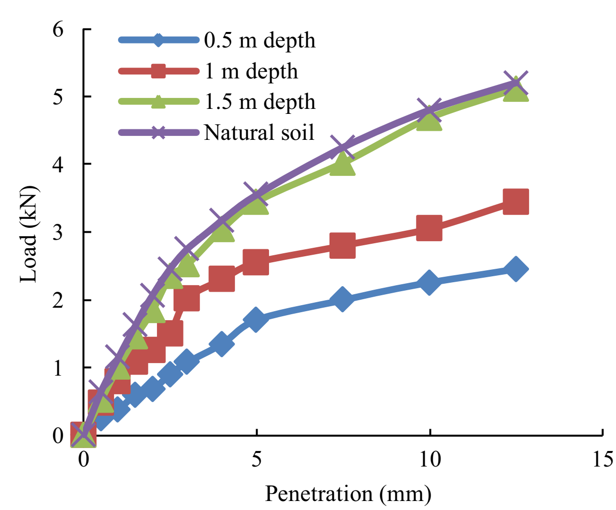


Fig. 25. Load vs. penetration curves (un-soaked) of dumpsite and natural soils from Solan.

back scattered electron signals, whereas EDS quantitatively analyzes the elemental composition of material. SEM and EDS have been applied on soil samples from the study regions in the Laboratory of Material Science at the National Institute of Technology (NIT) Hamirpur, Himachal Pradesh. Slides were prepared for 5 μm size soil fraction of the samples. The slides were air-dried firstly and then heated at 500 °C–550 °C for 30 min, and subsequently scanned to obtain the elemental composition of the soils (Adefemi and Wole, 2013).

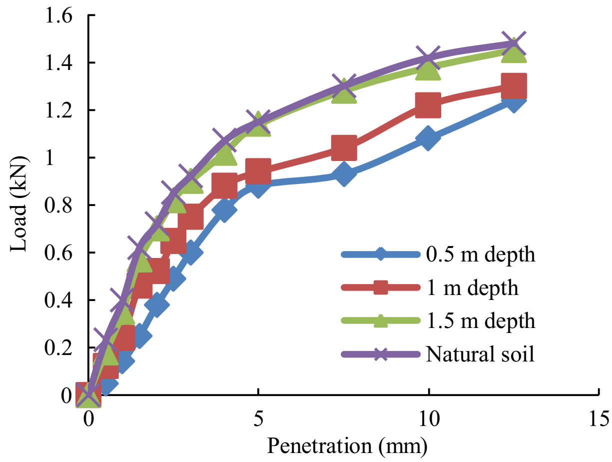


Fig. 26. Load vs. penetration curves (soaked) of dumpsite and natural soils from Solan.

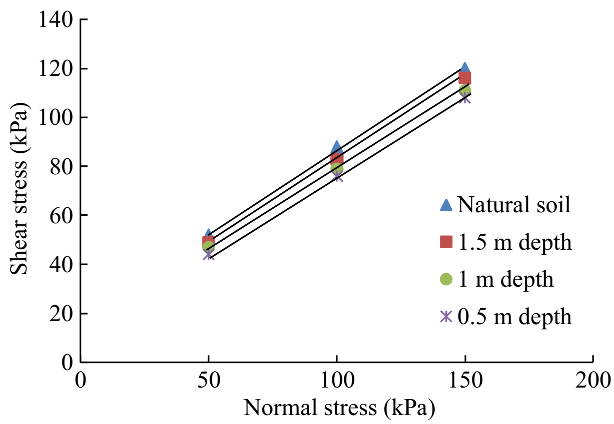


Fig. 27. Shear stress vs. normal stress curves of dumpsite and natural soils from Solan.

3. Results and discussion

3.1. Characterization of municipal solid waste

The physical compositions of solid waste vary depending on its types and sources. The nature of the deposited waste in a landfill will affect gas, leachate production and composition by virtue of relative proportions of degradable and non-degradable

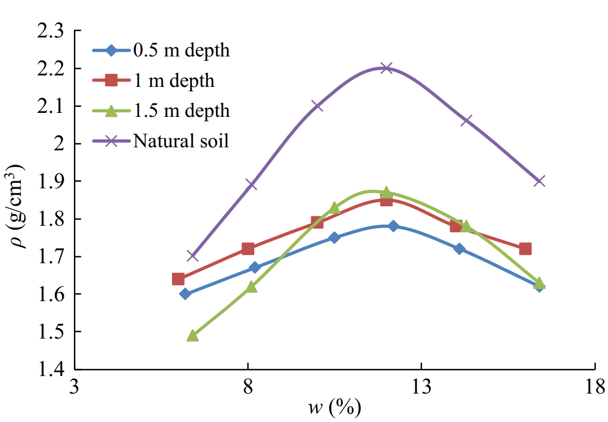


Fig. 28. Variations in maximum dry density with optimum moisture content of dumpsite and natural soils from Solan.

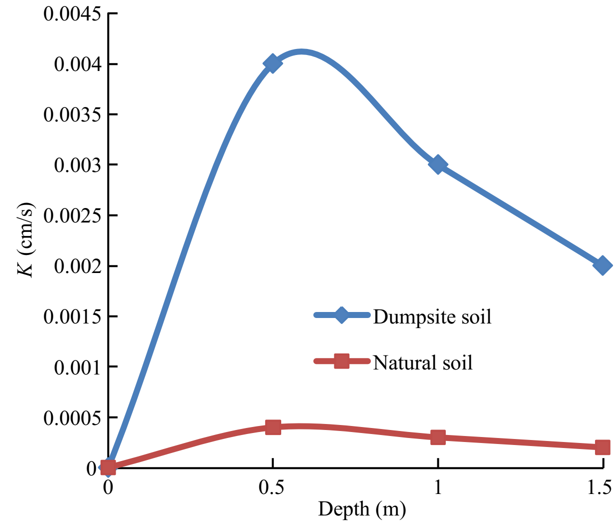


Fig. 29. Comparison in variation of hydraulic conductivity with depth of natural and dumpsite soils.

components, moisture content and specific nature of biodegradable element. Because of the heterogeneous nature of solid waste, determination of composition is not easy. Statistical procedures are difficult to be used. Usually, the procedures based on random sampling techniques are adopted to determine the composition of solid waste. To obtain a sample, the waste mass is reduced to about 100 kg by quartering. The results of physical characterization of the MSW from the study regions of Himachal Pradesh, including Solan, Sundernagar, Mandi and Baddi, in summer season are shown in Table 4.

