CHARACTERIZATION AND SETTLEMENT ANALYSIS OF MUNICIPAL SOLID WASTE

THESIS

Submitted in fulfillment of the requirement for the Degree of

DOCTOR OF PHILOSOPHY

By

DISHA THAKUR

Enrollment No. 166603

DEPARTMENT OF CIVIL ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,

WAKNAGHAT, HP, INDIA

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NOVEMBER, 2019

……....DEDICATED TO

MY PARENTS………

TABLE OF CONTENTS

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DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the Ph.D. thesis entitled **"Characterization and Settlement Analysis of Municipal Solid Waste"** submitted at **Jaypee University of Information Technology, Waknaghat, Himachal Pradesh, India**, is an authentic record of my work carried out under supervision of **Prof. Ashok Kumar Gupta** and **Dr. Rajiv Ganguly.** I have not submitted this work elsewhere for any degree or diploma. I am fully responsible for the contents of my PhD. thesis.

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Date: 21/01/2020

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SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled **"Characterization and Settlement Analysis of Municipal Solid Waste",** submitted by **Disha Thakur** at **Jaypee University of Information Technology, Waknaghat, Himachal Pradesh, India,** is a bonafide record of her original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

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(Disha Thakur)

ABSTRACT

The disposal of municipal solid waste in unscientific and haphazard manner causes harmful impact on environment. The open dumping is most common method adopted for waste disposal in most of the developing countries including India which require immediate attention for minimizing its impacts on environment and human health. Therefore, disposal of waste in engineered landfill helps in reducing the impact of waste. In this regard, the present study focused on evaluation of current waste management practices adopted in the study region, waste characterization and effect of degradation on properties of waste. The study of geotechnical parameters of waste provides a base line for assessing the stability of landfill. The degradation of waste changes the waste properties with time and affecting the stability of slopes of landfill. Thus, analysis of shear behavior of waste was done for determining the shear strength of waste with degradation and age of waste. Further, the stability of landfill depends upon the factors like biodegradation, moisture, temperature, compression, density of waste. Thus, the analysis of settlement of waste in the landfill was determined for analyzing the stability and structural integrity of different components of landfill.

The waste management practices adopted in the study area were evaluated using wasteaware benchmark indicator and quantification of results obtained was done using the matrix method. The wasteaware benchmark indicator showed that despite of good collection efficiency of waste, the performance of the environmentally controlled treatment and disposal methods, 3R’s methodologies in the study area were poor. The matrix method indicated the overall weightage of 38% for efficiency of waste management practices adopted in area which lies in low/medium index. The characterization of waste for the study area showed the presence higher fraction of organic waste (56%) followed by paper (12.2%) and plastic (10.2%). The chemical characterization of waste revealed that higher C/N ratio of waste make it suitable for composting. Depending upon the characterization results, suitable alternatives for handling the waste and recommendation for adopting the suitable waste to energy (WTE) techniques has been presented.

The geotechnical properties of waste influence the stability of landfill which changes due to degradation of waste. The degradation of waste changes its mechanical properties with time. The observed results depict that degradation of waste changes properties of waste thus increasing the inert fraction in waste. The degradation of waste results in closer packing of particles, reducing the voids, increasing the unit weight and shear strength of degraded waste than fresh waste. The compressibility of fresh waste was observed to be 0.19-0.29 and for degraded waste it decreased from 0.12-0.17. The shear behavior of waste sample was analyzed using large direct shear test for determining the effect of age and degradation on strength of waste. The results showed that for fresh and degraded waste friction angle increases from 16° to 24° and cohesion varied from 30.8 - 35.5 kPa. The effects of depth on the shear strength were observed for the degraded waste which showed variation in cohesion and friction angle from 31.9 – 33.2 kPa and 19° -21° respectively.

Further, analysis of effect of open dumping on the geotechnical and geochemical properties of soil were evaluated. The SEM and EDX analysis comprehend the morphology and elemental composition of soil. The assessment of geotechnical properties showed the presence of mix waste fraction in soil. The specific gravity, compaction, permeability and CBR of dump soil showed lesser values in comparison to natural soil. However, the effect of waste was observed to be higher in top layer and decreased with increasing depth in subsoil.

Analysis of the settlement of waste under anaerobic conditions is important for stability after post closure of landfill. In this context, the settlement of fresh sample was analyzed under constant loading of 50 kPa over a period of 202 days. The results showed the immediate settlement of 29.9% in waste sample and the primary settlement of 10.14% was observed to be completed after 48 hours of load application. The results showed that the higher rate of initial settlement was due to organic fraction, poor compaction of waste. The degradation constant for the waste was determined to be 0.477 day^{-1}. The secondary settlement of 5.85% at end of 202 days was observed in the reactor. The settlement of waste was modeled to predict the post closure settlement of landfill and it was observed that for 202 days, biodegradation and mechanical compression results in settlement of 6.4% and 10-18% respectively. The prediction of settlement helps in considering the effect of degradation and compression on stability of landfill while designing the components like final cover and drainage system.

Keywords: Characterization, Municipal Solid Waste, Shear Strength, Anaerobic Digestion, Biodegradation, Compression, Settlement.

ABBREVIATIONS AND ACRONYMS

AAS	Atomic Adsorption Spectroscopy
AD	Anaerobic Digestion
C&D	Construction and Demolition
CIPET	Central Institute of Plastic Engineering and Technology
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organization
CTS	Combined Treatment System
EDX	Energy Dispersive X-ray Spectroscopy
GDP	Gross Domestic Product
GHG	Green House Gas
GOI	Government of India
HHVs	High Heating Value
HPSPCB	Himachal Pradesh State Pollution Control Board
ISWM	Integrated Solid Waste Management
MBT	Mechanically Biologically Treated
MC	Municipal Corporation
MoEF & CC	Ministry of Environment, Forest and Climate Change
MoUD	Ministry of Urban Development
MNRE	Ministry of New and Renewable Energy
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NGO	Non-Governmental Organization
NEERI	National Environmental Engineering Research Institute
PIB	Press Information Bureau

RDF	Refuse Derived Fuel
SEM	Scanning Electron Microscopy
SPCB	State Pollution Control Board
SWM	Solid Waste Management
SWOT	Strength Weakness Opportunities and Threats
TERI	The Energy Resource Institute
TPD	Tons Per Day
ULB	Urban Local Bodies
US EPA	United State Environmental Protection Agency
WHO	World Health Organization
WEEE	Waste Electrical and Electronics Equipment
WTE	Waste to Energy

NOTATIONS AND SYMBOLS

θ	Moisture content
ρ	Density of waste
$\% \ f$	Percentage of waste under diverse classes
τ	Shear stress (kPa)
σ	Normal Stress (kPa)
$\Delta\varepsilon_v$	Vertical strain increment (%)
$\Delta\sigma_v$	Vertical stress increment (kPa)
ϕ	Angle of internal friction (°)
γ_0	Initial unit weight (kN/m³)
γ_e	Unit weight at maximum applied stress (kN/m³)
α_ε	Creep parameter
ε_c	Creep induced settlement strain
ε_{bi}	Strain due to biodegradation
ε_{mi}	Strain attributable to mechanical compression
C_m	Coefficient of compressibility for mechanical compression
$\Delta\gamma_j$	Increment of unit weight imposed by lift j on lift i
ρ_0	Initial value of density, kg/m^3
ρ_m	Maximum value of density, kg/m^3
X_{fi}	Organic content at any stage of degradation
X_{fo}	Initial organic content
Δh	Change in height of waste due to creep
c	Cohesion (kPa)
c_v	Consolidation coefficient,
$C_{\alpha\varepsilon}$	Coefficient of secondary settlement
d	Max. drainage path length (m)

H	Thickness of the landfill (m)
H_i	Initial height of compacted lift (m)
h_p	Height of waste at end of primary settlement (mm)
k	First-order degradation rate constant (day^{-1})
M_s	Initial mass of biodegradable organics in waste (kg)
M_{si}	Masses of different components of waste
t	Elapsed time after loading (days)
t_1	Time of completion of primary settlement (days)
T	Time factor
$V_{i,N}$	Initial volume of every layer (m^3)
$V_{S,N}$	Total volume of layers of landfill (m^3)

List of Figures

List of Tables

CHAPTER -1

INTRODUCTION

1.1 Background

The waste within household, communities, market and public service actions is an inevitable by-product of the human activities. These activities are domestic, agricultural, commercial, industrial and satisfying the growing needs of habitats resulting in generation of waste [1,2,3,4]. Due to growing industrialization, urbanization and prospering economy in India, the generation of MSW has increased to large extent which results in difficulties for its management to people and urban local bodies (ULB) [5,6,7]. The generation of solid waste, composition and treatment methods varies for different countries depending upon the existing management system, prevailing economic conditions and other associated factors [8,9].

The mismanagement of solid waste and unscientific disposal may lead to health hazards and environmental problems. Thus, the generated solid waste if managed properly can be reused as a source for the energy generation and fuel recovery. The proper management of waste needs the cooperation and collaboration for the efficient delivery and comprises the aspects for generation of waste, collection, transportation, recycling, treatment and final disposal [10,11]. The MSW is termed as unwanted material generated from various activities from residential, commercial, institutional sectors, agricultural activities etc. The *US Environmental Protection Agency* defines MSW as trash or garbage which consists of everyday items like furniture, clothing, grass, packaging, food scraps, appliances, packaging etc. that comes from schools, hospitals, homes and business [12]. The different sources of MSW were shown in *Figure 1.1*.

The municipal solid waste mainly arises from household waste and commercial waste including degradable and non-degradable matters [13,14,15]. The generated waste is heterogeneous in nature constituting paper, plastic, food waste, glass, metals, textiles, yard waste and other miscellaneous materials [16]. The generation and management of MSW has emerged as growing problem at worldwide, regional and local levels due to economic development and fast-growing population in developing countries [11,17,18]. The problems due to different issues including urbanization, increased population and increased consumption of goods and services thereby increasing the generation of waste [19]. The problem in effective management of waste majorly in urban areas is because of unscientific approach for waste management which has worsen the problems of environmental pollution, health of people, hygiene [20]. Thus, for effective and sustainable management of waste, source and composition, rate of waste generation, collection, transportation, pretreatment and disposal methods need to be understood.

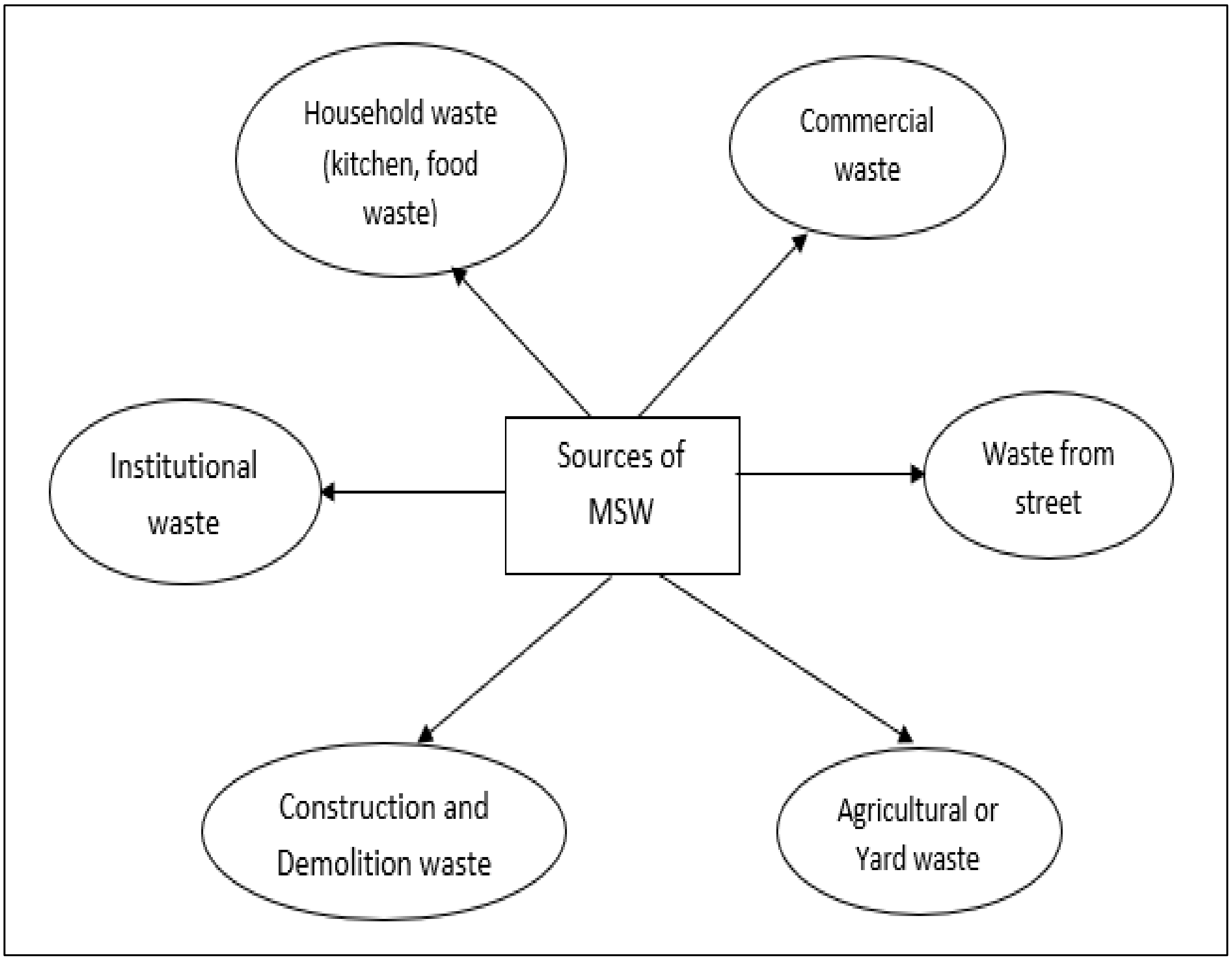


Figure 1.1: Various sources of MSW.

