Effect of Municipal Solid Waste Disposal on the Engineering Properties of Soil from a Non-Engineered Landfill

Disha Thakur, Ashok Kumar Gupta, Rajiv Ganguly

Abstract: The presents study showed the effect of open dumping on soil characteristics and biodegradation settlement analysis of soil in non-engineered landfill. The contaminated soil is referred to as waste soil which has different settlement rates due to the various categories and complex characteristics of waste. The degradation of waste causing percolation of leachate into soil affecting the strength and stability of soil. This paper includes the analysis of geotechnical properties and settlement analysis of waste soil and its comparison was done with natural soil. The geochemical analysis was carried out by Energy Dispersive X- Ray Spectroscopy (EDX) and Scanning Electron Microscopy (SEM). The elemental analysis of soil exhibited presence of high oxygen and silica content in uncontaminated soil. The analysis depicted that specific gravity, maximum dry density (MDD), permeability and California bearing ratio (CBR) showed decreasing trend variation for polluted soil. It was observed that cohesion for contaminated soil was found to be increased thereby increasing the shear strength of soil. Additionally, temperature, pH and moisture content hold a significant position for assessing the settlement. The settlement of soil due to biodegradation of MSW is estimated using empirical mathematical model for dump site depending upon pH, moisture content and temperature. Additionally, settlement is evaluated keeping in view the settlement due to biodegradation of MSW on soil, which further helped in determination of the suitability of the site for the construction and other recreational purposes.

Keywords**: *Biodegradation, Dumping, Geotechnical Properties, Geochemical Properties, Maximum Dry Density, Settlement.***

I. INTRODUCTION

Solid waste management is an integral constituent of urban and rural environment to make certain about healthy and safe surroundings. India now a days faces challenges like industrialization, urbanization, unplanned development, population growth and other associated developmental factors. It has been reported that 70% of Indian urban population generate about 1,30,000 tonnes/day of MSW with a per capita production rate of 0.5 kg/day with an expected annual rise of about 1.3% per year [1]. Further, reported characterization of MSW in Indian cities indicates about 40-60% of waste content is organic, 30-60% is inert material, 3-6% is paper and rest 1% miscellaneous [2]. About 90% of total waste produced in India is predisposed unsafely and dumped untreated in landfills or open area or is sometime burned in an uncontrolled manner resulting in generation of greenhouse gases [3]. However, in majority of such cities, MSW is dumped only in non-engineered landfill sites giving rise to different environmental and health concerns [4].

Solid waste comprises of both biodegradable and non-biodegradable materials that have harmful impact on both soil and groundwater [2]. The major source of contamination is leachate generated from MSW, which percolates through soil. In particular, contamination of the soil strata severely affects various engineering properties of soil like shear strength, consolidation, permeability, California Bearing Ratio (CBR) values and other related parameters and as such has been previously studied for determining the suitability of such contaminated soil for potential reuse including construction purposes or as sub-grade material [5-7]. Notably, many previous studies have determined that the effect of soil contamination was not uniform but highly dependent on type and nature of soil considered [7-9]. The effect of municipal solid waste showed a decrease in different geotechnical properties like specific gravity, shear strength and permeability [9,10]. Due to leaching, the soil gets contaminated and the properties of soil like specific gravity, maximum dry density, permeability and shear strength changes drastically [7-9].

The concentration of the contaminants in the soil can be analyzed with use of SEM and EDX [11]. However, the properties and settlement of MSW and waste soil becomes problematic to determine because of different settlement rates and heterogeneous properties and nature of the waste [6,7]. The mechanical compression, consolidation and presence of biodegradable content in soil lead to settlement.

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The compression of waste and soil have been studied by researchers [12,13] to analyze the settlement rate but studies on settlement of soil due to dumping of the MSW is limited to compression or consolidation only. However, biodegradation settlement of waste is an outcome of biodegradation of organic matter which results in reduction of solid mass [14]. Various mathematical and numerical models were available for estimating landfill settlement but did not incorporate major factors (pH, Moisture content, bulk density and temperature) contributing to biodegradation. A previous researcher [15,16] developed an empirical mathematical model for evaluating the settlement attributable to biodegradation of MSW.

The study on settlement of MSW in landfill has already been conducted by many researchers but study on settlement soil due to dumping of waste is limited only for mechanical compression. Thus, the present study focuses on assessing geotechnical, geochemical properties and biodegradation settlement of soil for an MSW dumping non-engineered landfill site located in Una Town in Himachal Pradesh, India. The geochemical properties are analyzed by SEM and EDX. The geotechnical properties like particle size distribution, compaction, permeability, shear strength and CBR are also carried out for samples from dump site and natural sample. The settlement of soil for MSW landfill using empirical mathematical model developed by researchers [14,15] is evaluated for assessing the impact of dumping on the soil.

II. STUDY AREA

The dump site is in Lalsinghi area of Una town in foothill range of Shivalik (Himalaya), at latitude 31°48' and longitude 76°28' with a total population of 18722 [17]. Location of site is shown in Fig. 1. The generation of MSW in town is about 6 metric tons per day which is being dumped openly and also increasing proportionately. The area is drained by River Swan which is the tributary of River Sutlej having catchment area of 1204 km^2 in Una.

The maximum rainfall per year varies from 966 mm to 1253 mm. Few important characteristics related to the study location are revealed by Table 1.

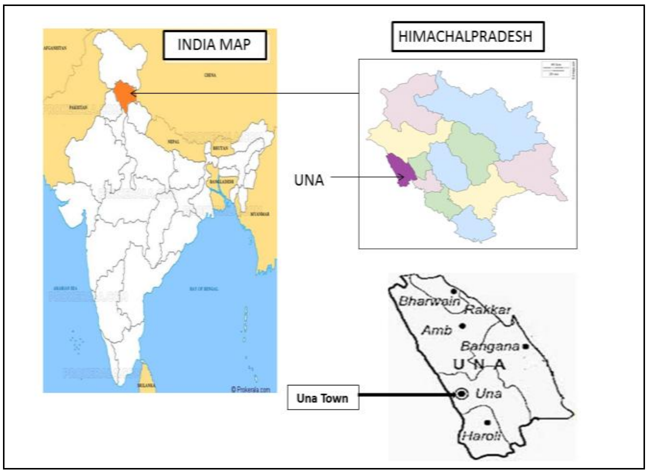


Fig. 1. Location of Study area.

Table 1: Details of MSW Dump Site.