The organic waste constituted the highest fraction of the total MSW generated from urban areas of Himachal Pradesh. Compostable/organic waste is mainly composed of kitchen waste including vegetables, food remains, fruits, etc. The content of organic waste thus observed in the study regions of Himachal Pradesh was 57.67% (Solan), 56% (Mandi), 52.83% (Sundernagar) and 50.83% (Baddi), respectively. Highest proportion of organic waste was observed in Solan as compared with the other three regions because the waste from fruit and vegetable markets of city was directly disposed of at the dumpsite. The literature study reports higher organic fraction of waste in Jalandhar (33%), Varanasi (31%), Bhopal (40%), Kolkata (50%), Chandigarh, Mohali, and Panchkula (22%–59%) having greater moisture content (Sethi et al., 2013; Rana et al., 2018).

3.2. Assessment of geotechnical properties of dumpsite soil in Himachal Pradesh

The effect of MSW due to illegal open dumping on the soil has been evaluated in the study regions of Himachal Pradesh. The variations in the geotechnical behavior of soil samples at depths of 0.5 m, 1 m and 1.5 m in all four study regions were investigated. The index properties and geotechnical assessment of the dumpsite and natural soil samples from various study regions including Baddi, Mandi, Sundernagar and Solan are summarized and listed in Tables 5–8, respectively, where OMC is the optimum moisture content.

Figs. 2–29 show the comparisons of the geotechnical properties of dumpsite and natural soils from Baddi, Mandi, Sundernagar and Solan, respectively.

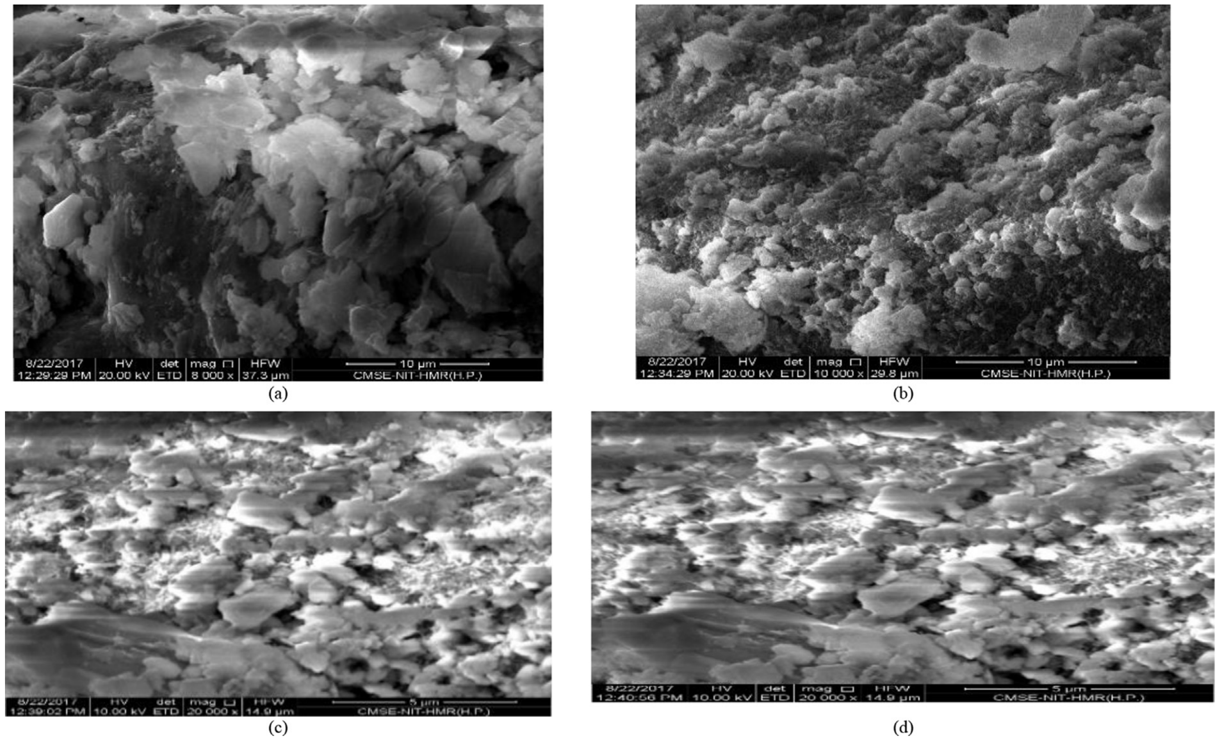


Fig. 30. SEM images of mineral particles in soil samples from Solan dumpsite.