Additionally, the disposal of waste in open land is common practice in most of the developing countries [1,3,21]. This method of disposing waste in open land causes serious health hazards and adverse environmental effects. So, construction of engineered landfill is one of the effective and environmentally acceptable method of disposing waste [6,22]. The biodegradable and non-biodegradable fraction of MSW have harmful impact on both soil and groundwater [7]. The leachate generated due to decomposition of waste migrates through soil leading to contamination of soil and groundwater [23,24]. Leachate is brown liquid containing heavy metals, toxic chemicals including solvent, organic or inorganic salts [25,26] affecting the ground water and soil properties [27,28]. The dumping of waste thus severely affects the engineering properties of soil like compressibility, permeability, shear strength, California Bearing Ratio (CBR) values and other related parameters [29,30,31]. Further, continuous disposal leads to the settlement of soil and causes the structural damage to the landfill. Settlement of contaminated soil and MSW is complex because of biodegradability, heterogenous nature, and density variability of waste. Thus, analysis of geotechnical properties and settlement behavior of soil is important for consideration of end use of landfill for recreational purposes.

The waste dumped in the landfill site decomposed due to presence of significant amount of organic matters present thus causing considerable amount of settlement. The settlement of MSW occurs over a long period of time which can be up-to 30-50% of the initial height of the waste and contributes to different settlements rates [32,33]. The settlement of MSW is due to high compressibility under influence of biodegradation of organic content and overburden load. The overburden load in landfill occurs due to additional overlying waste layer and thus increasing the stress at various depths [34,35].

Additionally, the stability is major concern to be overlooked during designing of landfill. The disposal of waste creates challenges for landfill designing and operation, mostly in hilly terrain. The complex characteristics and composition of waste thus makes it necessary for analyzing settlement, slope stability, seepage and cracking of components of landfill [36,37,38,39]. Thus, despite of analyzing the characteristics of waste for management and selecting suitable treatment option, the geotechnical characteristics of waste, soil and settlement behavior of MSW need to be considered for determining the structural stability and designing the landfill.

1.2 Waste Generation

1.2.1 Global Waste Generation

Breaking of the ecological diversity in the environment that results in the environmental pollution is the main factor caused by the humans. The growing population and increase in consumption have resulted in large production of waste worldwide. The developed countries are having high rate of per person waste generation as compared to developing which is mainly influenced by public habits, life style of habitats and economic growth [21,40]. As per the report of World Bank, the total solid waste generation is expected to increase from 2.01 billion tons in year 2016 to 3.4 billion tons in next 30 years [41,42]. The generation of MSW across the globe was estimated to be 13.3% of the total waste generated and is increasing at a very high rate [41]. As per the report of world bank, presently the global annual generation of waste is expected to increase from 2.01 billion tons in 2016 to 3.4 billion tons over next 30 years (*Figure 1.2*) with the per person waste generation rate varying between 0.11 kg/day–4.54 kg/day [41].

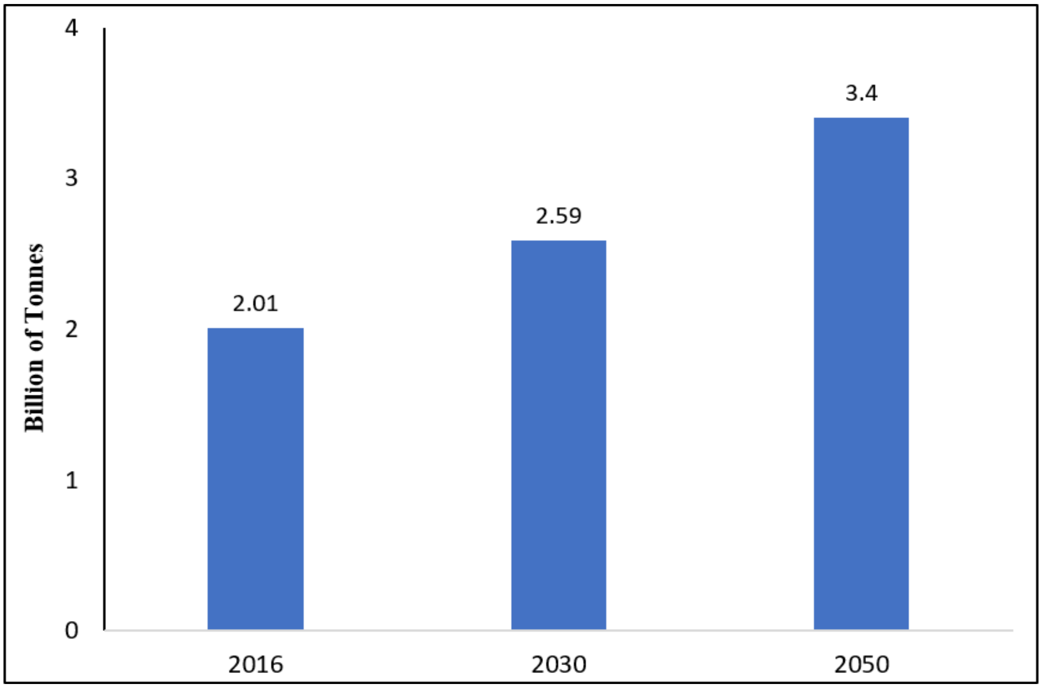


Figure 1.2: Global projected waste generation [41,42].

However, it was stated that global waste will be increased up to 70% by 2050 if urgent actions are not undertaken [41]. Per capita generation of waste is higher in European countries like Denmark (2.12 kg/day), Germany (2.19 kg/day), United Kingdom (1.87 Kg/day), France (2.01 kg/day) [43,44]. Similarly, the Asian countries like Hong Kong, Japan, China, Taiwan, India have higher per capita waste generation of 2.25 kg/day, 1.78 kg/day, 1.09 kg/day, 0.667 kg/day, 0.20-0.87 kg/day respectively [8,45]. The generation of MSW in Asian urban areas varies between 103-760 tons per day (TPD) [8,42,47,48,49]. Per person waste generation rate in different countries has been shown in *Figure 1.3*.

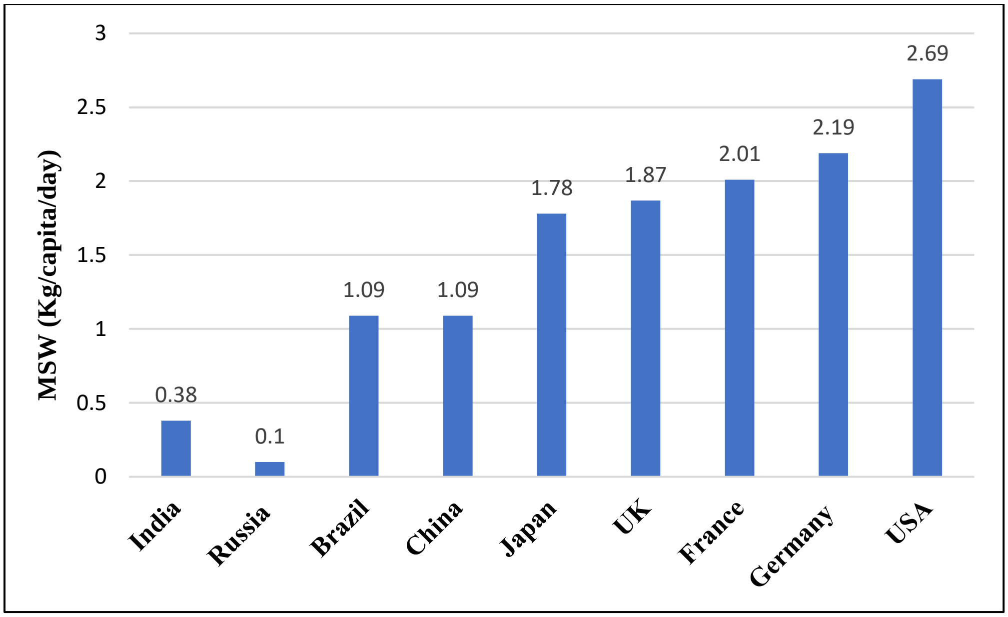


Figure 1.3: Per person waste generation rate in different countries [42].

The higher economic expansion and urbanization results in increased solid waste production. However, the urbanization and income level are directly related to rise in living standards thereby increasing consumption of good and services. The gross domestic product (GDP) is one of factors on which per capita generation of MSW of country depends and is increasing with increase in GDP. Per person/day waste generation for different income level is shown in (*Table 1.1*).

Table 1.1: Per Capita Waste Generation [41].

Income Level	**Projected Per Capita Waste generation (kg/day)**		
	Average	**2030**	**2050**
Low Income	0.40	0.43	0.56
Lower Middle Income	0.53	0.63	0.79
Upper Middle Income	0.69	0.83	0.99
High Income	1.58	1.71	1.87

According to report of World Bank, the growth of waste production in high income countries are expected to be least by 2030 as the economic development has reached at a point of less consumption [41]. The generation of MSW in high income countries is more than low income country depending upon the habits of people, living standard.

The composition of MSW varies for different countries and also within country, cities, urban and rural areas leading to variation in composition of MSW for developed and developing countries (*Table 1.2*) [1,13,50]. However, in developing countries 55-80% of waste comes from household, 10-30% commercial sector with quantities variation from streets, industries, institutions and others [51,52]. The generated MSW from the developing countries is rich in organic content having the higher densities [1,18,53]. However, the recyclable matter paper, plastics glass, metals etc. were found to be higher proportion in developed economies with lower fraction of degradable organic matter [8].

Table 1.2: Composition of MSW in different countries in world [42].

Country	**Organic**	**Paper**	**Plastic**	**Metal**	**Glass**	**Others**
USA	25	38	9	7	6	15
Japan	27	45	9	8	7	4
China	36	3.7	3.8	0.3	2	54.2
Canada	34	29	11	6	7	13
Australia	51	23	7	5	7	7
Hong Kong	37.2	21.6	15.7	3.9	3.9	17.7
France	27	30	10	10	10	13
India	42	5.7	3.9	1.9	2.1	44.6
Sri Lanka	76	10.6	5.7	1.3	1.3	5.1
Bangladesh	84	5.7	1.7	3.2	-	3.2
Nepal	80	7	2.5	0.5	3	7
Malaysia	43	23.7	11.2	4.2	3.2	14.7
Denmark	40	33	8	3	6	10

All values are in %.

1.2.2 Waste Generation and Management in India

Being the second most populated country, India is one of the fastest growing economy in the world. The continuously rising population of nation has imposed a massive burden on economy, resources and the health services. In developing countries like India, the waste generated has a high fraction of biodegradable matter about 35-60% with higher moisture content and density because of food and cultural habits of people [2,13,54]. In India, the overall MSW generation is projected to be about 52 million tonnes per year [55] out of which 23% is processed and taken to the landfill for final disposal. The growth rate of population of the country is 17.6% [56] with per person waste generation rate of 0.2-0.87 kg/day having increasing rate of 1-3% per year [55,57]. The waste generation in country for projected years 2001 to 2051 (*Figure 1.4*) was estimated to be increased by 146% with increase in population [58].

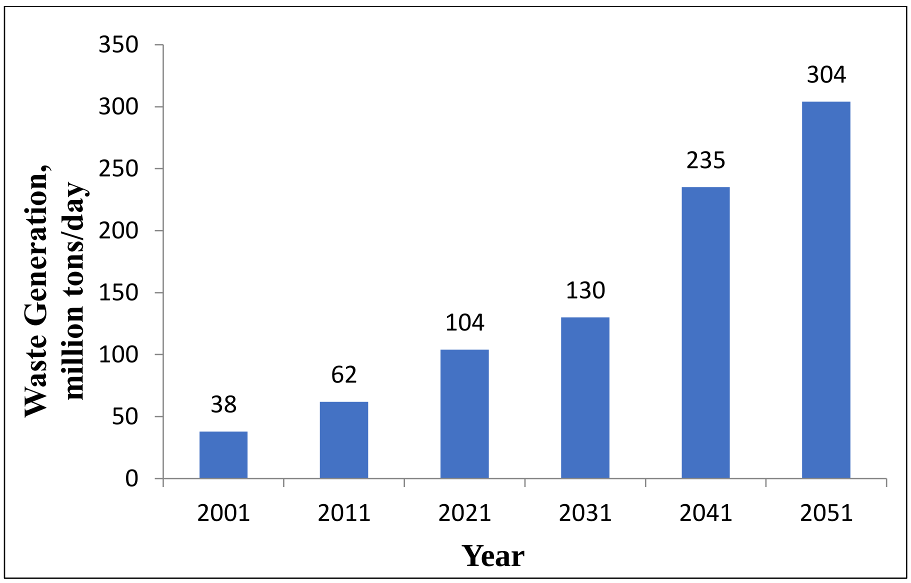


Figure 1.4: Estimation of waste generation in India for projected years (2001-51).