S.No.	Description	Lalsinghi Dump Site
1	Total Area	1,983 sq. m
2	Maximum Height of Garbage	8m
3	Current rate of Dumping	5,444 kg/day
4	Garbage dumped till 2016	4,65,30,97,949 kg
5	Depth of Groundwater Table	10 m

III. METHODOLOGY

a) MSW Sampling

Sampling of waste from dump site was done as per guidelines recommended in ASTM Standard [18]. MSW was gathered from vehicles that collect waste during unloading of waste at dump site for a period of 10 days. 100 kg of representative sample was extracted from the total sample collected during sampling period of 10 days. Waste material was emptied on a plastic sheet and mixed to get homogeneous mixture. A representative sample of 100 kg was then obtained to characterise the waste using quartering method. Separation of waste is performed with the assistance of rag pickers for substantial waste characterisation.

b) Soil Sampling

The soil samples for various tests were prepared as per ASTM Standard [19,20] and Indian standard methods [21-28]. The sampling of soil is done during month of March-April, prior to rainy season, so that rain water may not affect the properties of soil. The contaminated samples were collected within the site from four trial pits underlying the MSW dump at depth of 0.5m, 1m and 1.5 m below ground level. For comparison, uncontaminated natural soil samples were also taken from a distance of 1 km from the dump site. Soil samples are extracted through auguring in order to collect representative samples. Careful transportation of samples is attained by packing soil samples in plastic bags.

c) Geochemical Analysis

The geochemical testing of samples was done to determine the elemental composition and morphology of soil using SEM and EDX analysis. SEM provides a beam of electron in a scan model. The electrons interrelate with atoms that formulate the sample to produce waveforms which contain details regarding features like electrical conductivity and sample surface topography. SEM analyses the surface of material and help to resolve the contamination issues. EDX gives the information about presence of elements and composition of materials using slides of prepared samples heated at high temperature of 500-550°C [5]. SEM and EDX are used to observe the surface of cells, microscopic structures and observations and display the three-dimensional objects [5, 11].

d) Laboratory Analysis

The soil samples collected from dump site and uncontaminated samples were then analyzed for geotechnical geochemical and settlement properties.

The geotechnical testing of samples includes determination of specific gravity, particle size distribution, maximum dry density, permeability, shear strength (c, ϕ values), CBR of the samples as per IS standards [21].

e) Settlement Analysis

Settlement of soil causes problems such as cracking of structure, damage to foundation etc. Hence, in case of dumping of MSW in open lands, properties of soil get deteriorated causing settlement of soil. The settlement of soil due to overburden is not considered because of less impact of MSW loading on soil. Thus, the settlement of soil due to degradation of MSW is considered for analysis. The characterisation of waste showed that effect of moisture content is higher on settlement because of higher organic content present in waste. However various models were developed by researchers [29-31] for biodegradation settlement but they did not consider the major factors like pH, moisture content, temperature and density into considerations. Biodegradation is a complex process which requires factors like pH, moisture content (θ) and Temperature (T) to be considered for settlement evaluation. Hence, the model developed by the researchers [15, 16] is used for evaluating the settlement which has considered all these required factors.

Parameters for modelling

It was assumed that soil comprises of layers having finite thickness. The soil layer of thickness 5m is assumed for consideration having 10 layers (0.5m each). The density of soil is evaluated and it varied with the depth.

The top layer of soil is assumed to have MSW fraction mixed with soil thus having different phases of slowly degradable, moderately degradable, rapidly degradable and highly degradable content. The decay rate (k) for slowly degradable, non-degradable, rapidly degradable and moderately degradable waste are 0.00001day^{-1},0.00 day^{-1}, 0.001day^{-1}, 0.0001day^{-1}. Based upon the past studies the temperature of in range of 32°C to 42°C is considered as optimum for degradation of MSW [15, 29, 38]. Thus, temperature of 42°C and pH for both acidic and alkaline condition (2 to 14) is considered as favourable conditions for biodegradation [15, 16, 29]. The moisture in layers varies spatially with depth. However, based on actual field condition and modelled parameters of soil, settlement is evaluated.

IV. RESULTS AND DISCUSSION

a) Characterization of MSW

Physical characterisation of MSW for a particular study area depends upon type of waste being dumped and its source. The waste generated is heterogenous in nature making the determination of various components more of a complex procedure. Therefore, random sampling procedure is adopted for physical characterization [2, 32]. The results from characterisation of waste showed that the organic component in waste is higher and mainly composed of kitchen, food and vegetable waste (Table 2). The biodegradable waste in the dump site is around 56% having highest proportion of biodegradable waste in summer season [33]. However it was observed that organic waste for Indian cities is in higher fraction ranges between 20-55% [1, 2, 4].

Table 2: Physical Composition of MSW in Una.

Sr. No.	Components	%age fraction
1	Organic matter	56.1±1.08
2	Paper	12.2±0.76
3	Polythene/Plastic	10.3±0.59
4	Glass	1.0±0.03
5	Metal	1.2±0.38
6	Inert	10.5±0.72
7	Others	8.7±0.19

Note: Number in the parentheses is standard deviation. Other includes leaves, wooden matter, thermo-cole, coconut etc.

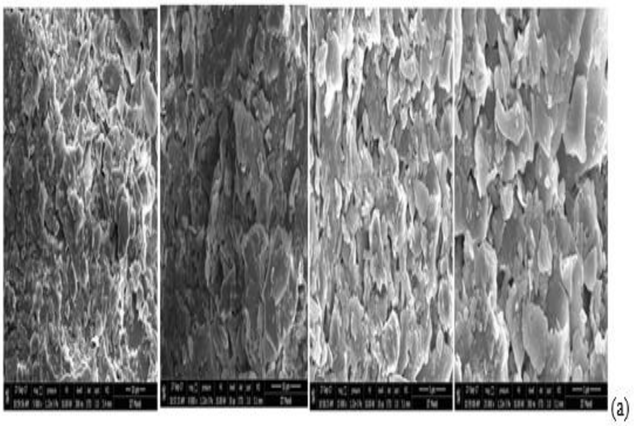
b) Geochemical Analysis of Soil

The result of analysis by SEM and EDX showed that the geometric arrangement of particles and structure of soil sample, shape of particle and elemental composition of the soil for contaminated soil samples and natural soil. The SEM micrographs of sample were shown at different magnification (5000, 10000, 15000, 25000) for both contaminated and uncontaminated soil.

Fig. 2 shows micrographs for contaminated soil samples. The details of the elements using EDX analysis in the sample is shown in Fig. 2 (a, b) and Table 3 which showed the observed elements in the sample.

The EDX analyses of the contaminated sample in Table 2 revealed the composition of elements, series and distribution of the atomic weight in soil. The eight elements detected in contaminated soil were oxygen, sodium, magnesium, aluminum, silica, potassium, calcium, iron. The percentage atom of oxygen is higher in contaminated soil followed by silica and alumina.

The SEM and EDX analysis of uncontaminated soil is shown in Fig. 3 (a, b). Table 4 revealed that presence of five elements oxygen, aluminum, silica, potassium and iron, having higher atomic and weight concentration of oxygen and silica in uncontaminated soil. The uncontaminated sample has appreciably high composition of silica content. The concentration of silica in soil showed the presence of quartz mineral in soil. The SEM micrographs showed that soil fraction consists of roughly spherical and largely irregular particles for samples.