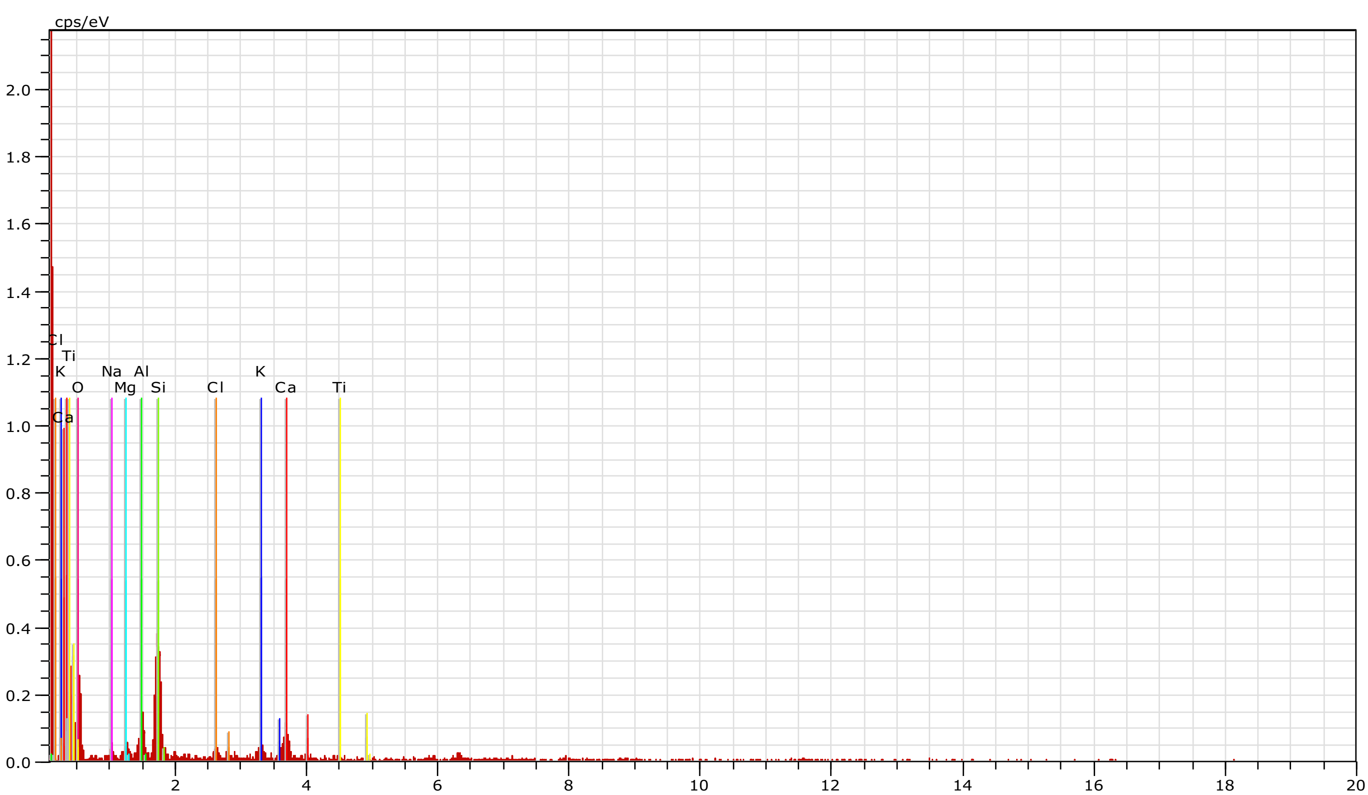


Fig. 31. EDS analysis data of soil samples from Solan dumpsite.

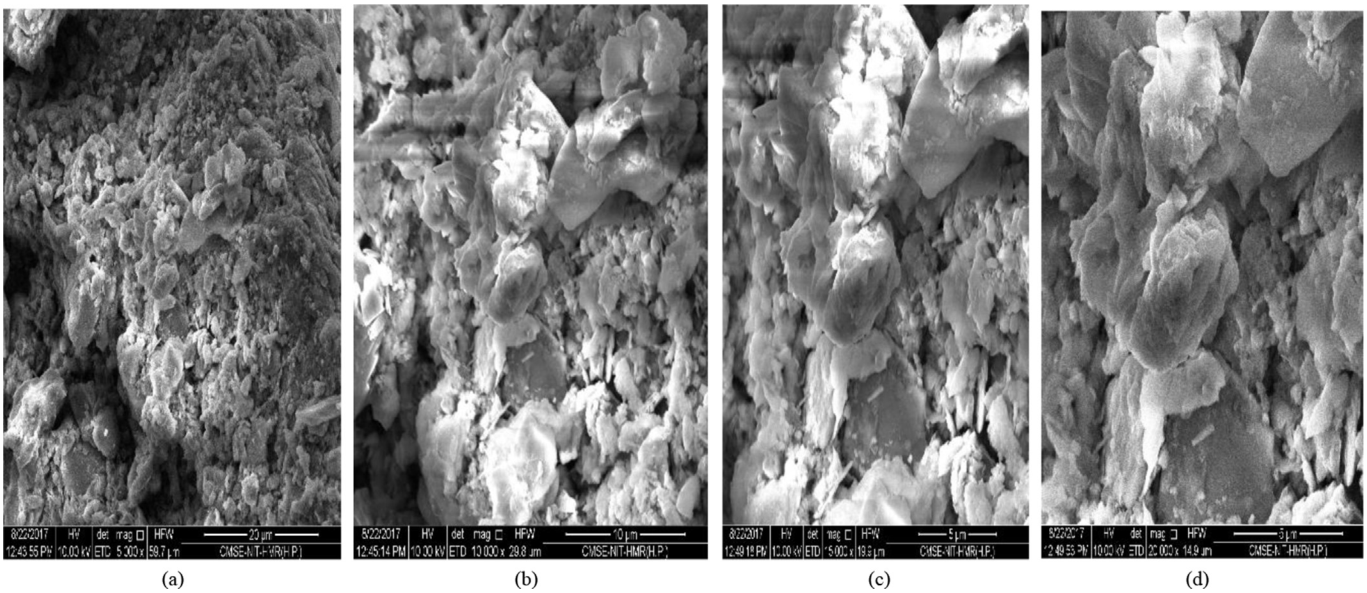


Fig. 32. SEM images of mineral particles in soil samples from Mandi dumpsite.