Source: Compiled from research papers and document available [55,58].

As per the Report of World Bank (2012), waste generation in India is estimated to be 1.2-1.42 kg per person per day by next 15 years [42]. The urban areas in India contributes majorly in the waste generation of more than 1,00,000 MT per day [59,60,61]. The large metropolitan cities like Mumbai generates waste about 11000 MT/day, Delhi about 8500 MT/day, Bangalore about 5000 MT/day and other large cities Chennai, Ahmedabad generates about 4000-5000 MT/day of waste [61,62]. The increase in waste generation in large Indian cities is shown in *Figure 1.5* [63]. The production of MSW at a high rate is result of better and high standard of living in urban areas and has become difficult for the municipalities and government to manage the waste [11,64]. The waste in urban area or metro cities is found to be rich in organic and biodegradable matter as presented in *Table 1.3*.

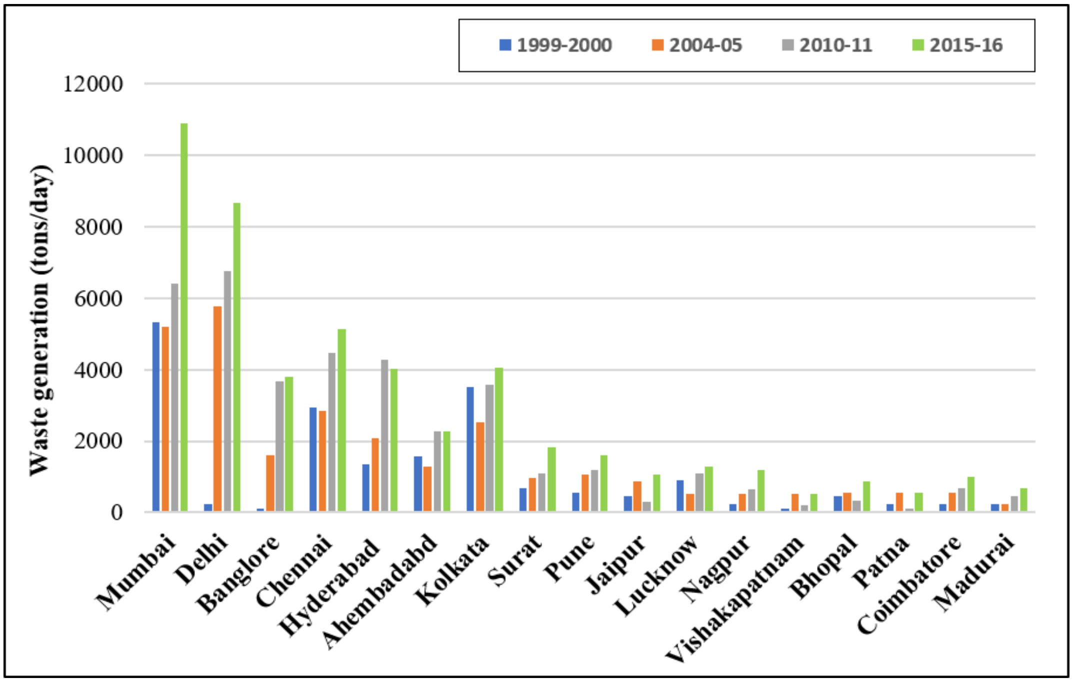


Figure 1.5: Waste generation rate in major cities in India [63].

Table 1.3: MSW composition in Urban areas in India [55,61].

Region	MSW Generation (TPD)	Organic (%)	Recyclable (%)	Inert (%)	Moisture (%)	Calorific Value (kcal/kg)
Metro Cities	51402	50.89	16.28	32.82	46	1523
Other Cities	2723	51.91	19.23	28.86	49	2084
East India	380	50.41	21.44	28.15	46	2341
North India	6835	52.38	16.78	30.85	49	1623
South India	2343	53.41	17.02	29.57	51	1827
West India	380	50.41	21.44	28.15	46	2341
Overall Urban India	130000	51.3	17.48	31.21	47	1751

The waste generation in India is about 39,031 tons per day in 58 cities [55,65] which further increased to 50,592 TPD as investigated by CIPET [55]. Major urban population of country about 65.2% are settled in metro cities and class I cities, generating high amount of waste [66]. The production of waste from the class II and Class III cities is about 3991 MT/day [55].

Due to devastating growth in population and urbanization, sometimes it become difficult for government and municipalities for meeting the continuously increasing demands due to reduced budget available for municipal authorities [67,68,69]. However, the mismanagement of MSW generated in country is because of different reasons including lack of efficient methods for treatment and disposal of waste and deficiency of resources for management of waste. The poor organization of MSW make collection, storage, transportation and disposal the MSW difficult thus leading to illegal and open dumping often in outskirt of town. In India, waste management scenario is not encouraging as around 90% of MSW is disposed on land without giving any prior treatment leading to health hazards, environmental pollution [5,67,73,74,75]. The management of MSW in India is governed by Municipal Solid Waste rules 2000 further revised in 2016 (Management and Handling Rules (MoEF) [72]. The components for effective waste management are shown in *Figure 1.6.*

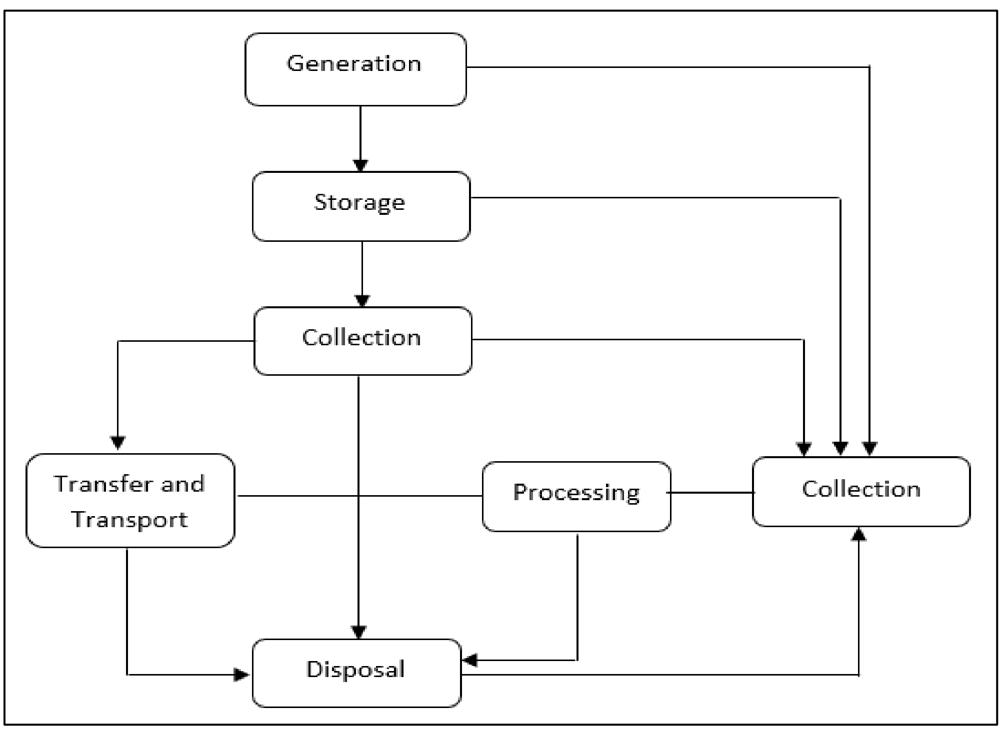


Figure 1.6: Components for Solid Waste Management System.

The quantum of waste generation depends upon the consumption patterns, lifestyle of habitats, socio-economic factors and seasons. The mismanagement of waste has led to the human health risk and adverse impact on environment and poor disposal on land causes the deterioration of water quality and other socio-economic problems [70,71]. The management of waste is necessity and service provided by urban local bodies (ULB) or municipalities. For the consideration of best principles for habitats, public health, environment, aesthetics etc., the waste management should be accompanied with control of waste generation, storage, collection, transportation, processing and final disposal.

The characterization indicates that major portion of MSW is organic 40-60%, 3-6% paper, 30-50% inert material, and 1% others [1,18,63,75]. As per the report of CPCB, in India the total waste generated is 1,45,626 MT/D out of which 101938 TPD (70%) is collected, 18130 TPD (12.45%) is processed and treated [2,55]. The per capita waste generation rate is about 0.2-0.87 kg/capita/day which is higher for urban areas in comparison with rural areas [75]. In Indian cities the present MSW management has worsen with time due to the brimming conditions of the open landfills [53,76]. However, the inefficient management exists in India due to lack of data on generation and characterization, lack of awareness and negligence in implementation of laws thus reduced the provision of budget, resource allocation for management of MSW [77,78].

The total urban population in India is about 377 million [56] accounting for 31% of total population which generates about 1,43,449 MT/day of waste [13,62,79]. The waste generation in states of India is presented in *Table 1.4*. The growth rate of waste generation in India is estimated to be 1-1.33% annually [2,66]. The mismanagement of waste generated in urban cities of developing country is common practice due to lapses in implementation of SWM rules [70].

Common practice of open dumping or burning of MSW leads to contamination of surrounding environment including soil, water and air [8,80,81,82,83]. The efficient MSW management requires appropriate infrastructure, maintenance and upgradation for all activities. But due to unplanned and continuous growth of urban centers, these processes have become expensive and complex. Also, the poor financial status of the municipal corporations had made it difficult to provide the public services in urban areas. Thus, for an effective waste management appropriate waste management polices needs to be framed which can reuse the society’s waste as potential resource. The data regarding composition, quantity and quality of waste is important for sustainable waste management system. The MSW management comprehends scheduling, engineering administration, legal, financial aspects associated with production, collection, transportation, treatment and disposal for environmentally compatible manner.

Table 1.4: Waste generation in different states of India [55].

Sr. No	State/UT	Waste Generation (MT/D)	Sr. No.	State/UT	Waste Generation (MT/D)
1	Andaman & Nicobar	115	18	Maharashtra	22570
2	Andhra Pradesh	6,525	19	Manipur	176
3	Arunachal Pradesh	181	20	Meghalaya	268
4	Assam	1134	21	Mizoram	201
5	Bihar	1192	22	Madhya Pradesh	6424
6	Chandigarh	340	23	Nagaland	342
7	Chhattisgarh	1959	24	Odisha	2460
8	Delhi	10500	25	Puducherry	495
9	Daman Diu & Dadra	81	26	Punjab	4100
10	Goa	240	27	Rajasthan	6500
11	Gujarat	10145	28	Sikkim	89
12	Haryana	4514	29	Tamil Nadu	15547
13	Himachal Pradesh	342	30	Tripura	421
14	Jammu & Kashmir	1792	31	Telangana	7371
15	Jharkhand	2451	32	Uttar Pradesh	15500
16	Karnataka	10000	33	Uttarakhand	1400
17	Kerala	1576	34	West Bengal	8675
				Total Waste Generation =	**1,45,626**

1.3 Infrastructure of MSW Management

1.3.1 Waste Generation and Composition

Since last two decades, result of rapid urbanization, development, economic growth and increased population, has increased the generation of waste enormously due to high consumption of services and resources. The quantity of waste generated is mainly influenced by population, living standards, habits of people, variation in seasons [13,42]. The overall waste generation in India is about 62 million tons per year with growth rate of about 4% [55,84]. The waste is divided into following categories (*Figure 1.7a*) i) biodegradable or organic waste ii) dry or recyclable waste and iii) inert waste.