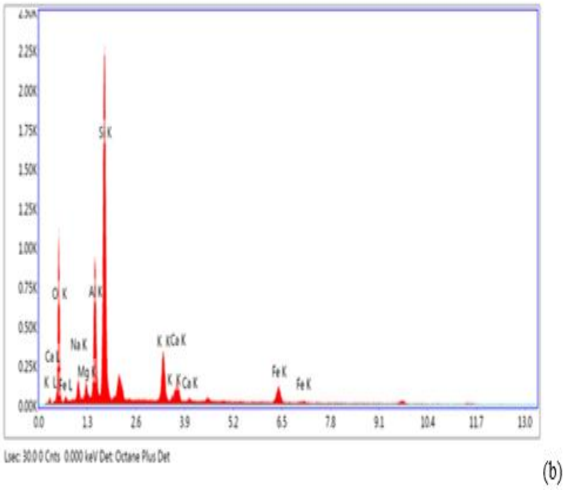
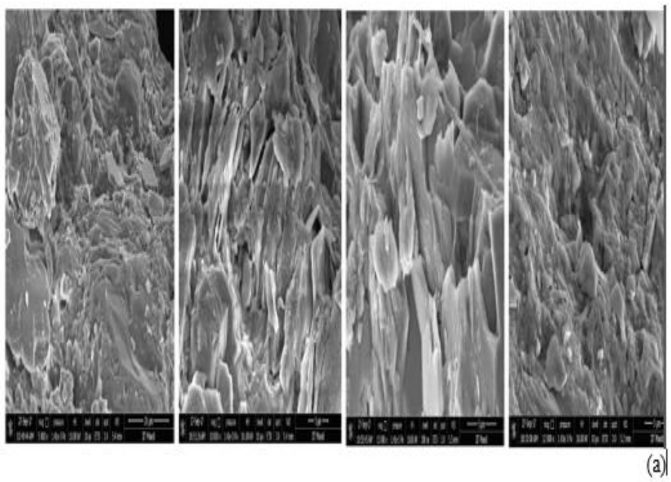


Fig.2(a). SEM Micrographs of contaminated soil with different magnifications.
Fig. 2(b). Elemental analysis of contaminated soil by EDX analysis.



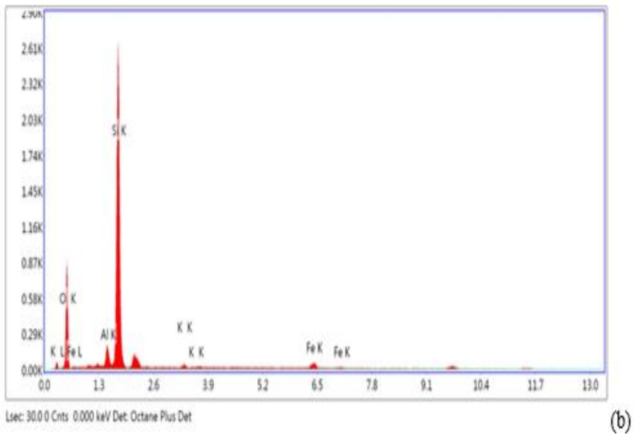


Fig. 3(a). SEM Micrographs of uncontaminated soil with different magnifications.
Fig. 3(b). Elemental analysis of uncontaminated soil by EDX analysis.

Table 3: Quantitative analysis of detected elements in contaminated soil.

Element	Normalized Weight %	Atomic Weight %	Error %	K ratio
O	40.49	56.66	9.45	0.11
Na	2.74	2.67	13.28	0.01
Mg	1.02	0.94	15.62	0.01
Al	10.53	8.74	5.87	0.07
Si	28.14	22.43	4.95	0.18
K	6.66	3.81	6.90	0.05
Ca	3.68	2.06	9.19	0.03
Fe	6.73	2.70	10.56	0.06

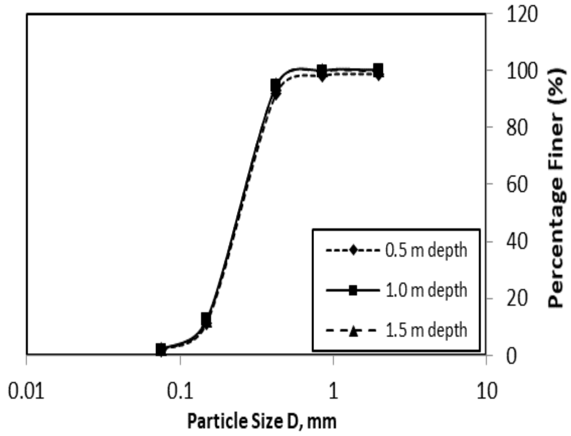


Table 4: Quantitative analysis of detected elements in un-contaminated soil.

Element	Normalized Weight %	Atomic Weight	Error %	K ratio
O	43.22	58.54	8.90	0.15
Al	3.16	2.54	8.44	0.02
Si	46.83	36.14	3.72	0.35
K	0.88	0.49	33.14	0.01
Fe	5.91	2.29	13.14	0.05

c) Geotechnical Analysis of Soil

Particle Size Distribution

Sieve examination for particle size distribution of contaminated and uncontaminated soil samples are carried out as per Indian Standards [24]. The particle size distribution curve for contaminated soil and uncontaminated soil depict that sample is mainly composed of sand. However, curve showed that sample collected at 0.5m depth consists of degraded waste fraction which results in presence of finer particle. The particle size distribution for contaminated soil and uncontaminated samples are shown in Fig. 4 (a,b).

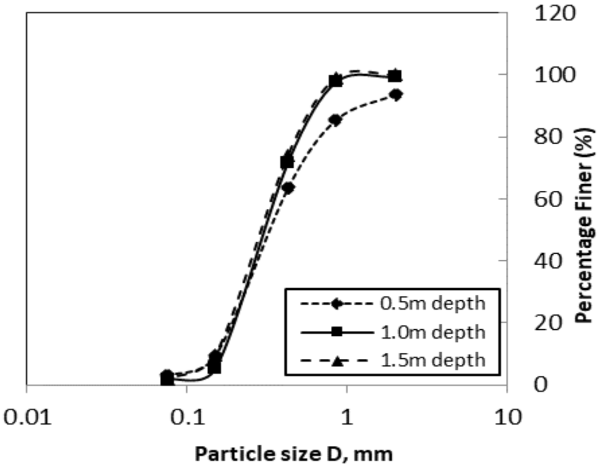


Fig. 4(a) Particle Size Distributions for contaminated soil.

Fig. 4(b) Particle Size Distributions for un-contaminated soil.

Fig. 4 (a,b) showed that the particle size distribution for study samples classified as poorly graded sand (SP). The C_c and C_u for the study samples were observed in range of 0.92-0.97 and 2.07-2.58 for contaminated and uncontaminated soil respectively. The results showed that value of C_u lies below 4 indicating soil is poorly graded (SP) [34].

Specific Gravity

The analysis was performed by specific gravity bottle (500 ml flasks) [22]. The specific gravity of contaminated soil varied between 1.95-2.08 at depth of 0.5 m which increases with depth. The impact of dumping tends to reduce with depth thereby increasing specific gravity of soil. The specific gravity for uncontaminated soil was determined to be 2.46. It could be noted that uncontaminated soil has highest specific gravity as compared to contaminated soil.