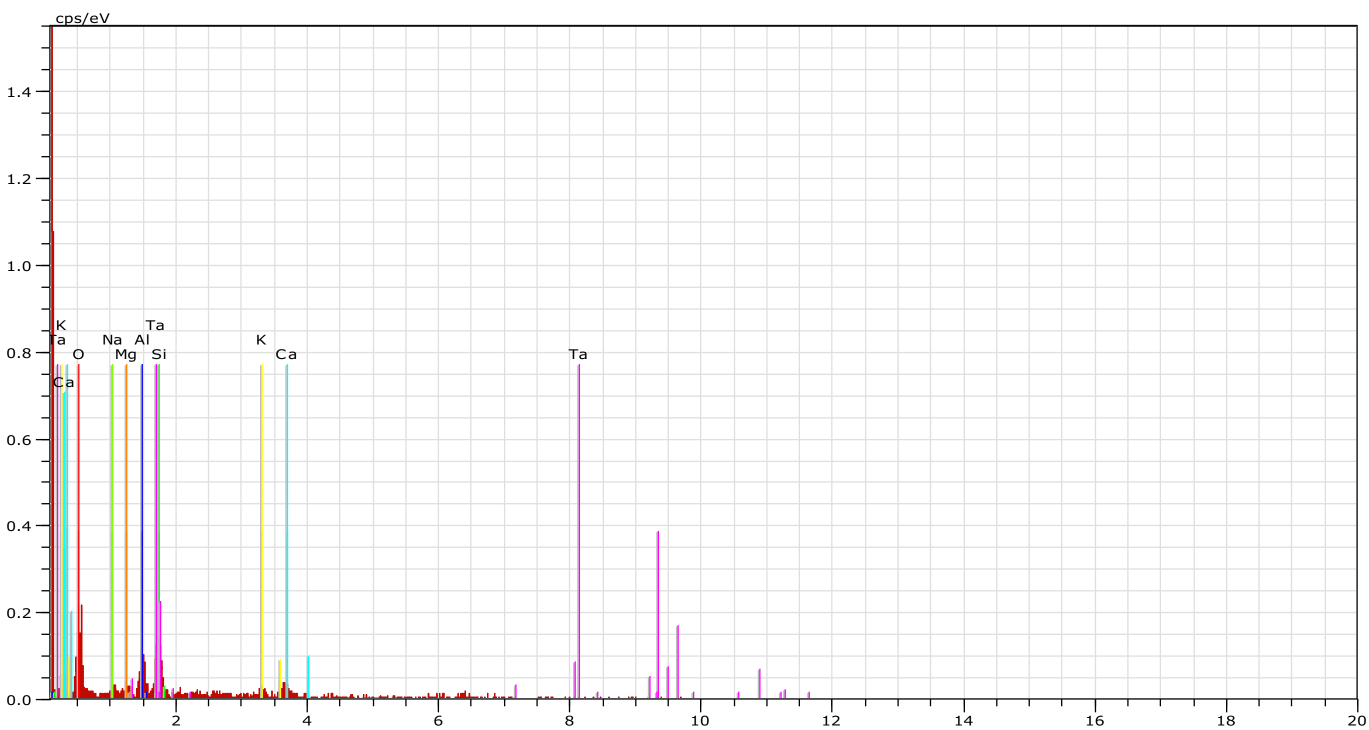
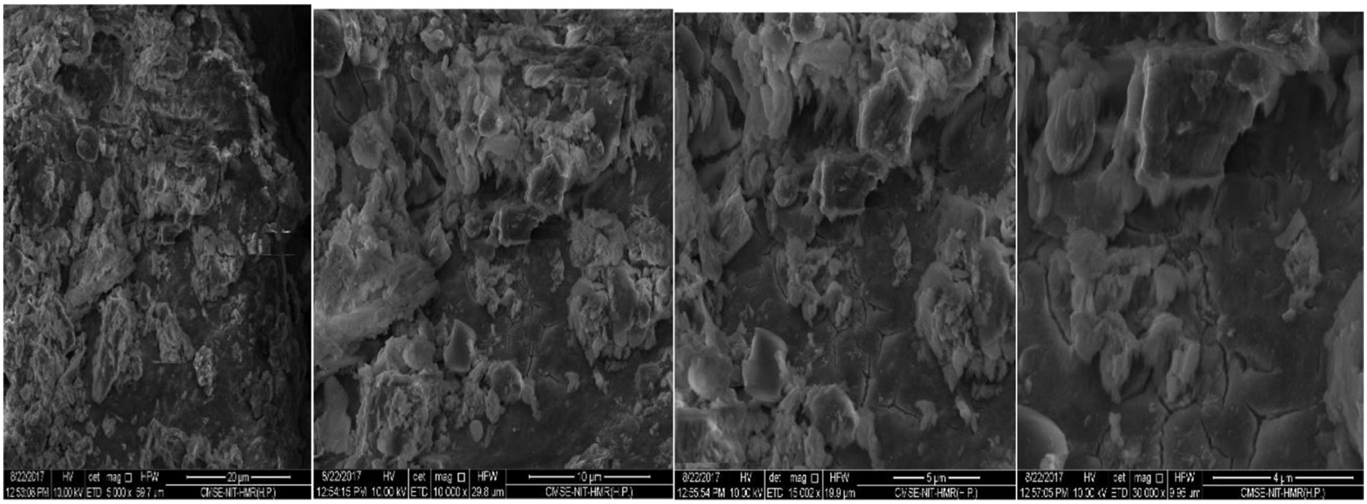


Fig. 33. EDS analysis data of soil samples from Mandi dumpsite.

Experimental investigation was done to determine the possible effect of open dumping of MSW on the dump-yard soil. Tables 5–8 show the variations in geotechnical properties of natural and dumpsite soils from four study regions of Himachal Pradesh. The results revealed that the specific gravity of the dumpsite soils lies in the range of 1.19–2.24 for the four study regions, which shows the presence of organic matter in the soil, and the specific gravity of the natural soil in the study regions was reported as 2.57, 2.56, 2.55 and 2.56, respectively. The liquid limit and plasticity index of the dumpsite soils lie in the ranges of 23.4%–24.4% and 5%–6.9%, respectively, whereas the natural soil exhibits liquid limit of 26%–28% and plasticity index of 11%–14%. Interestingly, the dumpsite soils show lower dry density, lower CBR value and greater hydraulic conductivity as compared to the natural soil. This is because of the decomposition of the organic matter and the percolation of leachate through voids into the soil, which changes the engineering properties of the soil. The smaller values of cohesion and angle of internal friction of dumpsite soils exhibit lower shear strength as compared to the natural soil. The contaminated soil has decaying organic matter continuously, and hence the specific gravity, dry density and shear strength of the



(a) (b) (c) (d)

Fig. 34. SEM images of mineral particles in soil samples from Sundernagar dumpsite.