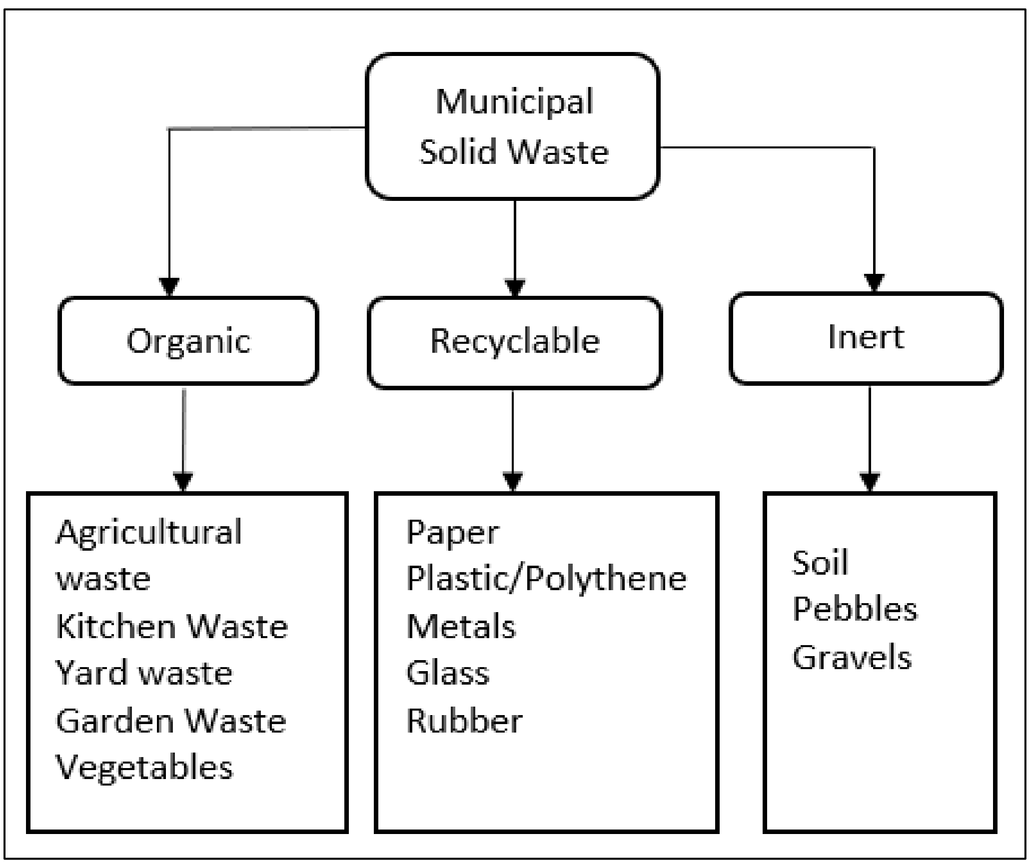


Figure 1.7(a): Components of MSW [1,42,55].

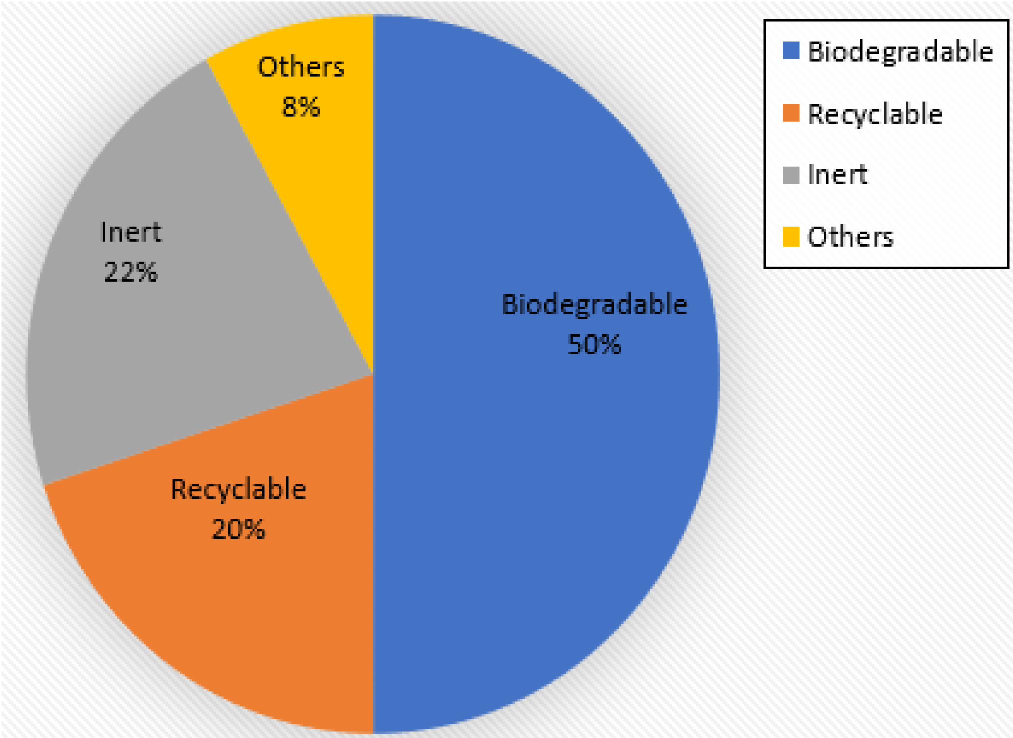


Figure 1.7(b): Composition of MSW in India [55].

The composition of waste generated *Figure 1.7(b)* showed about 50% of waste generated in India is organic and the recyclable and inert waste is growing each year with urbanization [55]. The MSW in developing countries is rich in organic matter having higher moisture content [1,2,8]. *Table 1.5* presents the physical characteristics of MSW. The waste in the Indian cities have higher fraction of organic content and presence of high inert fraction is due to direct disposal of construction and demolition waste in landfill. The chemical characteristics of Indian MSW consists of nitrogen, phosphorous, potassium, C/N ratio as shown in *Table 1.6.*

The presence of nitrogen, phosphate, potassium indicates that the MSW having high organic matter and is rich source of nutrients can be utilized as fertilizer using composting process [5]. These characteristics are also useful for considering the use of MSW as source of energy and also helps in adopting the suitable technologies for waste processing. The waste composition and characteristics are important parameters for selecting the suitable treatment and waste to energy (WTE) technologies.

Table 1.5: Physical characterization of Municipal Solid Waste in Indian cities [50,55].

City	Compostable (%)	Paper (%)	Textile (%)	Leather (%)	Plastic (%)	Metal (%)	Glass (%)	Ash, Fine earth (%)
Ahmedabad	40	6.0	1	-	3	-	-	50
Bangalore	45	8.0	5	-	6	3	6	27
Bhopal	45	10.0	5	2	2	-	1	35
Mumbai	40	10.0	3.6	0.2	2	-	0.2	44
Delhi	31.78	6.6	4	0.6	1.5	2.5	1.2	51.5
Hyderabad	40	7	1.7	-	1.3	-	-	50
Indore	43	5	2	-	1	-	-	49
Jaipur	42	6	2	-	1	-	2	47
Kanpur	40	5	1	5	1.5	-	-	52.5
Kolkata	40	10.0	3	1	8		3	35
Lucknow	40	4	2	-	4	1	-	49
Ludhiana	40	3	5	-	3	-	-	30
Madras	44	10	5	5	3	-	-	33
Patna	45	4	5	2	6	1	2.0	35
Pune	55	5	-	-	5	-	10	15
Surat	40	4	5	-	3	-	3	45
Nagpur	30.40	4.5	7	1.9	1.25	0.35	1.2	53.4
Varanasi	48	3	4	-	10	-	-	35
Vishakhapatnam	35	3	2	-	5	-	5	50

Table 1.6: Chemical characterization of MSW in India [2,55].

Population (million)	Nitrogen (%)	Potassium (%)	Phosphorous (%)	C/N
0.1-0.5	0.71	0.63	0.83	30.94
0.5-1	0.66	0.56	0.69	21.13
1-2	0.64	0.82	0.72	23.68
>2	0.56	0.67	0.64	26.45

1.3.2 Collection and Transportation of MSW

The effectiveness of MSW management system depends upon the collection, transportation and disposal of waste. The management of MSW in Indian cities is responsibility of Municipal Corporation for providing bins for biodegradable, inert waste, trucks, tractors and tippers for transportation and discarding of waste [67,85]. However, in India the collection capacity of waste is less than the waste generated leading to ineffective [86,87]. The collection of MSW involves door to door collection from the municipal bins provided at commercial, institutional places to improve the quality of collection. The collection efficiency of waste in states of India is given by MNRE and CPCB 2016 as shown in *Figure 1.8.*

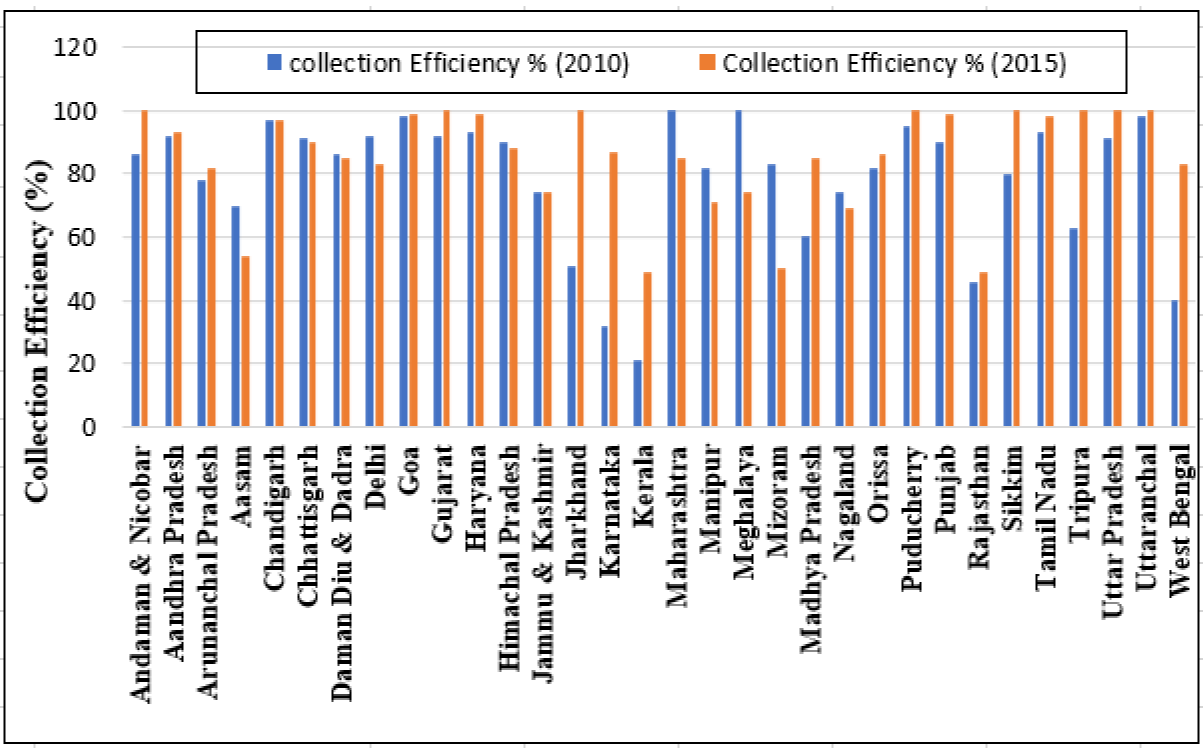


Figure 1.8: Collection efficiency in Indian states [55].

For improving the waste collection concept of "*segregation at source*" is introduced by government of India (GOI) under "S*wachh Bharat Mission"* which can thus reduce the burden of waste at site. In this context segregation of biodegradable, non-biodegradable, recyclable, non-recyclable waste should be encouraged to improve the collection efficiency. The efficiency of collection of waste is about 70-100% for metropolitan cities of country while for smaller cities it decreases to about 50% [1,2,55].

According to SWM rules, 2016 [72], it is responsibility of municipal corporation to manage and transport waste for final disposal at site. However, the transportation of waste is affected by cost, capacity of vehicle, route and design of vehicle [4,11]. In India, about 70% of cities are lacking the transportation facilities being an subsidize to problem of MSW management. The increased urbanization and population growth in cities led to traffic jamming and consequently it become difficult for vehicles to arrive at the disposal sites. Various studies conducted on MSW management reported that the transportation facilities in various cities are poor and outdated. This leads to poor collection, reduces transfer efficiency and increasing the operation and maintenance cost. Additionally, the limited budget provision for the municipalities and lack of funds available results in poor transportation and disposal of waste. As about 80 to 90% of the whole budget of MSW management is utilized for the collection and transportation facilities thus leaving the less budget available for treatment and disposal of waste.

1.3.3 Treatment and Disposal of waste

In India most of ULB's are not having adequate sanitary landfills and the MSW is dumped in outskirts of town or cities. The indiscriminate disposal of waste at open dump or non-engineered landfill sites is majorly associated with the harmful impacts on human health, environment (like soil, water, air). The segregation of municipal solid waste is important aspect for treatment of waste before final disposal. According to *MSW management rules 2016,* the organic or biodegradable waste should be used for composting, vermi-composting, digestion (anaerobic or aerobic) for its treatment and utilizing it as fertilizer [72]. The recyclable and non-biodegradable waste depending upon its composition can be utilized for energy recovery using suitable processes like incineration, gasification, refuse derived fuel (RDF), pyrolysis [88,89,90,91,92].

The treatment and disposal facilities of MSW in the main Indian cities is summarized in *Table 1.7.*

Table 1.7: MSW treatment and disposal in major Indian cities. [2,55].