The specific gravity diminution of contaminated soil is due to decay of particles because of organic content present in soil which makes soil less [5, 10]. The organic content present in soil varies with depth from 1.25% to 0.385%. This variation in organic content is because of MSW fraction present in top layer of soil.

Moreover, it can be seen that soil tendency to convert into organic soil is found to increase with increase in leachate migration as lowest specific gravity is observed for soil at 0.5 m depth for contaminated soil.

Compaction Characteristics

The compaction behavior of samples is tested as IS code [25]. As per the particle size distribution curve; it is observed that all soil samples are primarily sandy soil. The highest dry unit weight (γ_d) corresponds to OMC whereas minimum dry unit weight corresponds to lowest point as shown in Fig. 5 (a,b). The reults showed small variation in sample collected from dump site. So average variation for MDD of contaminated samples has been presented in Fig. 5(a).

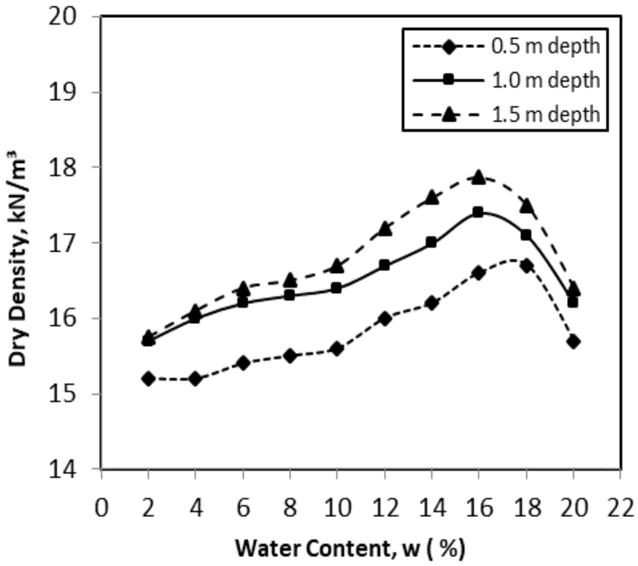


Fig. 5(a) Compaction Curve of contaminated soil from Standard Proctor Test.

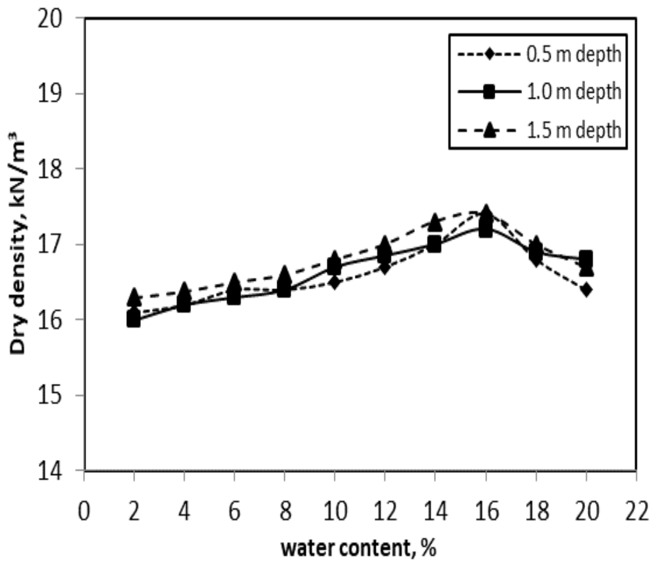


Fig. 5(b) Compaction Curve of uncontaminated soil from Standard Proctor Test.

From the curves it was observed that variation in the MDD of soil is because of leachate migration into soil [6, 7, 9]. The compaction curve shows that sample at 0.5m depth has lower MDD value than at depth 1.5 m but there is no much variation in values below 1m because impact of MSW dumping is decreased. The highest dry density of contaminated soil minimized from 17.18 kN/m^2 to 16.5 kN/m^2 and optimum moisture content of soil increased from

15.8% to 17.5% with increasing effect of MSW on the soil. The MDD of uncontaminated soil is more than contaminated soil. The dry density of soil decreased due to migration of leachate and concentration of leachate if increased in soil also results in lower dry density [9, 36].

Permeability

Permeability characteristic of soil samples is determined using constant head method for cohesion less soil as per IS Standard (IS: 2720-17) [26]. It is observed from Fig. 6 (a) and (b) that permeability of contaminated soil is less as compared to uncontaminated soil. The reason for variation in permeability can be due to accumulation of heavy metals which migrates along with leachate through the soil [9, 35, 37].

The permeability of soil at upper layer (0.5 m) is less than soil at 1m and 1.5m depth. Permeability of dump soil varies with depth from 2.57×10^{-5} to 2.32×10^{-4} cm/sec for dump soil and 5.8×10^{-4} *to* 6.7×10^{-4} cm/sec for uncontaminated soil. The heavy metal gets deposited in soil matrix thereby inducing bond between soil particle and leachate film which reduces the porosity. This deposition of heavy metals limits the water flow via the soil and hence decreasing soil permeability.

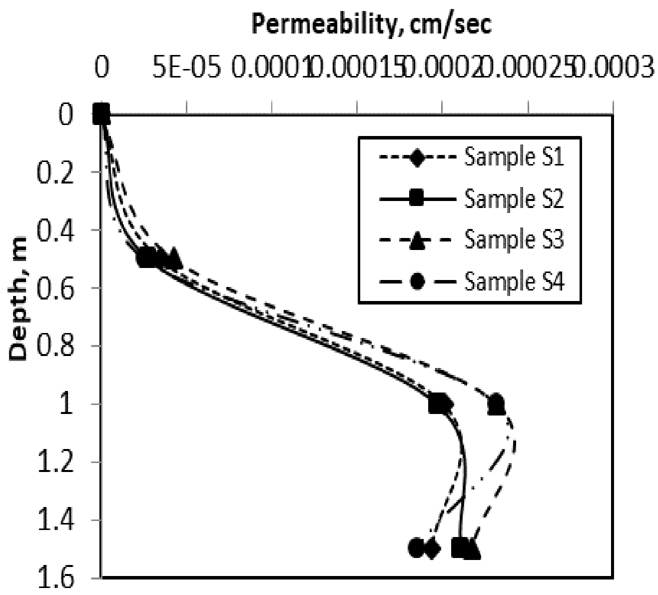


Fig. 6(a) Variation of permeability of contaminated soils with depth.