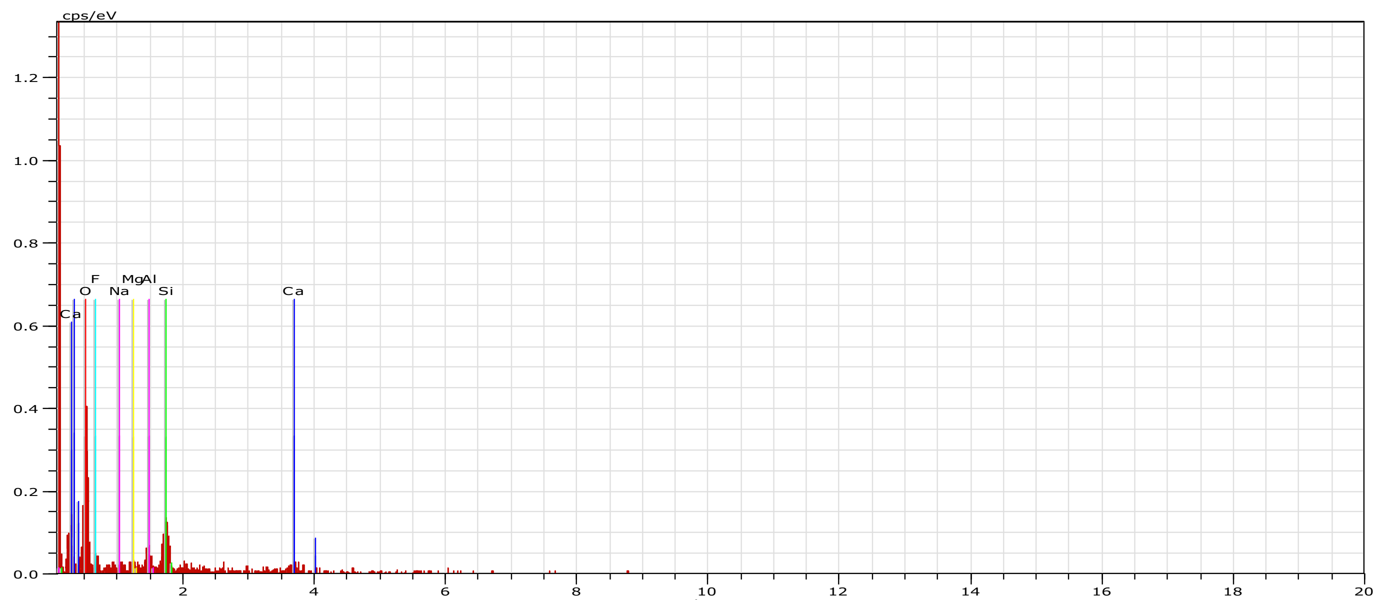


Fig. 35. EDS analysis data of soil samples from Sundernagar dumpsite.

contaminated soil decrease as compared to the soil taken from un-contaminated site.

It is observed that the soil taken at 0.5 m depth shows smaller values of MDD, cohesion and CBR and higher hydraulic conductivity as compared to the soil taken at 1.5 m depth. The MDD of all four dumpsite soils ranges from 1.78 g/cm^3 to 1.87 g/cm^3, whereas it ranges from 2.1 g/cm^3 to 2.2 g/cm^3 for the natural soil. The liquid limit and plasticity index of abandoned dumpsite soil in south-western Nigeria were reported as 36% and 13%, respectively (Adefemi and Wole, 2013). The CBR value of dumpsite soil varies in the ranges of 12.3%–16.8% in un-soaked condition and 4%–5% in soaked condition, whereas for the natural soil, the value is 18% (un-soaked) and 6% (soaked), respectively. Compared with the natural soil, the CBR values of dumpsite soils in un-soaked and soaked conditions decrease by 19.16% and 25%, respectively, which shows that for CBR tests in both conditions, the natural/virgin soil has more strength than the contaminated soil. The hydraulic conductivity of the dumpsite soils, in the range of 3.2×10^{-3}–4×10^{-3} cm/s, is greater than that of the natural soil, which ranges from 3.2×10^{-4} cm/s to 4×10^{-4} cm/s. Interestingly, for a compacted natural soil to be used as hydraulic barrier, it must possess the hydraulic conductivity of less than or equal to 1×10^{-7} cm/s (Adefemi and Wole, 2013). Sujatha et al. (2013) concluded that the soil having medium sandy content is coarse-grained with coefficient of curvature and coefficient of uniformity in the ranges of 0.9–1.15 and 7–15, respectively. The liquid limit, plastic limit and plasticity index lie in the ranges of 20%–30%, 13%–16% and 3.3%–13.4%, respectively, whereas in the study regions of Himachal Pradesh, the nature of soil is well-graded one with more fractions of silty sand and less fraction of clayey content. The coefficient of uniformity and coefficient of curvature are 6 and 1.5, respectively. However, the liquid limit, plastic limit and plasticity index are on an average of 24%, 19% and 5%–11%, respectively.