City	Disposal (%)	Treatment (%)
Mumbai	91	9
Ahmedabad	95	5
Hyderabad	94	6
Bhopal	82	18
Surat	75	25

In India, about more than 90% of waste is openly dumped and is considered as one of the most viable process for disposal of waste due to low economical costs involved [1,2,45]. This process of illegal burning and open dumping has emerged as an ineffective waste management practice [1,18]. The method of direct disposal of waste on land causes the deterioration of soil properties, water quality due to migration of toxic leachate into soil and water and burning of MSW causing the emission of toxic gases into environment, deteriorating the air quality. Additionally, the lack of land availability for the disposal of waste in large cities or town are of immediate concern.

1.4 Environmental Impact of MSW

The urbanization and population growth in the country is solely responsible for the increased generation of waste and has become a problem for the municipalities for managing the waste which leads to odor, poor aesthetic, harmful for environment and human health [93,94,95]. The main fraction of MSW in India is organic which soon after disposal starts degrading. The degradation of MSW leads to generation of leachate and emission of toxic gases causing the harmful effect on living organism and habitats and are also responsible for increasing the global warming potential [95,96].

The MSW has potential to generate the leachate even after the closure of landfill which consequently emerged as problem of water contamination due to leachate migration. The generation of leachate is affected by factors like rainfall, water deposited in waste, temperature resulting in concern for the migration into land as it is categorized by high concentration of organic and inorganic chemicals [47,57,97-100]. In this context, the leachate characteristics are affected with age of landfill, having pH value between 4 - 6.5 (acidic nature) due to carboxylic acid formation during initial five years and the pH varies between 8 to 8.5 (alkaline) due to methane generation in older landfills. The emission of landfill gases (CO_2, CH_4, hydrogen sulfide, nitrogen, carbon monoxide etc.) due to dumping of waste changes the climatic conditions and causing threat to environment. The generation of CO_2 equivalent per year in India is about 16 tons which is expected to increase about 20 tons of CO_2 equivalent per year by 2020 [101]. Nevertheless, scarcity of financial aids for municipalities, the mismanagement of MSW and lack of availability of treating facilities and disposal of MSW has become a matter of concern. Thus, appropriate steps should be taken for remediation of environmental pollution and scientific disposal of MSW with provision of capping system should be considered for minimizing direct emission of gases to environment and reducing the harmful impact on human health.

1.5 Impact of MSW dumping on soil

The most alarming problem emanating from waste in developed and developing countries is management and disposal of waste. The threats caused by indiscriminate dumping MSW in large quantity are increasing enormously and thereby affecting sources of water, soil and properties of soil [31]. MSW disposed in open land and low laying areas without any preventive measures becomes a cause for soil and ground water pollution [102,103]. The heterogeneity of MSW and its complex characteristics affects the soil texture, color, agricultural and engineering properties. The leachate generated due to degradation of MSW contains toxic chemicals and organic, inorganic compounds, heavy metals (Cd, Pb, Cr, Zn, As etc.), migrates into soil and thereby polluting the soil and ground water. Soil pollution due to dumping of MSW, alter the properties of soil and also having impact on soil organisms and vegetation growth in soil [104]. Therefore, the facilities are required for increased amount of waste disposal and preventing the leachate migration into subsoil by proving the cover system to existing dumping site or constructing engineered landfill. However, the stability of the landfill depends upon the properties of underlying soil.

In this context, the evaluation of properties of soil are the major requirement for designing and analyzing the stability of landfill and reuse of site for recreational purposes. Thus, the geotechnical characteristic like compaction, shear strength, permeability, compressibility of soil has been analyzed and discussed.

1.6 Effect of degradation of MSW on Settlement Characteristics

Land filling is considered as one of the appropriate and cost-effective method for disposal of waste [2]. Thus, understanding the geotechnical properties of MSW is necessary for designing and operation of the landfill. The composition and heterogeneous nature of MSW affects the void ratio, water content, unit weight, shear strength and compressibility and are important parameter for analyzing landfill performance [37]. However, the composition and characteristics of waste varies with moisture content for developing and developed [2,77]. Also, the degradation of organic matter of MSW occurs due to micro-organisms present and moisture content which influences the physical stability of structure. This process occurs in different phases of aerobic, transition, acidogenesis, acetogenesis and methanogenesis and thereby increasing the rate of degradation. Waste degradation changes properties of municipal solid waste and these changes are used for assessing the geotechnical stability and failures like cracking, settlement, slope stability of landfill [105].

However, the prediction of settlement is complex because of heterogeneous nature of MSW, moisture content, variable density, unit weight, compression characteristics [106]. The settlement of municipal solid waste is associated with large reduction in volume of waste due to degradation of organic content of waste and initial compression. The settlement of MSW occurs in three processes (i) immediate/initial compression (ii) mechanical creep and (iii) bio-compression [34,107,108,109,110].

The immediate compression of MSW is stress dependent which occurs with increasing vertical stress. The mechanical creep and bio-compression occurs under constant vertical stress and are time dependent processes. The reorientations and physical yielding of MSW occurs during the mechanical creep and biodegradation and settlement of MSW is affected by moisture content, temperature because of the presence of micro-organisms in waste [111].

In this context, the properties of MSW in the geotechnical perspective are important at the time of closure of landfills and its expediency for land development practices. Therefore, the analysis of geotechnical properties and variation with degradation of MSW have been of paramount importance for stability and structural integrity of landfill.

1.7 Regulatory Framework for Waste Management in India

In India the MSW management is one of the most neglected aspects and thus for MSW administrative authority, it has been mandatory to undertake responsibility for regulating the activities of MSW management and handling. To handle the problems related to MSW the Municipal Solid Waste (Management and Handling) Rules 2000 were introduced by government of India (GOI) under supervision of Ministry of Environment and Forest and Climate change (MoEF&CC), National Environmental Engineering Research Institute (NEERI), Central Pollution Control Board (CPCB), Ministry of Urban Development (MoUD) and State Pollution Control Boards (SPCB). The guidelines were further improved and revised in 2013, 2016 as MSW Management and Handling Rules 2000 (revised in 2013, 2016).

The management rules for handling and managing different types of waste are:

Municipal Solid Waste Management and Handling Rules 2000 (revised draft 2013, 2016): The guidelines are designated for ULB's and municipalities by MoEF to lay down the mandatory functions.

Plastic Waste (Management and Handling) Rules 2016: Guidelines for managing plastic waste and minimizing the use of recycled plastic bags for packaging and ban on use and disposal of plastic at public place.

Bio-medical Waste (Management and Handling) Rules 2009 (draft revised in 2011, 2016): To prevent the disposal of hospital and bio-medical waste along with the MSW.

Hazardous Waste Rules 1989, (revised in 2003, 2010): The hazardous waste is typically identified depending upon properties like corrosivity, ignitability, toxicity and to ensure this waste do not get mixed with MSW, is the responsibility of ULB's.

E-Waste (Management and Handling) Rules, 2016: Recovery of reusable and valuable material from Waste Electrical and Electronics Equipment (WEEE).

Construction and Demolition (C&D) Waste Rules, 2016: To obstruct the disposal/demolition of construction and demolition waste along with MSW and separate disposal sites needs to be used for the particular waste.

1.8 Need of the Study

The MSW management has become a challenge for the country with increasing urbanization and population. The management of waste is one of important and essential service provided by municipalities and ULB's for maintaining the cleanliness of the town or city. However, the municipal authorities dispose the MSW in dump yard or on open land outside the city in haphazard manner. Improper and ineffective management of waste in India is due to absence of segregation, deficiency of transportation vehicle, open dumping and illegal burning of waste. Despite of dumping of the waste, the management of waste associated with treatment and scientific disposal are lacking in Indian context. Implementation of strategies for effective MSW management includes consideration of factors like living standards, habits of people, climatic and socio-economic conditions. Also, the flaws in MSW management in India are due to lack of data availability regarding generation, treatment, limited resources availability for collection, transportation of waste and limited information about characterization of waste which limit the waste management in country.

Una is one of the cities in Himachal Pradesh which is experiencing the growth of commercial, institutional and industrial sector, thus requires consideration for managing the increased waste being generated. In this context, on considering the environmental impact and health issues of dumping waste, current study emphases on the assessment of existing practices of waste management in study area and characterizing the waste generated. The remedial measures for improvement of MSW management are also recommended. Additionally, no literature is available for enumerating the impact of open dumping on properties of soil in the study region. Considering the efficient disposal of waste in engineered landfill, the stability and structural integrity of landfill is major factor which depends upon the MSW characteristics and settlement behavior of MSW. The observed characteristics of MSW can be utilized for analyzing landfill stability and settlement. Thus, the present study focuses on determining the effect of dumping on soil and settlement of MSW owing to biodegradation of waste. Depending upon the analyzed geotechnical characteristics, the determination of the effect of MSW on soil and its remedial measures for minimizing the harmful effect along with the recreation needs to be done. In addition, researches in specific areas or nations are necessary for qualitative analysis.

1.9 Objectives of Research Work

The objectives for the present research work comprise:

1) To evaluate the existing municipal solid waste (MSW) management practices in Una Town, India.
2) To determine the physical and chemical characteristics of municipal solid waste in Una Town.
3) To assess the effect of degradation on geotechnical properties of municipal solid waste.
4) To study the impact of degradation on stress-strain behavior of MSW.
5) To evaluate effect of municipal solid waste dumping on geotechnical properties of soil.
6) To determine the settlement of municipal solid waste under anaerobic digestion conditions.

1.10 Thesis Outline

- The first chapter is essentially a brief introduction to the study conducted which gives an overview on solid waste and status of waste management in India including generation, collection, storage, transportation and final disposal of waste. Additionally, chapter also highlights the effects on environment including water, soil and air pollution and human health because of non-engineered landfill sites and open dumping of waste. Further, the initiatives and steps taken for waste management and handling by government and responsibility of municipalities and ULB's were also discussed.

- The second chapter deals with review of available literature related to management of MSW and consequence of dumping waste openly or unscientifically on environment in global and Indian context. The studies showing the geotechnical behavior of MSW, effect of aging on properties of MSW and its impact on soil and surrounding environment was discussed in this chapter. The research carried out earlier and facts and gaps in the context of present research work are discussed in this chapter.

- The third chapter discussed the existing MSW management practices carried out in study location Una, town, Himachal Pradesh. The analysis of current management practices in study area was done using Integrated Solid Waste Management (ISWM) benchmark indicators. This method is also called as "*wasteaware*" benchmark indicator used along with the matrix method for quantification and understanding system analysis approach for improving, analyzing and understanding the efficiency of SWM services. The suggestions and recommendation have been presented in this chapter for improvement of waste management practices in the town.

- Fourth chapter present the physical and chemical characteristics of waste for different seasons (summer, monsoon, winter) for analyzing the energy potential (calorific value) of MSW to manage waste generated for sustainable development. The mathematical models were used to assess the energy generation potential in terms of calorific value of waste. Different waste to Energy (WTE) techniques for utilization of energy value based on characterization results were also discussed in this chapter.

- The fifth chapter presents the analysis of geotechnical properties of waste to determine the strength, compression characteristics etc. which can further be utilized for evaluation of settlement of landfill.

- The sixth chapter deals with the analysis of stress strain behavior with aging/degradation of MSW. The effect on shear strength of MSW due to degradation is an important factor in term of consideration of landfill slide failure, settlement of landfill.

- The seventh chapter presents the effect of MSW on geotechnical properties of soil with in the periphery of dump site. The chapter discussed the variation in geotechnical properties of soil in comparison with natural soil to assess the level of pollution due to direct disposal of MSW on the land. The scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) techniques has been used to analyze the element configuration and morphology of dump soil and natural soil as well.

- Chapter eight deals with the evaluation of settlement of MSW under the anaerobic digestion condition being a vital element for designing of landfill. It includes the biogas determination (CO_2, CH_4), leachate quality, temperature variation and rate of biodegradability of MSW under the simulated laboratory conditions. In this context, the settlement of MSW was determined under the different loading conditions, with leachate recirculation to increase the rate of biodegradation.

- Chapter nine discusses the summary and conclusions derived from the study and also some recommendations for improving waste management practices in Una town are given mentioning the future scope of the research work.

CHAPTER -2

LITERATURE REVIEW

2.1 Introduction

The enormous growth in waste generation due to rise in population, economic development and growing urbanization has resulted in major environmental issues at global and national level [1,17]. The management of MSW has thus become the challenge due to inadequate waste management processes and treatment technologies which affects the environment and health of living beings [6,7]. The problems in waste management are multifaceted because of waste generated, heterogenous nature and reduced amount of financial resources to municipalities [96]. The most common method adopted for the waste minimization is unscientific disposal of waste in open land and low-lying areas [1,48,114]. However, the disposal of municipal solid waste without any prior treatment or management poses threat to the environment and human health. The production of leachate due to degradation, illegal burning which results in emission of gases (methane, carbon dioxide, hydrogen sulfide etc.) results in the contamination of soil, water and air [97,99,101,103]. Therefore, it is mandatory to improve waste management system for the processing, treatment and disposal of waste.

In this regard, the literature has been studied for understanding the generation of waste, management practices adopted, characterization and impact of waste disposal on environment across the world and in the developing nations. Thus, this chapter reviews the literature of the relevant study that will provide the information and facts regarding the efficient and effectual waste management system. Further, the characteristics and mechanical behavior of MSW were studied which would help in providing theoretical and conceptual background for present study.