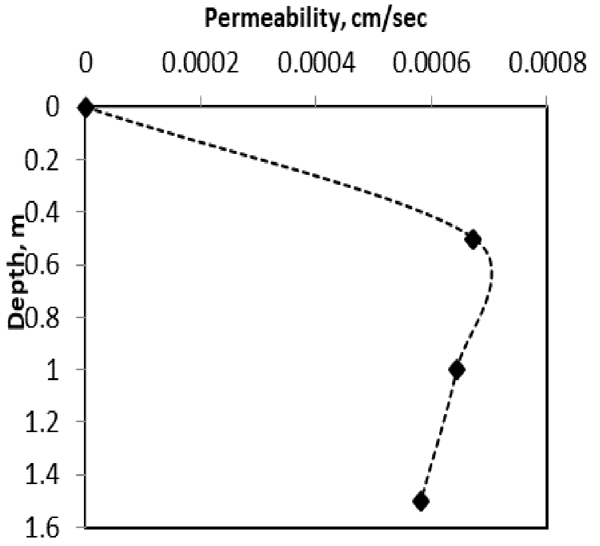


Fig. 6(b) Variation of permeability for un-contaminated soil with depth.

Shear Strength

The shear strength constraints of soil are portrayed by means of direct shear analysis as given in IS: 2720- Part 13 [27]. The specimens are prepared at OMC within the shear box (60×60×25 cm). The specimens were subjected to normal stresses of 0.2 kg/cm^2, 0.4 kg/cm^2, 0.6 kg/cm^2.

The samples were then sheared at rate of 1.25mm/min. The deformations, horizontal and vertical were then recorded by system connected to the apparatus. The shear strength constraints (**c and ϕ**) were then determined from the maximum shear stresses and normal stress curves Fig.7 (a,b). Fig. 7 (a,b) showed slopes of failure envelopes for both contaminated and un-contaminated soil specimen. It is observed that contaminated soil samples depict an increase in *c* value for sample at 0.5m depth than sample at 1m and 1.5m depth and friction angle (*ϕ*) increase with depth.

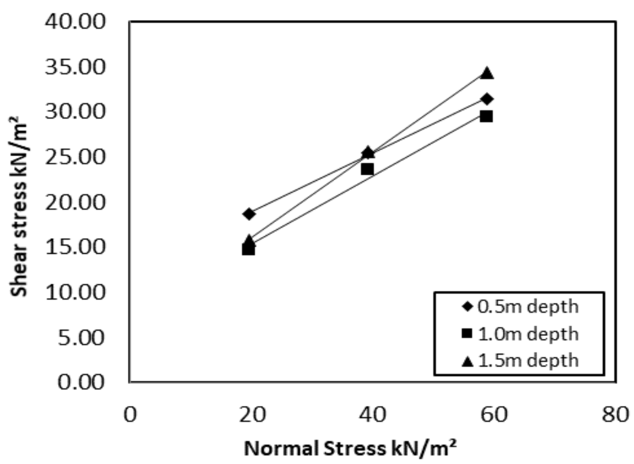


Fig. 7(a) Shear strength envelops for contaminated soil at different depths.

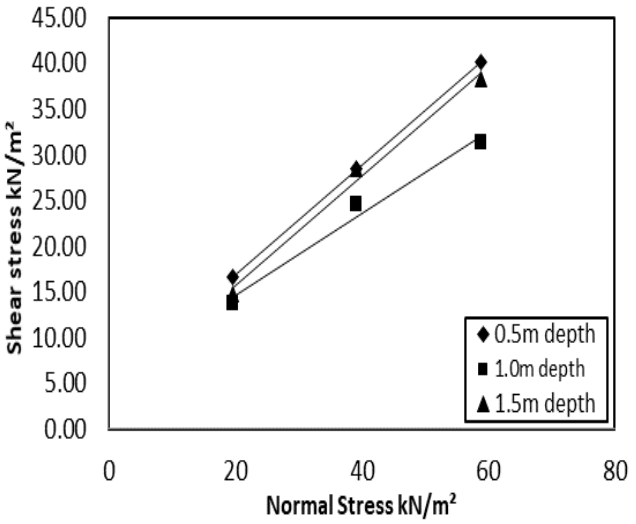


Fig. 7(b) Shear strength envelops for un-contaminated soil at different depths.

The angle of internal friction for sample collected within dump site ranges from 18.64° to 20.55° for 0.5m depth with increased cohesion and increases from 21.05° to 25.41° for 1.0 to 1.5 m depths with lower cohesion values. Thus, it was observed that cohesion of samples collected within the dump site is higher than uncontaminated sample [9] affecting the shear strength constraints of soil. The raise in cohesion value for 0.5 m depth can be accounted for the fact that the contamination through leachate deposits various cations like Ca, Mg and Mn which induces bond between the particles [8]. The increase in ϕ can be due to soil degradation by microorganisms which makes contaminated soil orient into a denser packing. Since particle degradation of contaminated soil can be expected, it could further lead to production of more angular particles and consequently a higher ϕ [9, 10, 36].

California Bearing ratio Test

The soil specimens from the dump site were analyzed for CBR using IS:2720, Part 16 [28]. The specimen was prepared at proctor maximum dry density. The California bearing ratio test of the specimen was used to characterize the strength and the bearing capacity of studied soils for soaked and un-soaked conditions. CBR tests were conducted on sample for three days soaked in water and on un-soaked samples using standard compaction energy.

Fig. 8(a, b,) and Fig. 9 (a, b) showed the variation of CBR values of samples under soaked and un-soaked conditions. The plot of load-penetration is obtained and CBR values for penetration of 2.5mm and 5mm are determined. The CBR value for penetration 2.5mm and 5mm were calculated and greater value of CBR should be considered for analysis.

The CBR value of dump soil varies in range of 4.63%-5.62% for un-soaked condition and 1.52-2.07% for soaked state. The CBR value for natural soil varies from 5.45-5.81% for un-soaked and 1.77-2.03% for soaked conditions respectively. The CBR value of dump soil as compared with the natural soil decreased by 12% -17% and 20-25% for un-soaked and soaked conditions respectively.

The observed results for geotechnical properties showed that dumping of waste in open land causes degradation of soil and thus showing decreasing trend in specific gravity, MDD, shear strength, CBR and permeability of soil [9, 35, 37]. The experimental result showed that upper layer (0.5m) of soil is contaminated because of MSW thus having the effect of contamination more than lower depths. The influence of contamination decreased beyond 1.5 m depth of soil thus having properties similar to uncontaminated soil. This is because the effect of MSW is lower beyond 1.5 m depth. Due to the contamination of soil, organic matter is decaying and thus affecting properties of soil like shear strength, CBR, dry density etc. as compared to uncontaminated soil. This depict that the strength of uncontaminated/natural/virgin soil is more as compared to contaminated/dump soil.