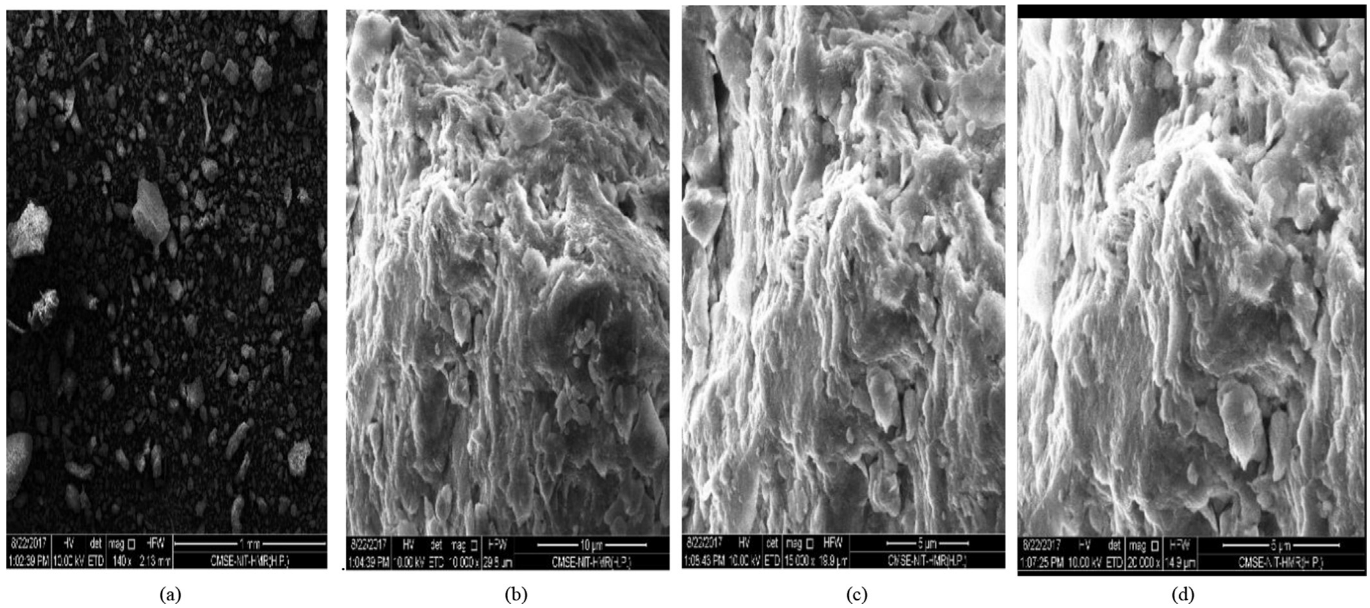


Fig. 36. SEM images of mineral particles in soil samples from Baddi dumpsite.

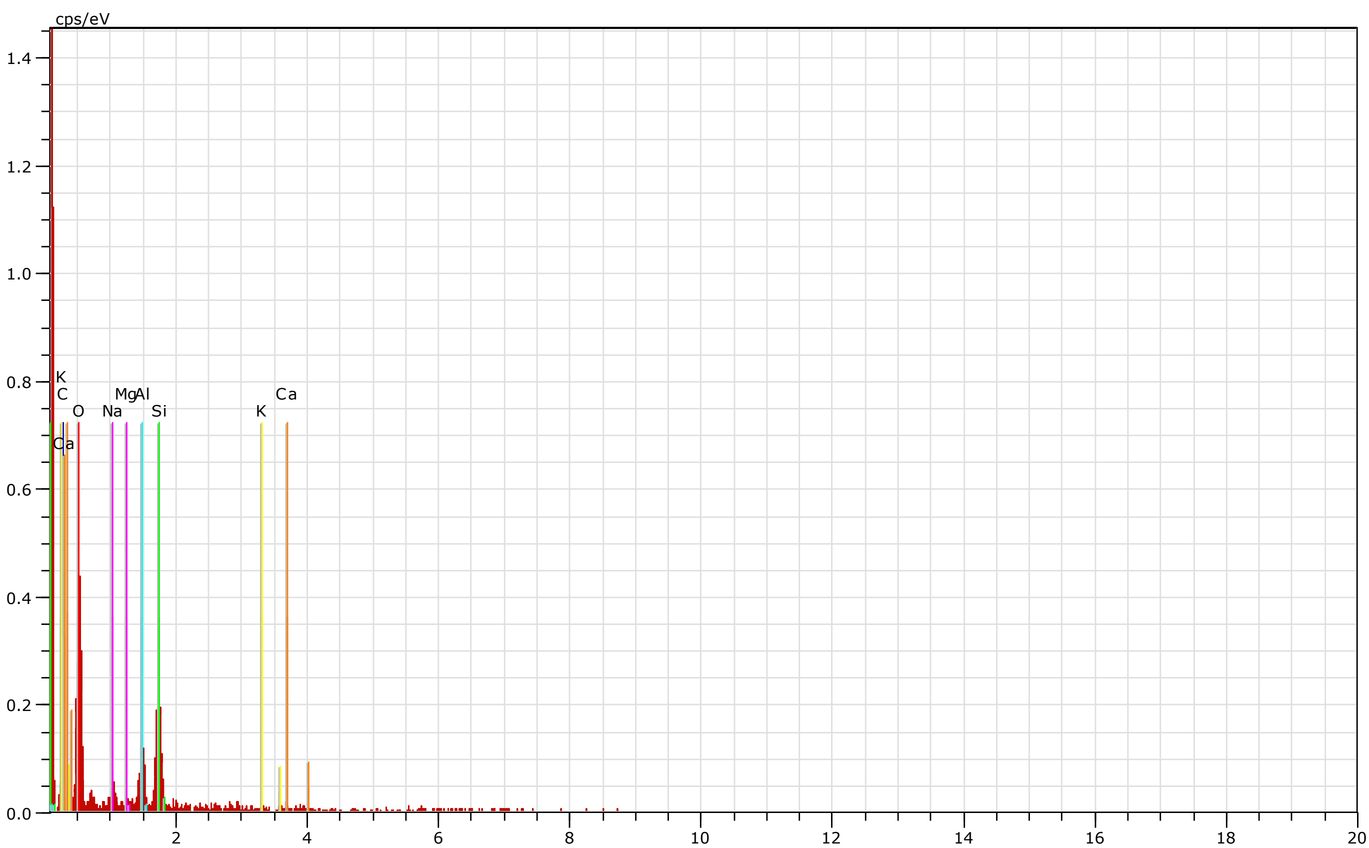


Fig. 37. EDS analysis data of soil samples from Baddi dumpsite.