2.2 Review of Literature

Continuous rapid pace in urbanization, industrialization and development, the quantities of waste generation are projected to increase considerably. Also, large economies like China, India, Japan, USA, France are witnessing the unabated growth in waste generation and its impact on environment is growing very fast which may worsen in future [45,112]. Despite of growth in waste generation, the quality of management system, treatment methods and urban environment has not been improved. However, best efforts of waste avoidance by reduction, reuse, recovery has been attempted world-wide and despite of that landfill and waste disposal sites are the final option for ultimate disposal of residual waste, incineration residues [41,50].

A study conducted by World Bank [41] reported that municipalities in low income countries spent 20% of their budget on waste management despite of that 90% of waste is being openly dumped or burned. The solid waste management system in middle income and high-income countries in world accounts for more than 10% and about 4% of budget for waste management.

It was estimated that the waste generation across the world was about 2.01 billion tonnes annually and about 33% of waste was in an environmentally safe manner. Worldwide per person waste generation was about 0.74 kg generally ranges between 0.11-4.54 kg. Per capita waste generation is expected to increase up-to 19% by 2050 for high income countries and up-to 40% for middle- and low-income countries.

A survey conducted by World Health organization (WHO) 1999 stated that generation, quantity of MSW varied for countries, place of living, state, region, areas and other associated factors. However, the growth in population and urbanization has added volume to waste generation and thus required recovery and reclamation services in areas [113]. The developing countries facing problems associated with waste management system are critical than developed countries. The reduction in quality of services provision for waste management was due to lack of financial resources available [57,17,114,115].

The study conducted [1,41,68] provided a review on waste management system and its harmful impacts on environment, human health, economic development. The study conducted by Parrot et al. [116] showed that lesser developed and developing countries produces the waste having higher organic content. In the developing countries, identification of waste stream is essential for assessing the environmental and health issues [1,2,17] for adopting the effective waste management approach.

A study [117] observed the amount of MSW dumped in landfill and for recovery, checking the level of recyclable materials and compost. The increased waste generation has become a major concern for environmental problems and has made it difficult to find solutions for tackling the huge amount of waste generated [54,68]. The management of MSW has become a problem with increased generation of waste. The study analyzed that characteristics of waste with different socio-economic groups, seasons and it was observed that waste generation from the lowest income group is less and also during the winter season lowest amount of waste is generated.

The sustainability of waste management in Asian countries being a heterogeneous region are multifaceted. The study conducted by researcher [8] concluded that sustainability for SWM should incorporate the 3R (reduce, reuse and recycle) technology which is to be compatible with nature of civilization, people and waste as well [8]. The study also observed that Asian countries like Japan showed sustainable approach while countries like China are attempting to meet new demands from unremitting development. Thus, countries have potential to establish the sustainable SWM system through ISWM systems.

The study conducted [75] analyzed and compared the characteristics of different seasons and socio-economic groups indicating that lowest income group produced least amount of waste. The waste characterization for different socio-economic groups and seasons concluded that the waste generated is less during the winter and low-income group generates least amount of waste.

Generally, the trend of throw away culture and disposing waste in landfill or open dumps is being followed throughout the world. Knowing the fact that for sustainable development limited resources are available therefore economic opportunities from waste needs to be utilized [8,118].

For handling the waste, ISWM was introduced in 1995, that includes activities like generation, collection, transport, separation, recycling and disposal for efficiency of system [119]. To attain the sustainable solid waste management, improvement in policies, rules and regulations, legal framework is obligatory. Therefore, the Municipal Solid Waste Management Rules (2000) for handling and managing the waste has made it mandatory for administration to take all responsibility of waste except generation.

Being the second fastest growing economy in world, India is facing many problems for municipal solid waste (MSW) management majorly when it comes for disposal of waste at suitable locations [6,120]. India is having about 16% of world's population [50] and majority of them are living in urban areas. The relocation of people from rural to urban areas has increased the waste generation. In this context, the management of waste is a condemnatory element for sustainable environment toward waste segregation, collection, storage and dumping facilities to minimize its harmful effects. The generation of waste varies for different countries and depends upon the economic condition, income level, habits of people [2] and showed a positive correlation with economic growth [1,50]. It was estimated that by year 2031 waste generation will increase to 165 million tons and up-to 436 million tons by 2050 [72].

Generally, the waste generated from the residential, commercial, institutional sectors gets mixed with construction and demolition waste, industrial waste and disposed in landfill [1,6]. It was reported by CPCB, Ministry of Urban development, Government of India that total waste generation in India is about 52 million tons annually [55,87]. The waste generation in Indian cities is about 1,45,626 MT/day [55] and inert fraction of MSW contributes about 12 million tons from street sweeping and C&D waste [2] which accounts about a third of the total solid waste generated.

The waste generation and characterization may vary for each state, city, town, district and region depending upon the life style of people, food habits [2,7]. Indian states producing higher proportion of MSW includes, Delhi, Tamil Nadu, West Bengal, Maharashtra, Uttar Pradesh [2]. The increment in annual waste generation rate is 1 to 1.5% with increase in population. The waste generation statistics in Indian states has been shown in Table 2.1.

The higher population density and lower MSW services were normally observed in low income areas [8,121] thereby generating abundant volume of waste which is finally disposed in landfill or open dump sites [122].

The study conducted [50] revealed that major class I cities (population > 1 lakh) in India generates about 32,460 TPD of waste which includes major Indian cities like Delhi, Mumbai, Chennai, Ahmedabad, Kolkata, Hyderabad and Bangalore [65]. It was estimated that population of country would be 1823 million by 2051 and MSW generated would be 300 million tons annually [2,65].

Depending upon population size, per capita waste generation rate has been presented in *Table 2.2*.

Table 2.1: Waste generation statistics in different Indian states [2].

Sr. No.	States	MSW Generation (TPD) 2000	MSW Generation (TPD) 2009-2011	MSW Collection (TPD) 2009-2011	Treated (TPD) 2009-2011	Growth, %
1	Andhra Pradesh	4376	11500	10655	3656	163
2	Assam	285	1146	807	73	302
3	Delhi	4000	7384	6796	1927	85
4	Gujrat	NA	7379	6744	873	-
5	Karnataka	3278	6500	2100	2100	98
6	Kerala	1298	8338	1739	4	542
7	Madhya Pradesh	2684	4500	2700	975	68
8	Maharashtra	9099	19204	19204	2080	111
9	Manipur	40	113	93	3	182
10	Meghalaya	35	285	238	100	713
11	Orissa	655	2239	1837	33	242
12	Punjab	1266	2794	NA	Nil	121
13	Puducherry	69	380	NA	Nil	451
14	Rajasthan	1966	5037	NA	Nil	156
15	Tamil Nadu	5403	12504	11626	603	131
16	Tripura	33	360	246	40	991
17	Uttar Pradesh	5960	11585	10563	Nil	94
18	West Bengal	4621	12557	5054	607	172

Table 2.2: Waste generation rate [2,45,77,123, 124].

Population	Waste Generation (kg/capita/day) (CPCB 2000b)	Waste Generation (kg/capita/day) (Kumar et al., and Kumar S and Goel S. 2009)	Waste Generation (kg/capita /day) (Annepu 2012)
>2000000	0.43	0.22-0.62	0.55
1000000-2000000	0.39	0.19-0.53	0.46
500000-1000000	0.38	-	0.48
100000-500000	0.39	0.22-0.59	0.46
<100000	0.36	0.17-0.54	-

The ineffectiveness of waste management and collection services are result of poor transportation facilities, lack of man power, insufficient funds and lack of advanced treatment facilities. However, the urban waste management is getting worse due to land unavailability, weak technical and financial capacity [78]. Additionally, the waste generated in Indian cities mostly consist of biodegradable matter, recyclable, inert fraction [45].

The study conducted [2] on current status of MSW management reported that rapid increase in urbanization and population growth had resulted in enhanced rise in waste generation and unscientific handling of waste. The study suggested that participation of communities is need of hour for waste management. The decentralized waste treatment processing facilities like composting units in large cities through community participation should be set up. The recycling of non-biodegradable component should be done in formal recycling sectors or industries, to be treated as resource. Various studies conducted [65,67,77] in mega/metropolitan cities of India showed the challenges in waste management system with growing population and per capita waste generation.

The study [1] showed that urban regions of India generates about 48 million tonnes of MSW and this may rise up to 250 million tonnes by 2050. The processes followed are being done in haphazard manner which reduces the efficiency and therefore, management, handling of waste has become the responsibility of municipalities. The study also revealed that about 90% of the total waste is disposed unscientifically in open dumps and landfills and the improper management of MSW caused serious hazards to the inhabitants. Thus, for the sustainable, effective waste management segregation, collection, storage and treatment of waste are the condemnatory elements which affects environment. However, the effective waste management is foremost matter of concern in developing countries like India. Therefore, study concluded that the lack of resources like availability of funds, infrastructure, suitable planning, insufficient data are the factors affecting the sustainability of waste management system. The involvement of private-public sector through NGO's, public awareness to inculcate health hazards of waste should be encouraged for better management system.

The MSW characterization and better management helps in adopting the suitable alternatives for treating the waste. However, in India it was estimated that about 80% of waste generated is directly disposed of in open lands [6]. The dumping causing the environmental hazards is considered as third highest pollution after water and air pollution.

The approaches and methodology for improving the waste management policies, rules, legal framework are mandatory for accomplishment of ecological and sustainable waste management system. An approach 'wasteaware' benchmark indicator have identified drawbacks and downfalls in existing waste management system using quantitative and qualitative indicators [124-126].

The waste aware benchmark indicators assemble components like background information of area, public health collection services, quality of collection, treatment and controlled disposal method and governance factors. The performance of management system and facilities were assessed using the benchmark indicator and assessment of recycling, treatment facilities of MSW management system have been done [124]. The benchmark indicator comprises of quantitative component: physical, resource management and qualitative component which is part of governance, financial sustainability and national policies framework and local institutions.

The study conducted to analyze the existing waste management practices in Himachal Pradesh showed that practices adopted were very poor and needs improvement [115,127]. The efficiency of waste collection and waste collection services in the study areas were categorized in low/medium index. The methods of environmental control, treatment and disposal of waste also showed the poor performance. The study provides remedial measures for improving the waste management practices in Himachal Pradesh.

The management of waste has become an issue due to drastic increase in generation of waste and depending upon present scenario the management and finding solutions for treatment and safe disposal have become difficult [79,83]. The waste collection, transportation, treatment and disposal facilities available are inadequate and unavailability of man power, advanced treatment facility, finances are major factors for deprived strategy for MSW management which often leads to illegal and open dumping of waste without concerning environmental standards [128].

A study in different Indian cities showed that the average composition of waste includes 30-45% of organic matter, 6-10% of recyclable and remaining fraction of waste is inert. The majority of cities in India are facing problems in compost and waste to energy facilities because of mixed nature of waste leading to poor quality of end product [77].

The waste disposing in open land in India is in practice which poses harmful effects on health and degrading environment [82]. So, identifying the deficiencies in current management practices, the suitable alternatives and options needs to be taken for minimizing the adverse effect of waste.

The study carried out [129] showed adverse effect of dumping on soil, groundwater and air. The leachate generated from the waste percolates through soil and polluting the groundwater. In this context, for minimizing the effect of waste disposal it is essential to understand the nature, characteristics and waste composition. However, lack of data available regarding generation, characterization in India has restricted the management programs for sustainable and efficient system [48].

The study conducted [17] observed that generation of waste and characteristics of waste vary for country to country, region to regions and it depends upon the economic condition, industrial activities. The regulations and guidelines for waste management are important for adopting the suitable waste management practices.

The study of characterization [9] in Sangamner, Maharashtra showed the high organic fraction (61%) present in MSW and presence of organic carbon in waste was about 40.2%. The nitrogen content of organic fraction (0.73%), phosphate content (0.93%) and potassium content (0.35%) indicated the potential of organic fraction to be a source of nutrient for crops if used as a fertilizer [5]. The inorganic fraction in MSW mainly contributed by stones rocks, sands accounting about

12.5%, plastics 6%, metal 5%, glass 2%. The higher moisture content in MSW is mainly contributed by cooked waste, food waste [130].

The physical and chemical characteristics analyzed [18] the higher fraction of biodegradable and inert content in municipal waste. The seasonal variation was observed mainly in compostable matter is during summer and winter seasons. The biodegradable matter in waste accounts about 32.5±6.2%, paper 3.65±2.28, plastic 6.5±1.98, glass 0.2±0.19 and 33.12±5.4 for inert fraction. The volatile fraction in waste was observed to be 20.4±4.45%, ash content 42±7.05%, fixed carbon 7.5±4.34 and calorific value 4270±160.2 kJ/kg. The carbon present is 28.2±3.28%, hydrogen 3.77±2.25%, Sulphur 0.63±0.65% in waste. The characterization of waste indicated that the waste in study area is rich in biodegradable/organic fraction and inert. The study exhibited the importance of segregation of waste for adopting suitable waste to energy facilities, different treatment technologies including bio-methanation, incineration, composting, refuse derived fuel and landfilling [18].