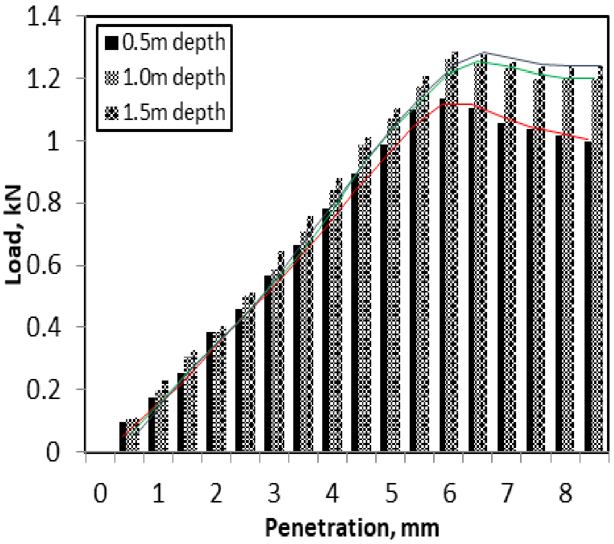


Fig. 8(a) Histogram of Load and Penetration for contaminated soil (un-soaked condition).

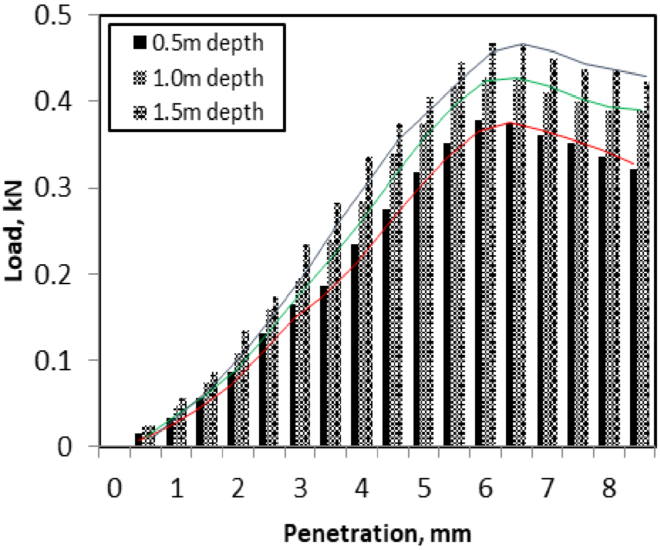


Fig. 8(b) Histogram of Load and Penetration for contaminated soil (soaked condition).

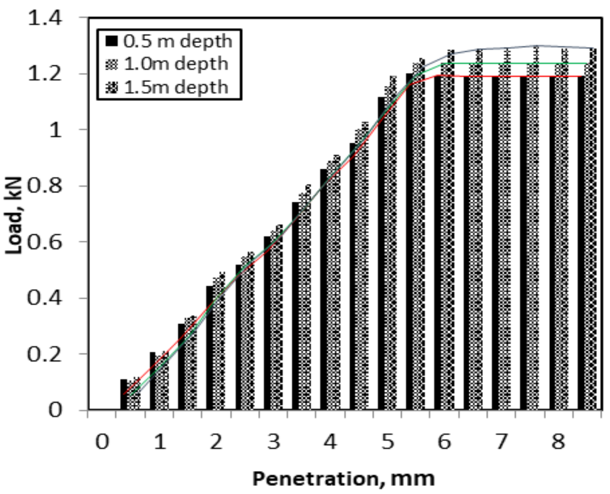


Fig. 9(a) Histogram of Load and Penetration of uncontaminated soil (un-soaked condition).

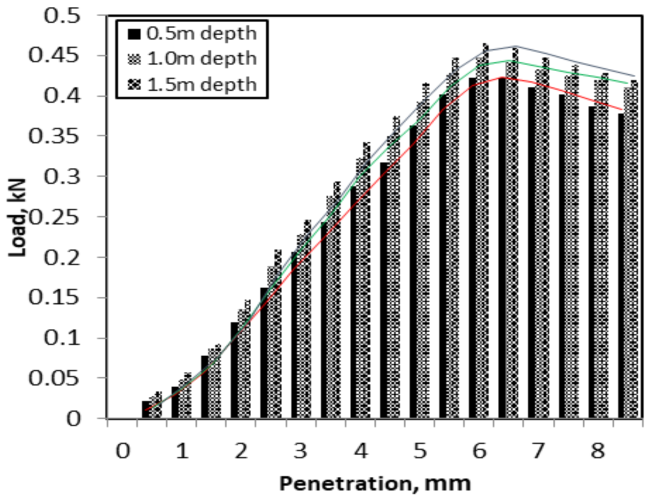


Fig. 9(b) Histogram of Load and Penetration of uncontaminated soil (soaked condition)

d) Biodegradation Settlement Analysis of soil

Variation of settlement with changing pH of soil (temperature and moisture content constant)

Based upon the actual parameters and assumed values of pH, moisture content and temperature, settlement of soil is evaluated. Fig. 10 showed the settlement of soil with time for actual moisture content, temperature with varying pH values. The actual pH values for sample vary with layer and for different phase of MSW (slowly, moderately, rapidly and highly degradable). The pH values adopted for analysis are both acidic and alkaline conditions for observing the settlement pattern of soil. The results for settlement analysis depict that settlement of soil increases at slow rate but continue afterwards.

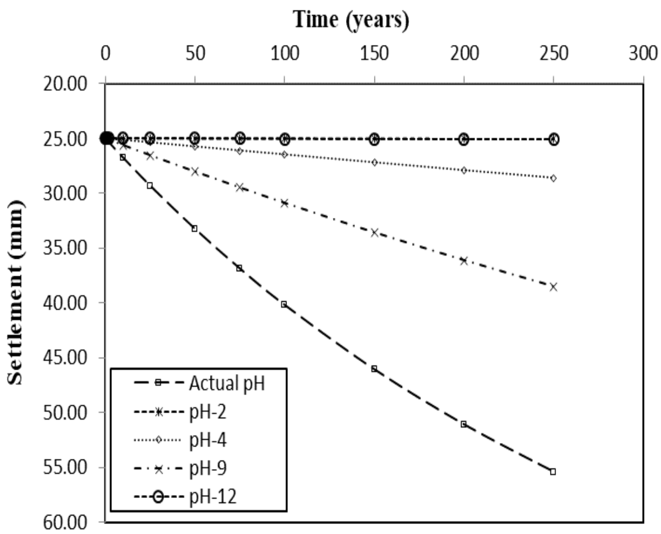


Fig. 10. Settlement of soil with variation in pH for biodegradation model.

The result showed that the increase in settlement of soil for acidic (pH-2) and alkaline (pH-12) nature are almost same and increased at a very slow rate. However, the variation in pH values (actual pH of soil samples, 4, 9) showed the increase in settlement having significant increase in successive years. It can be observed from the results that the rate of degradation of soil is more owing to growth of micro-organisms present in soil which tend to grow in moderate pH conditions.

Variation of settlement with changing moisture content of soil (constant pH, temperature)

Settlement with changing moisture content observes increase in settlement of soil. The actual parameters for temperature and pH were used for estimating temporal and spatial variation of moisture content.