Apart from this, the results of physical characterization of the MSW revealed that there is a major proportion of organic matter present in the waste. Leachate contamination alters the geotechnical properties of soil including compaction, density and strength properties. The effect of leachate into the soil decreases with depth and it is reflected by the variation in concentration. This is due to the chemical reactions between the leachate and soil particles. The present study is to investigate the changes in geotechnical properties of dumpsite soil compared with those of the natural soil. The above graphical representations showed that the natural soil has

Table 9
SEM quantitative analysis of detected elements for soil samples from Solan.

Element	Atomic No.	Series	Unnormalized weight (%)	Normalized weight (%)	Atomic weight (%)	Error (%)
O	8	K-series	27.33	54.66	69.3	7.8
Si	14	K-series	10.63	21.27	15.36	0.7
Ca	20	K-series	4.13	8.26	4.18	0.3
Al	13	K-series	3.64	7.27	5.47	0.4
K	19	K-series	1.25	2.5	1.3	0.2
Mg	12	K-series	1.1	2.21	1.84	0.2
Na	11	K-series	0.87	1.74	1.54	0.2
Ti	22	K-series	0.6	1.2	0.51	0.1
Cl	17	K-series	0.44	0.89	0.51	0.1
Total			50	100	100	

Table 10
SEM quantitative analysis of detected elements for soil samples from Mandi.

Element	Atomic No.	Series	Unnormalized weight (%)	Normalized weight (%)	Atomic weight (%)	Error (%)
O	8	K-series	20.66	45.96	64.55	6.2
Si	14	K-series	8.33	18.53	14.83	0.7
Al	13	K-series	4.7	10.47	8.72	0.5
Ca	20	K-series	4.6	10.23	5.74	0.6
Ta	73	M-series	3.06	6.8	0.84	0.4
K	19	K-series	2.74	6.09	3.5	0.4
Na	11	K-series	0.46	1.03	1.01	0.1
Mg	12	K-series	0.4	0.89	0.82	0.1
Total			44.96	100	100	

increasing trends in all of the properties including the specific gravity, compaction and strength parameters. Experimental investigation showed that the dumpsite soil at the upper level of 0.5 m depth was more contaminated compared with the natural soil. Beyond 1.5 m depth, the influence of contamination decreased and hence at that depth, the properties of dumpsite are almost similar with those of the uncontaminated soil.

However, the results revealed that there is no significant difference in the properties of uncontaminated and contaminated soil till now. This can be explained by the characterization of MSW from the dumpsites of all four regions of Himachal Pradesh. The characterization of MSW revealed that the waste consists of the major proportion of organic matter at the four dumpsites. The specific gravity, dry density and strength properties are found to be lower as compared to those of the natural soil because of the degradation of the organic matter present in the MSW. The proportion of toxic materials including metal, plastic, batteries, biomedical waste, glass and bottles is found to be less in the waste of dump-yard because the dry waste is already collected by rag pickers before it is disposed of in the dumping yards. Therefore, there is less chance of presence of toxic heavy metals in the waste till now. However, increasing population in Himachal Pradesh will lead to industrialization and urbanization due to which the volume and varieties of solid waste are going to increase.

Table 11
SEM quantitative analysis of detected elements for soil samples from Sundernagar.

Element	Atomic No.	Series	Unnormalized weight (%)	Normalized weight (%)	Atomic weight (%)	Error (%)
O	8	K-series	33.77	62.1	73.1	8.6
Si	14	K-series	10.13	18.63	12.49	0.8
F	9	K-series	3.68	6.77	6.71	2.6
Ca	20	K-series	2.96	5.44	2.56	0.5
Al	13	K-series	2.6	4.78	3.33	0.3
Mg	12	K-series	0.7	1.28	0.99	0.2
Na	11	K-series	0.54	0.99	0.81	0.2
Total			54.38	100	100	

Table 12
SEM quantitative analysis of detected elements for soil samples from Baddi.

Element	Atomic No.	Series	Unnormalized weight (%)	Normalized weight (%)	Atomic weight (%)	Error (%)
O	8	K-series	38.71	53.32	60.35	9.7
Si	14	K-series	15.7	21.63	13.94	1.1
C	6	K-series	7.8	10.74	16.19	4.7
Al	13	K-series	6.16	8.49	5.7	0.6
Na	11	K-series	2.3	3.17	2.5	0.4
Ca	20	K-series	0.92	1.26	0.57	0.3
K	19	K-series	0.74	1.02	0.47	0.2
Mg	12	K-series	0.27	0.37	0.27	0.1
Total			72.59	100	100	

3.3. Reclamation of dumpsites after dumping of solid waste

After the completion of dumping of solid waste in the dump-yard, final capping must be provided with at least 60 cm barrier layer, 15 cm drainage layer and 45 cm vegetation layer (Central Pollution Control Board (CPCB), 2000). In the study locations of Himachal Pradesh, it is investigated that there is no such significant change in the properties of dump-yard and natural soils due to the presence of few toxic materials in the dumpsites. We can further explain this by an example. The shear strength of dumpsite soil has been evaluated as 103 kPa on average and that of the natural soil is reported as 110 kPa, with a slight difference of 7%. However, with the increasing generation, it is expected that the properties of the dump soil will deteriorate significantly by the time it reaches the end of the lifespan. In this context, with suitable treatment and soil stabilization, the dump soil can be used for lighter construction including shops, parking facilities, gardens, lawns, and parks after the provision of vegetation layer of soil to support the natural plant growth for minimizing the chance of soil erosion. However, the soil may not be used for heavy civil engineering construction purposes until very specialized soil treatment is carried out including repeated checks for settlement.