The study on characterization [19] observed that the waste management process in the city is inadequate and inappropriate due to poorly designed bins, torn out collection vehicles, lack of man power including poor waste collection and treatment facilities, processing and disposal facilities. The waste collected from the city was observed to have low density and higher calorific value. The waste is having the C:N ratio of 26.6 which showed its suitability for converting waste into compost. Thus, the treatment facility adopted is aerobic composting and high plastic waste generation promotes the waste recovery goals [19].

The study conducted by [114] also observed that waste in tricity region is having higher fraction of organic content followed by inert fraction [114]. The biodegradable fraction found in waste from Chandigarh is about 52%, Mohali 46.7% and for Panchkula 42.6% and inorganic fraction was found to be 17.4%, 15.1 and 15.7% for Chandigarh, Mohali and Panchkula respectively. The moisture content in waste is 50% for Chandigarh, 46% Mohali and for Panchkula 40%. The average calorific value of waste was found to be 1929 kcal/kg for Chandigarh, 1801kcal/kg Mohali and 1542 kcal/kg for Panchkula. The carbon content in waste varied from 38.18%, 33.8%, 31.9% and oxygen 11.41%, 10.2%, 11.1%, hydrogen 4.42%, 4.2%, 4.2% and nitrogen about 1.35%, 1.53%, 1.1% for Chandigarh, Mohali and Panchkula respectively. Elemental composition observed thus help in determining type and treatment facilities for waste component [75].

The study conducted on characterization of MSW in Himachal Pradesh [127,131] showed the presence of high organic content (50-55%) in the waste. The study was conducted on the different cities of Himachal Pradesh showed that the C/N ratio of waste is in optimal range (20-30) to convert it into compost. The potential of converting the waste into source of biogas was observed to be higher due to high organic fraction of waste in Himachal Pradesh. The heavy metal concentration for the studied location was found within permissible limit except concentration of chromium and Iron was higher in Baddi region, being the industrial area of the state. The study also showed the methane generation in the studied area varied between 11.57-15.78 ppm CH_4/g and thus having the potential of energy generation from the municipal solid waste [131].

Further, the literature review showed that waste consists of biodegradable fraction (51%), recyclable (17.5%) and inert material (31%) [45]. In developing countries, the organic fraction is found in range of 35-60% with higher moisture content [54,131,132]. The study conducted by [1], observed the biodegradable fraction of 40-60%, inert content 30-40%, 3-6% paper, and plastic, glass, metal <1%. The average calorific value of waste varied between 800-1000 kcal/kg. The leachate generated from the degradation of waste containing organic and inorganic substances therefore contaminating soil, water. Also, the biogas generation rich in methane contributes in global warming if released to atmosphere [18,80].

The characteristics of MSW varies for different countries, cities, regions depending upon the income levels of people. The organic waste is inversely proportional to income levels [133]. It was found that for lower income level regions the organic fraction is higher with significantly higher moisture content. However, the heating value of waste decreases with moisture content, so high heating value (HHVs) of waste is not sufficient for energy recovery during certain periods. Additionally, waste having the high calorific value, combustible matter can be used as the energy source [134,135].

The energy potential from the waste can be utilized by converting waste into energy source using suitable treatment options. The treatment methods depend upon the composition, characteristics of waste which helps in minimizing the impact of MSW on environment. Also providing additional source of energy [136]. The determination of energy value of waste by thermal, biological conversion are the common practices adopted [90,134-136].

The processing of municipal solid waste for minimizing the burden from landfill can be done by recycling the recoverable material and converting the biodegradable fraction into compost. Composting is most common and effective method adopted world-wide for accomplishing the sustainable waste management. However, presence of heavy metals in waste thus contaminates the compost [45].

The study conducted by [80], showed that Indian cities estimates about 40-60% of organic matter which can be recycled by converting waste into compost. The C:N ratio (19-25) of waste was found to be in recommended range (20-40) for converting waste into compost. The study concluded that utilization of MSW compost helps in recycling the waste and use of compost can increase the fertility of soil thereby reducing the volume of waste [80].

The studies conducted [80,137] observed traces of heavy metals in MSW which may come from the batteries, fertilizers, paints, dyes that gets disposed in landfill. The presence of metals like Zn, Cu, Pb, Cr is not for short period however even after dumping of waste and closure of landfill, leaching of heavy metals will result in the groundwater and soil pollution [20,25].

Waste disposed in landfill or open dump poses effects on environment and human health. Therefore, disposal of waste in engineered landfill after suitable treatment helps in reducing these adverse impacts. In this context, the characteristics and mechanical behavior of waste are important factors in designing the landfill.

The engineering properties of waste are essential for designing of the landfill. The studied parameters showed dependence of geotechnical parameters on waste composition, degree of compaction, degree of decomposition and climatic conditions [138]. The study conducted by [139] observed the physical characteristics of waste for geotechnical analysis. The study revealed that the characteristics of waste are having effect on mechanical properties [139]. The slope stability of landfill is dependent on shear strength of waste [140]. The settlement of waste is dependent upon the decomposition of waste and compressibility characteristics.

The study conducted [37] showed the behavior of MSW for overall stability of landfill. The study was carried to analyze the performance of two landfills and it was observed that high organic content in waste results in higher moisture content and fiber content in waste [37]. About 50% of waste in the landfill is easily degradable which results in short and long-term deformations in landfills. The geotechnical parameters of MSW analyzed showed that easily degradable content in MSW tends to reduce the shear strength of waste. Study observed that with the decomposition of waste the shear strength increases with increase in fiber content and permeability reduces [37,142].

The study [105] observed the behavior of MSW under recirculation of leachate. The leachate recirculation in MSW results in increased biogas generation and accelerated the biodegradation. The organic content of MSW was decreased from 84 to 58% and unit weight increased from 7.12 to 10.79 kN/m^3 from fresh to highly degraded waste respectively. The permeability of waste reduced from 10^{-2} to 10^{-4} cm/sec from fresh to degraded waste. The primary compression ratio was observed to follow the increasing trend with degradation and varies from 0.24 to 0.32. The cohesion of waste decreases with vertical stress and angle of internal friction decreases from 30˚ to 12˚ for initial stage of degradation to most degraded waste [105].

Research [141] for fresh and degraded waste showed the variation in geotechnical properties of synthetic MSW for different phase of biodegradation. It was concluded that for degraded waste hydraulic conductivity decreases. The compression ratio was decreased from 0.34 for fresh waste to 0.15 for degraded waste. The shear strength of waste increases with increase in cohesion from 1 kPa to 16-40 kPa and decrease angle of internal friction from 35˚ to 28˚ for fresh and degraded waste respectively [141].

Studies carried out by [36,143,144] reported that the organic content, paper, wood and fiber decreases with increase in age of waste. The geotechnical characteristics like shear strength, permeability, compressibility decreased in degraded waste. However, the moisture content present in waste did not follow any pattern [36,37]. The shear strength parameters, cohesion (c) showed increase with strain and angle of internal friction (φ) firstly decreases and then further increases with increase in strain. The value of shear strength parameter varied for different places or countries which mainly caused due to fibrous materials present in waste [36,140,143].

The study [143], presented the physical and mechanical properties of MSW from two dump sites of Delhi. The large shear testing was done for determining the shear behavior of MSW. The composition of waste showed about 60-80% of soil like material present in waste [143]. The unit weight of waste showed increase with age and increase in depth [36,143]. The analysis of compression index of waste indicates low percentages of compressible material present in waste due to decomposition of waste fraction. The increase in φ value was observed with decrease in cohesion of waste.

Researcher [144] also observed the effect of waste composition and decomposition of strength properties of soil. The study was conducted on the fresh waste decomposed in laboratory to produce the different state of decomposition. The orientation of fiber in direction of applied stress, and increased soil like material, inert increases the angle of internal friction (φ) of MSW. However, study observed no relation between c and waste composition [144].

A study showing the effect of biodegradation, leachate and production of biogas on shear strength properties of municipal solid waste [145]. It was observed that initially the shear strength of waste depends upon the composition and biodegradation of waste influenced the strength properties of waste. However, the increased moisture content in waste results in decreasing shear strength of MSW. The testing of MSW under consolidation drained (CD) condition showed cohesion and friction angle of degraded samples increased with increased in axial strain from 5 to 20%. The cohesion varied from 35.90 to 66.42 kPa and angle of friction varied between 29° to 38° [145].

The effect of waste composition, decomposition, moisture conditions, leachate management and overburden pressure on stress behavior of MSW has been observed by many researchers [140,144,146,147]. Mostly, the shear strength behavior of MSW was observed using large scale direct shear test with size of specimen (diameter or width) 300mm [140,144,148]. With increase in the strain or displacement, the shear strength of MSW increases [38]. However, the shear resistance was observed to be increased with increase in unit weight, compaction efforts and shearing rate [140].

The large shear strength testing of MSW was conducted to observe the shear response of MSW [140]. The effects of waste composition, confining stress, unit weight and loading rate were observed. The orientation of fibrous material and amount has a significant effect in shear strength of waste. the study showed that fibers in direction parallel to shear surface are having little effect on shear strength than fibers oriented in perpendicular direction. The shear strength was observed to be increased with increase in unit weight, compaction efforts and shearing rate.

The MSW is anisotropic material with heterogenous properties due to presence of fibrous material like paper, soft plastics and wood which changes the orientation after applied compactive efforts and vertical load [149]. The effect of fiber content significantly affects the shear response of MSW which tends to decrease with lower fibrous content [140,149]. The orientation of fiber content showed the variation with the horizontal plane. Thus, large scale displacement is however needed to obtain the peak shear strength of municipal solid waste [147].

A large-scale laboratory testing of MSW was conducted by [148], study the behavior of MSW on strength characteristics. The study showed the effect of composition, fibrous material, orientation, rate of loading, confining stress, stress strain compatibility and unit weight on the strength characteristics of waste. The study showed that shear strength is best characterized at cohesion of 15 kPa and angle of internal friction 36˚at pressure of 1atm [148].

The shear strength behavior of MSW was analyzed using back analysis of failed slopes [146]. The study carried out observed the effect of moisture condition, daily cover, leachate management, overburden pressure on the designing of landfill. The study reported that the shear resistance increases with increasing displacement or strain [146].

Apart from this, it is clearly known from past studies that open dumping of MSW on soil is common method adopted for disposing waste in India [1,6]. It was estimated by Energy Research Institute that about 1400 sq. km of land would be required by India for disposal of MSW by 2047 which may increase the land pollution. Consequently, the degradation of waste results in leachate generation which affects soil and ground water qualities [17,20].

The study conducted [31] showed the geotechnical properties of soil get affected due to leachate migration. The leachate concentration in MSW makes soil alkaline varying the pH value of soil [31]. The maximum dry density and compressive strength of waste decreased at shallow depths and in deeper depths the variation is much less due to less impact of leachate. It was observed that the physiochemical characteristics of dump soil affected due to leachate [150].

The effect of open dumping on soil in Kerala, India was studied by [151]. Evaluation of impact of leachate percolation on quality of water and soil was done after collecting samples from or nearby areas of the dump site. The effect of synthetic leachate on quality of soil was assessed and physicochemical properties were assessed by treating soil with synthetic leachate.

The study of municipal solid waste on soil and ground water was analyzed [152]. The impact of open dumping was analyzed by collecting samples of soil and water in or around the dumpsite. Dumping of waste has increased the MDD of soil. The investigation also revealed that cohesion value and compressibility of soil has increased due to diffusion of organic content into soil. Groundwater near the vicinity of dump yard was observed to be polluted severely [152].

Another study conducted by [153] analyzed the pollution potential on soil and plants. The analysis revealed that the dumping of waste has increased the concentration of heavy metals in soil and thereby affecting the vegetation growth.

The impact of MSW on soil and plants was analyzed [154], that is dumped near main roads in Nigeria. The analysis carried out to assess the contamination on plants showed that presence of heavy metals on plant leaves rather than rots and shoots. The presence of Zn, Cr, Pb was found in the dump site samples. The presence of micro-macro nutrients in sample was due to high pH and organic matter present in waste [154].

Influence of open dumping on the soil, plant and earthworms was studied by researcher [155]. The metal contamination of the soil showed high presence of Co, Cr, Cu, Pb and Zn in samples near around the dump site [155]. The study showed that the transfer of metals to plants and earthworm poses risk to environment and human health. It was also suggested that assessment of risk and remediation potential of contaminated soil could be done by study of metal accumulating plants.

The dumping of MSW in open land affected the soil properties due to migration of leachate and thus affects the soil stability and strength [156]. The study investigates the geotechnical parameters of soil and observed that permeability of contaminated soil is more than natural soil. The smaller cohesion value exhibits the smaller shear strength of the dump soil. The study also obtained the micrographs of SEM analysis showing the presence of kaolinite flakes with low shrinkage and swelling properties.

Effect of dumping the waste on shear strength of soil was studied in Chandigarh city. The study revealed that the leachate generation due to degradation of waste has affected the shear strength characteristics of soil which are important characteristics for checking the suitability of soil for various construction purposes. The soil samples were collected from the dump site to check the variation in soil properties due to open dumping and leachate infiltration [157].