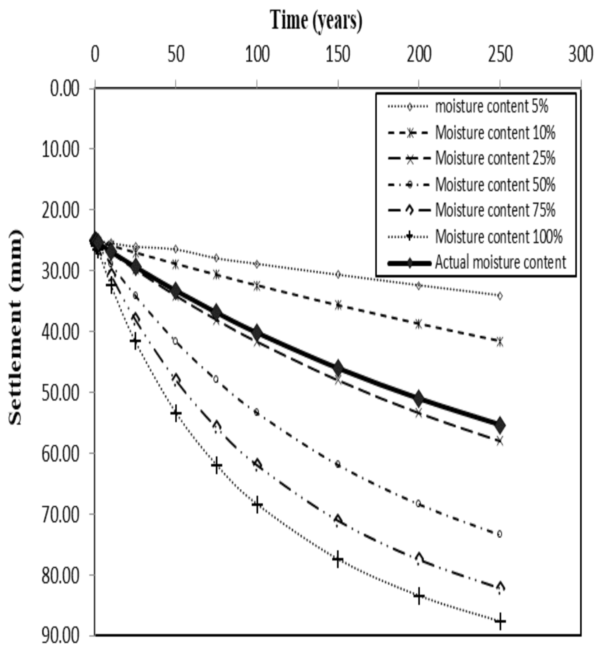


Fig. 11. Settlement of soil with variation in moisture content.

It was observed from the results that settlement increases with increase in moisture content. The variation of settlement with moisture content is shown in Fig. 11. It can be seen that difference in settlement is less for initial 1-5 years and then increases with time.

Variation of settlement with change in temperature of soil (constant pH, moisture content)

Fig. 12 showed the variation in settlement with observed and predicted temperature during the different time. It was observed from the graph that the variation in temperature leads to biodegradation of organic matter. With the increase in temperature, settlement of layer increases significantly. Settlement of soil starts after 5th year and continuous increase was observed for next successive years. The increase in temperature promotes the growth of microorganisms results in decomposing the material.

The obtained results depict that the settlement at actual temperature condition during sampling period is significant and increases with time.

The model developed is function of pH, moisture content and temperature and plays a significant role in biodegradation. The nature of refuse dumped on basis of degree of degradation predicts the settlement of soil.

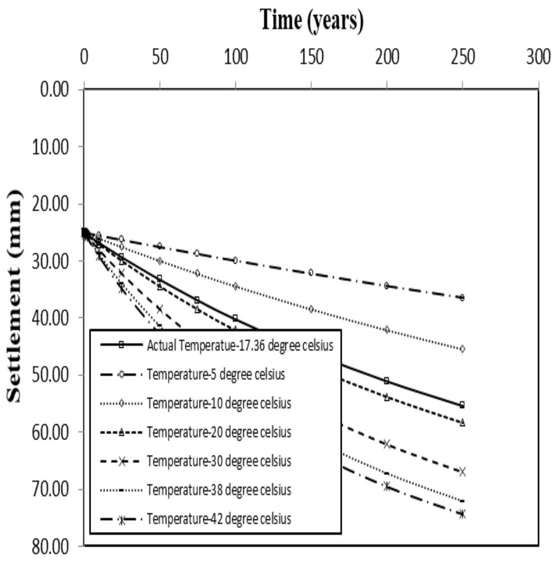


Fig. 12. Settlement of soil with variation in temperature.

The parameters given are considered for sensitivity analysis for determining settlement. The model was subjected to field parameters and analyzed results of soil which predict the settlement of soil beneath MSW. The model used the predicted values of degradation constant for the settlement variation however it depends upon the rate of degradation of MSW which is being evaluated after the analysis of MSW. The settlement analysis of soil from model showed that settlement rate increases with increase in temperature, pH and moisture content. However, the variation in settlement is observed and it can be predicted that if the organic content and fraction of MSW and amount of waste is increased in soil the settlement of layers will be increased [16,38,39].

V. CONCLUSION

The contamination of soil due to open dumping affects the environment and posing health hazards to human beings. The characterization of MSW for the study area showed the higher content of organic matter with lower proportion of contaminated material like metals, batteries, glass etc. in waste. The laboratory analysis of parameters like specific gravity, MDD, shear strength of soil affected due to MSW dumping showed lower values than natural soil. Thus, it can be concluded that contamination tends to modify the nature of soil from inorganic to organic. The SEM and EDX analysis of the sample showed presence of silica content in contaminated and uncontaminated soil and amount of oxygen in soil is also higher which showed presence of higher moisture content. The geotechnical characteristics of soil were affected due to open dumping having higher effect on the upper layer of soil.

The value of specific gravity in lower layers is similar to uncontaminated soil which showed that level of contamination in lower layers is lesser which has not much affected the properties of soil. However, there is insignificant variation in particle size for samples which is found to depict soil as poorly graded sand (SP).

The results showed that MDD reduces from 17.18 kN/m³ to 16.5 kN/m³ and OMC increases from 15.8% to 17.5% for the contaminated soil compared to uncontaminated soil for which MDD is 17.1 kN/m³. This reduction in MDD is due to degradation of organic substance available in waste. Consequently, decrease in void ratio is attained and hence smaller permeability of contaminated soil. The electrically neutral sand particle gets charged due to deposition of heavy metals thereby increasing bonding between soil particles and inducing apparent cohesion. Hence, it could be concluded that shear strength of contaminated soil is higher than uncontaminated soil. The higher values of cohesion and smaller angle of internal friction of dumpsite soils reveal reduced shear strength when distinguished with natural soil. The CBR value of dump soil as compared with the natural soil decreased by 12% -17% and 20-25% for un-soaked and soaked conditions.

In this context, treatment of soil and analysis of settlement should be done to avoid any damage or reducing differential settlement in near future. Thus, settlement analysis of soil showed that increase in moisture content, temperature accelerate the biodegradation process of MSW and thus increasing the settlement of soil layer containing MSW. The predicted settlement of soil is significant for causing differential settlement in soil and mainly depends upon the amount of MSW fraction in soil. Thus, with increase in MSW dumping and rate of degradation, settlement of soil is increased. In this context, it is recommended that for minimizing the adverse effect of MSW on soil an engineered landfill should be constructed.