3.4. SEM analysis and element composition by EDS

The geometrical arrangement and structure of soil samples were illustrated by SEM, while the element composition was analyzed by EDS. The EDS analysis combined with the SEM detected some elements with their atomic percentage and weight percentage including oxygen (O), calcium (Ca), magnesium (Mg), potassium (K), silicon (Si), sodium (Na), iron (Fe), carbon (C) and titanium (Ti). SEM micrographs of soil samples from the study regions at four different magnifications (8000, 10,000, 15,000 and 20,000) and corresponding EDS analysis data are shown in Figs. 30–37. The micrographs obtained by SEM analysis revealed major fraction of kaolinite flakes having low shrink swell capacity and low cation exchange capacity of the soil samples at four different dumpsites.

The details of EDS analysis data of soil samples from Solan are presented in Fig. 31. The quantitative analysis of detected elements is listed in Table 9.

SEM images of mineral particles at four magnifications (8000, 10,000, 15,000 and 20,000) for Mandi dumpsite soil samples are shown in Fig. 32. The details of EDS analysis data of soil samples are indicated in Fig. 33. The quantitative analysis of detected elements is listed in Table 10.

SEM images of mineral particles at four magnifications for soil samples from Sundernagar dumpsite are shown in Fig. 34. The details of EDS analysis data of soil samples are illustrated in Fig. 35. The quantitative analysis of detected elements is listed in Table 11.

SEM images of mineral particles at four magnifications (8000, 10,000, 15,000 and 20,000) for soil samples from Baddi dumpsite are shown in Fig. 36. The details of EDS analysis data of soil samples are presented in Fig. 37. The quantitative analysis of detected elements is displayed in Table 12.

SEM quantitative analysis of detected elements in Table 9 reveals the type and series of elements, and their distributions with weight and atomic percentages found in soil samples from Solan dumpsite. The EDS detected nine elements including oxygen, calcium, aluminium (Al), potassium, magnesium, sodium, titanium and carbon in soil samples from Solan dumpsite, which is of K-series. The atomic weight of oxygen in the soils was greater than its normalized weight. The rest elements have less atomic weight as compared with their normalized weight.

Table 10 reveals that the EDS detected eight elements including oxygen, silica, calcium, aluminium, potassium, magnesium, sodium and tantalum (Ta) for Mandi dumpsite soil samples. Almost all of the above elements lie in K-series except Ta in M-series. The atomic weight of oxygen in the soils was greater than its normalized weight.

Table 11 indicates that the EDS detected seven elements including oxygen, silica, calcium, iron, aluminium, magnesium and sodium for Sundernagar dumpsite soil samples. All the elements lie in K-series. The atomic weight of oxygen in the soils was reported higher than its normalized weight.

Table 12 shows that the EDS detected eight elements including oxygen, silica, carbon, calcium, aluminium, potassium, magnesium and sodium for Baddi dumpsite soil samples. All the elements lie in K-series. The atomic weights of carbon and oxygen in the soils are greater than their normalized weights. The composition of oxygen in all four soil samples was larger due to the presence of moisture in the soils. The second highest fraction was of silica in all four dumpsite soils because of the presence of sandy particles in the soils.

4. Conclusions

Open dumping of MSW in the land poses serious hazards to the environment as well as the public health. The properties of the dump-yard soil including specific gravity, MDD and strength parameters have lower values as compared to those of the uncontaminated soil, which indicates that some level of contamination has taken place at the upper layer of the soil but has not been detected in the lower layer.

Apart from this, the soils at the dumpsites of all four study regions show greater permeability than the natural soil. As the leachate percolates into the subsoil, contamination migrates into the soil and hence pollutes the soil. The smaller values of cohesion and coefficient of internal friction of dumpsite soils exhibit smaller shear strength due to decaying of organic matter present in the waste at all the four dumpsites as compared to the natural soil.

The MSW characterization showed the major proportion of organic content and less proportion of highly contaminated materials in the dumpsite such as metals, batteries, glass and bottles. But due to the increase in industrialization and urbanization, the size of dumping lands and the varieties of solid waste will increase in future and will cause the increasing concentration of leachate. At present, it is revealed from the experimental investigation that the soils in the four regions of Himachal Pradesh can be used for construction purpose after any prior treatment to the soil. Apart from this, the soil after completion of dumping of waste may be used for agriculture facilities, parking facilities, gardens and any other lighter construction purposes. It is revealed from the study that as such, there is no significant change in the properties of dumpsite and natural soils till now. But with elapsed time, if improper dumping of waste continues, it may cause major effect on the soil properties in very near future.

In this context, it is recommended to construct proper sanitary engineered landfill system with liner system, leachate collection and treatment system, gas collection facility and final cover system to avoid the percolation of leachate into the soil and hence to prevent the soil contamination.

The micrographs obtained by SEM analysis showed major proportion of kaolinite flakes having soft and earthy soil with low shrinkage and swelling properties for all soil samples, and EDS detected nine elements for Solan dumpsite soil, eight elements for Mandi and Baddi dumpsite soils, and seven elements for Sundernagar dumpsite soil. The major composition of oxygen has been reported in all four soils due to the presence of moisture, followed by the silica content due to the sandy silty nature of soil.

Conflict of interest

The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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Prof. Ashok Kumar Gupta is Head of Department of Civil Engineering, Jaypee University of Information Technology (JUIT), Waknaghat, Solan, Himachal Pradesh, India. He obtained his BSc degree in Civil Engineering from University of Roorkee (now IIT Roorkee), MSc degree in Geotechnical Engineering from University of Roorkee in 1986, and PhD degree in Civil Engineering from IIT Delhi in 2000. His interest areas cover testing and modeling of geotechnical materials, finite element modeling and its applications to geotechnical engineering, continuum damage mechanics and its application to rockfill materials modeling, engineering rock mechanics and environmental geotechnics. He is Founder Chairman of Indian Geotechnical Society (IGS) Shimla Chapter.