REFERENCES

1. Kumar, S., Gaikwad, S.A., 2004. Municipal Solid Waste Management in Indian Urban Centres: An Approach for Betterment. Urban Development Debates in the New Millennium, Edited by K.R. Gupta, Atlantic Publishers & Distributors, New Delhi, 100-111.
2. Rana, R., Ganguly, R., Gupta, A.K., 2017. Evaluation of Solid Waste Management in Satellite Town of Mohali and Panchkula India. Journal of Solid Waste Technology and Management, 43(4): 280-294.
3. Hazra, T., Goel, S., 2009. Solid waste management in Kolkata, India: Practices and challenges. *Waste Management*, **29**, 470-478.
4. Sharholy, M.K., Ahmad, G.M., Trivedi, R.C., 2008. Municipal solid waste management in Indian cities – A review. Waste Management, 28, 459-467.
5. Adefemi, B.A., Wole, A.C., 2013. Geotechnical Characterisation of Abandoned Dumpsite Soil. Journal of Earth Science, **2**(3): 90-100.
6. Alhassan, M., 2012. The effects of municipal solid waste on the geotechnical properties of soils. International Journal of Environmental Sciences, Management and Engineering Research, **1** (5), 204-210.
7. Nanda, H.S., Shivaraju, R., Ramakrishnegowda, C., 2011. Impact of Municipal Solis Waste Disposal on geotechnical properties of soil. Proceedings of Indian Geotechnical Conference Kochi 183, 175-716.
8. Milad, Z.A., 2014. An experimental investigation of landfill leachate impact on surrounding soil. PhD Thesis Geo-environmental Research Centre, Cardiff, School of Engineering, Cardiff University.
9. Sujatha, E.R., Gurucharan, R., Ramprasad, C., Sornakumar, V., 2013. Impact of Municipal Solid Waste Dumping on the Geotechnical Properties of Soil and Ground Water in Ariyamangalam, Trichy, India. Electronic Journal of Geotechnical Engineering, 18 Bund K.: 2119-2132.
10. Nugroho, S.A., Yusa, M., Ningsi, S.R., 2012. Correlation between Index Properties and California Bearing Ratio Test of Pekanbaru Soils with and without Soaked. International Journal of Civil Engineering, 4(1), 53-63.
11. Harun, S.N., Zulfahmi, R.A., Rahim, A.S., Lihan, T., Idris, R.M.W., 2013. Effect of leachate on geotechnical characteristics of sandy clay soil. AIP Conference Proceedings 1571, 530. DOI: 10.1063/1.4858709.
12. Bareither, C.A., Benson, C.H., Edil T.B., 2012. Compression behaviour of municipal solid waste: Immediate Compression. Journal of geotechnical and Geo-environmental Engineering, Vol. 138 (9), 1047-1062. DOI: 10.1061/(ASCE)GT.1943- 5606.0000672.
13. Pauzi, N.I.M., Omar, H., Huat B.K., Misran H., 2010. Settlement model of waste soil for dumping area in Malaysia. Electronic Journal of Geotechnical Engineering, Vol. 15, Bund. R 1917-1929.
14. Gource, J.P., Staub, M.J., Conte, M., 2010. Decoupling MSW settlement into mechanical and biochemical processes—Modelling and validation on large-scale setups. Waste Manage. 30(8), 1556–1568.
15. Chakma, S., Mathur, S., 2007. Settlement of MSW Landfills Due to Biodegradation. Proceedings of Int. conference on Sustainable Solid waste Management, 5-7 September, Chennai, India. Pp: 234-238.
16. Chakma, S., Mathur, S., 2013. Post closure long term settlement for MSW landfill. J. Hazard. Toxic Radioactive Waste Manage. 17(2),81–88.
17. Census Report of India, 2011. Provisional Population of India. Director of Census Operations, New Delhi, India.
18. ASTM D 5231-92, 2016**.** Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste, ASTM International, West Conshohocken, PA, (2016), www.astm.org.
19. ASTM, Annual Book of Standards, 2008. American Society of Testing and Materials, West Conshohocken, PA.
20. ASTM Standard D 2487, 2008. Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System. West Conshohocken, PA: ASTM International (2008).
21. IS: 2720 (Part 1): Preparation of dry soil samples for various tests (1983).
22. IS: 2720 (Part 3/ Sec 1): Reaffirmed 2002. Methods of Test for Soils: Part-3, Determination of Specific Gravity, Fine Grained Soils. Bureau of Indian Standards (1980).
23. IS: 2720 (Part-2): Methods of Test for soils. Determination of water content. Bureau of Indian Standards (1986).
24. IS: 2720 (Part 4): Indian Standard Code of practice for Methods of Test for Soils, Determination of Grain Size Analysis. Bureau of Indian Standards (1985).
25. IS: 2720 (Part 7): Methods of Test for Soils: Part-7, Determination of Water Content Dry Density Relation using Light Compaction. Bureau of Indian Standards (1980).
26. IS: 2720 (Part 17): Methods of test for soils, Part 17: Laboratory determination of permeability. Bureau of Indian Standards (1986).
27. IS 2720 (Part 13), Indian Standard, Methods of test for soils (Reaffirmed-2011). Direct shear Test (Second Revision). Bureau of Indian Standards (1986).
28. IS: 2720 (Part 16): Methods of Test for Soils. Laboratory Determination of California Bearing Ratio. Bureau of Indian Standards (1987).
29. Chen, Y., Ke, H., Fredlund, D.G., Zhan, L., Xie, Y., 2010. Secondary compression of municipal and a compression model for predicting settlement of municipal solid waste landfills. J. Geotech. Geoenviron. Eng., 136(5), 706–717.
30. Hettiarachchi, C.H., Meegoda, J.N., Tavantzis, J., Hettiaratchi, J.P.A., 2007. Numerical model to predict settlements coupled with landfill gas pressure in bioreactor landfills. J. Hazard. Materials 139(3):514–522.
31. Yuen, S.T.S., Styles, J.R., 2000. Settlement and characteristics of waste at a municipal solid waste landfill in Melbourne. Proc., Geo Eng. Int. Conf. on Geotechnical and Geological Engineering, Vol. 2, Pub Hoek, Australia, 309–314.
32. Rana, R., Ganguly, R., Gupta, A.K., 2018. Physico-chemical characterization of municipal solid waste from Tricity region of Northern India: a case study. Journal of Material Cycles and Waste Management 20(1):678-689.
33. Thakur, D., Ganguly, R., Gupta, A.K., Ghali, V., 2019. Evaluation of existing solid waste management system in Una town India. In: Sustainable Waste Management: Policies and Case Studies. Springer Nature Singapore Pte. Ltd. 2020. https://doi.org/10.1007/978-981-13-7071-7_33.
34. Bowles, J.E., 2012. Engineering Properties of Soils and their Measurements. 4th edition, McGraw Hill Education (India) Private Limited, New Delhi.
35. Gratchev, I.B., Towhata, I., 2009. Effects of Acidic Contamination on the Geotechnical Properties of Marine Soils in Japan. University of Tokyo, *Proceedings of 19th International Offshore and Polar Engineering Conference*, pp. 21-26.
36. Bandini, P., Kumar, S.S., 2009. Effect of silt content and void ratio on saturated hydraulic conductivity and compressibility of sand-silt mixtures. Journal of Geotechnical and Geo-environmental Engineering, 135 (12), 1976-1980.

37. Sharma, H.D., Reddy, K.R., 2004. Geo-environmental Engineering: Site Remediation, Waste Containment and Emerging Waste Management Technologies, John Wiley & Sons, Hoboken, New Jersey.
38. Siddiqui, A., Powrie, W., Richards, D., 2013. Settlement Characteristics of Mechanically Biologically Treated Wastes. J. Geotech. Geoenviron. Eng., 139(10), 1676–1689.
39. Song, Y.S., Yun, J.M., Hong, W.P., Kim, T.H., 2003. Investigation of solid waste soil as road construction material. Environmental Geology, 44:203-209.