The heavy metal content and physico-chemical characteristics of soil mixed with MSW in Allahabad dump site were analyzed by [158]. The quality of MSW from three dump site were analyzed and it was observed that the nature of soil tends to change towards alkaline (7.24±0.62 to 7.76±0.24). However, the characteristics of soil changed from place to place and for different depths. Also, the study conducted [159] observed the effect on the groundwater and surface water near vicinity of dump site. The observed results showed that the closed dump site has no severe effect on quality of ground water and surface water.

The study conducted [160] on the soil and groundwater characteristics of Pallavaran solid waste dumpsite Chennai. The analysis of water quality showed that the parameters exceeds the permissible limits as prescribed by IS:10500. The quality of soil and water due to open dumping in the area has increased.

The study conducted [161] showed effect of leachate on characteristics of sandy- clay soil. The leachate downgrades the properties chemically more as well as physically or mechanically. Leachate in the soil decreases plastic, liquid limit, dry density, strength of soil. The interaction of soil and waste affects effective grain size, consistency limits, compaction, unit weight and strength characteristics [161].

Additionally, the continuous disposal of waste in open land causing environmental and health effects because of production of leachate and gas generating from biodegradation of organic content. Settlement of landfill is essential for designing of landfill as it is harmful to the function of landfill components like gas collection system, liner, cover system and other facilities of closed landfill. The degradation of MSW with time and increased moisture content causes the reduction in volume of waste and settlement [33,141] thus affecting the structural integrity of landfill.

However, the settlement of MSW landfill is complex and difficult to model due to heterogenous nature of MSW and effect of biodegradation of organic material. Various models were proposed and suggested by many researchers [33,35,162-167] for predicting the settlement of MSW landfill.

The study conducted [33] on settlement characteristics of MSW showed the reduction in volume of waste due to presence of organic solids for a longer duration. The study showed that the settlement in landfill occurs due to decomposition which depends upon the amount of biodegradable solids in waste and age of landfill [33]. The settlement data of landfill was analyzed and was applied to model proposed [168]. The study showed that the biological strain was estimated at 11-25% and biological compression was completed in 10-20 years. For waste age from 2-10 years, the biological strain and compression were observed to be dependent on decomposition conditions.

Another study was conducted to review the existing estimation methods depending upon theoretical and empirical background of settlement [162]. The study reviewed the rheological model, logarithmic function, biological model, extended soil model for predicting the settlement of nine MSW landfills. It was observed that the settlement due to biodegradation acts differently than settlement due to age and degradation of waste. The settlement related parameters in fresh samples have the higher value than old waste landfill. The study concluded that the predicted settlement of landfill decreases with age of landfill. The estimated long-term settlement observed for fresh landfill is about 20-60% of total thickness of landfill and for older landfill with age greater than 8 years, the potential of predicted settlement decreases. Further, it was estimated that landfill of age >20 years are having very slight settlement showing that long-term settlement was almost completed. Thus, it was observed from the study that for fresh landfill, the settlement potential has a wide range whereas for old waste landfills all models except extended soil model showed almost same range with small long-term settlement potential.

The settlement mechanism and the methods for estimating the settlement of MSW landfill, bioreactor landfill was studied by [169]. The coefficient of secondary compression of solid waste were estimated considering the effect of self-weight and external load. The study concluded that the post closure settlement of the landfill can be minimized by pretreating the waste. The study observed that the estimation of post closure settlement is important in designing, operation, and maintenance of landfill [169].

The long-term settlement of waste in landfill occurs due to secondary settlement of waste as observed [170]. It was observed by author that secondary settlement of waste has significant impact on stability after post closure of landfill. The generation of leachate due to increased moisture content present in waste increased risk to human health and environment. The study presents the detailed characterization of MSW, physical and chemical changes and change in volume due to degradation of waste. The study observed the effect of secondary settlement with depth and is stress dependent. The effect was observed under increased stress condition of 50 and 150 kPa, and increased stress led to 20% increase in rate of long-term secondary compression [170].

The biodegradation and compression behavior of municipal solid waste results in settlement of landfill studied by [165]. The study was conducted to observe the mechanical compression and biodegradation behavior on short- or long-term compression of MSW. The testing was conducted on optimal or without biodegradation of waste and results indicated that if biodegradation process was reserved, the creep settlement was insignificant. However, under the optimal biodegradable condition, compression may have same magnitude to primary compression. The influence of temperature on biodegradation of MSW is major factor and enhanced biodegradation at filling time increased the capacity and reduced the post closure settlement potential of landfill. The model used to predict the long-term settlement gives the estimation of ultimate strain and trend of settlement during design stage depending upon composition, biodegradation condition and waste filling process.

1D model which involve biodegradation process and mechanical settlement to predict the MSW landfill settlement behavior was developed by [166]. The proposed model and numerical method perform the parametric studies indicating rate of decomposition, decomposable organic fraction for biodegradation settlement. The short-term settlement is controlled by factors gas conductivity and coefficient of air volume change [166].

Various models were proposed for prediction of settlement of MSW which consider different combination for condition of landfill. Further, a model was proposed [167] which consider the mechanical creep behavior of MSW under varying loading conditions and time dependent biodegradation of MSW for calculation of settlement. This model helps in predicting the long-term stability of landfill [167]. The study observed that prediction of settlement is critical for designing of cover system thus the safety of appurtenant structures needs to be ensured. A constitutive model is developed which incorporates mechanical compression, mechanical creep and biodegradation induced compression. The study observed that model predict the total settlement in similar range to other models which incorporates the three components of settlement.

A practical approach for settlement evaluation and storage capacity of landfill for kitchen waste and landfills in developing countries was proposed [171]. The process involved the division of landfill into column units for determining the filling process. The compression of each layer in each unit was determined and variation in the unit weight and leachate level were taken into consideration. The compression was determined by stress-biodegradation compression model [171].

The biodegradation settlement of MSW is considerably time dependent. The microbial activities in landfill enhances and stabilize the biodegradable fraction in landfill [172]. This can be achieved by leachate recirculation through waste in landfill which provides a wet environment for microbial growth and increases the settlement rate in bioreactor landfill.

A study conducted on modelled settlement at varying moisture and pressure conditions in bioreactor landfill. The results observed that settlement prediction can be improved by connecting the settlement with generation and dissipation of gas pressure and moisture distribution [106]. Also, the aerobic and anaerobic process increases the degradation processes and increase the settlement as studied by [173]. The effect of aeration in aerobic degradation and in anaerobic degradation after aeration was observed and it showed that aeration helps in degradation of organic matter and increases the COD, activated the biodegradation potential for anaerobic conditions [173].

The study [173] observed that amount of biogas generation in the waste under the anaerobic condition is about 5 times than aerobic digestion. In the aerobic lysimeter increase of organic load in leachate was observed and increased COD after aeration confirms the activated biodegradation potential for anaerobic condition. The carbon used during aerobic and anaerobic digestion confirms the stabilization in aerobic lysimeter [173].

The MSW compression is mainly due to primary, secondary and decomposition settlement. The continuous biodegradation leads to leachate and biogas production and causing the settlement during operation time or even after closure of landfill. In this context, the study of primary and mechanical compression of MSW was conducted [174]. The study conducted showed that density of MSW is important factor for computation of settlement. The primary and mechanical compression in MSW occurred due to overburden load acting and primary consolidation continues for several years due to squeezing out of moisture from voids. The study conducted develop a mathematical model for estimating settlement using temporal and spatial density variation [174]. The study analyzed that bulk density results in smaller settlement and the however, the density of waste increases with overburden pressure. Thus, temporal and spatial variation should be considered to estimate the landfill settlement.

Another study conducted by [175] which models the gas generation in landfill. As landfills contributes about 2% of total greenhouse gas emission and is expected to increase 2% in next 15 years. Thus, model developed for determining the gas generation on post closure landfill. The optimum pH and temperature have positive effect on biodegradation of MSW. The variation in depth has significant effect on the gas generation and it was observed that at initial stage rate of gas generation is high and decreases with time. This model recommended use of temporal and spatial variation as bulk density of waste results in the smaller gas generation [175].

Further, on post-closure of landfill, the settlement was evaluated using the mathematical model and the effect of temperature, pH and moisture content was incorporated to assess the settlement [176]. The study determined the settlement due to mechanical compression and biodegradation. The mechanical compression incorporates the temporal and spatial variation accounting the effect of overburden to density of waste and biodegradation compression accounts the effect of pH, temperature and moisture content of waste on settlement. The model observed that rate of settlement increases with increase in temperature, pH and moisture content.

The effect of temperature on biodegradation of municipal solid waste in bioreactors was studied by [177]**.** The settlement properties and biodegradation velocity rate were analyzed during the test. The study was performed on different temperature conditions and production of biogas, leachate was monitored for 360 days. It was observed that the biodegradation of MSW was enhanced in proper temperature conditions (22˚C to 45˚C). An empirical equation was proposed for biodegradation ratio incorporating the temperature effect on biodegradation [177].

Several other studies were conducted [35,109,111,141,178] to identify relationship of degradation, leachate and mechanical behavior of MSW. The studies showed that the settlement of waste occurs due to stress and composition changes leading to settlement due to degradation in the landfill. These studies reported that main by-products of MSW due to biodegradation are heat, biogas, and leachate.

The experimental study carried out by researchers [35], showed the effect of MSW size, recirculation of leachate, on rate of biodegradation of waste. The smaller size of particles fastens the degradation of MSW and the organic fraction of MSW decreased. the leachate generated from the MSW was observed to have pH in range of 7-8 after two years of recirculation [35].

The impact of biological treatment on leachate quality was studied by [179]. The study showed that the MBT waste reduces the potential of gas generation and strength of leachate. However, the studies on analysis of heavy metals for MBT waste are limited. The studies conducted showed leachate circulation enriched waste stabilization by increasing the moisture content, micro-organism growth [179].

The stabilization of landfill is considered for post closure of landfill to prevent the damage and control the adverse effect on human and environment. Researchers [180] stated that landfill is considered as stabilized if leachate is not remained pollutant and gas production is negligible and majority of settlement has already occurred. The study observed that the during the test period, aerobic tank settle about 35%, anaerobic tank settled 21.7% and tank with no treatment settled 7.5%. Thus, the options for disposal and remediation of liquid waste are provided by study carried out [180].

The study on the settlement of bioreactor landfill was observed by many researchers [181-185]. The laboratory set up for modelling the settlement and decomposition were used over period of 225 days [185]. The initial compression observed was 17% and 26%, primary settlement 12% and 15% and secondary settlement 2% and 4% for dry and enhanced cell respectively. Further, the study conducted used five years settlement data under leachate circulation condition showed settlement of 13%-15% and control cell showed 8%-11% settlement in waste [183]. The settlement in MSW landfill in Melbourne Australia was observed by researchers [184]. The settlement for landfill was observed for 3.5 years and showed 6% in bioreactor landfill and about 3% settlement in dry landfill [184].

The analysis of settlement behavior was observed [181] in bioreactor landfill in North America. About 22-25% of settlement was observed over period of 1000 days which indicated that the settlement in bioreactor landfill is large and faster [181]. The settlement observed by [182] showed the behavior of compression and biodegradation. The experiment conducted on MSW over a period of 2 years showed that vertical pressure 130 kPa applied on waste gives the primary and secondary settlement of 25.4% and 23.9% respectively [182].

The mechanical-biological treatment of waste has also become popular as it reduces the amount of organic/biodegradable fraction to get disposed in landfills. The pretreatment of waste has effects on physical, chemical and biological properties of waste. The process involves sorting and segregation of recyclable, combustible material, shredding of waste to remove large size particles, and treatment of waste by aerobic and anaerobic processes. Thus, various studies were conducted to study the behavior of MBT waste on settlement of landfill [186-188].

The secondary settlement in MSW is due to effect of mechanical creep and biodegradation. However, the literature studies evaluated coefficient of secondary settlement ($C_{\alpha\epsilon}$) as continuing settlement with time under constant effective stress and has valuated $C_{\alpha\epsilon}$ as dependent on creep nature and biodegradation induced settlement. The study conducted [190] evaluated the compression indices for creep and biodegradation settlement in range of 0.02-0.03 and 0.02-0.19 respectively [189]. The combined compression indices for creep and biodegradation reported in range of 0.01-0.19 [190].

The study of landfill behavior of pretreated waste was carried out by [191]. The treatment of MSW owing to the changes in composition and properties of waste and also having a major influence on the degradation and settlement characteristics of waste in the landfill. The study revealed that the stabilization of mechanically treated waste was achieved within a year. The settlement due to mechanical creep is more significant than biodegradation induced settlement of waste [191].

The study carried out [187,188] studied the behavior of pretreated waste on separate effect of creep and biodegradation induced settlement [187,188]. The study was conducted to analyze the biodegradation and settlement on waste from two landfill sites. The degradable content in MSW reduced due to biodegradation. The comparison of obtained results for treated waste was done with untreated waste. The settlement of MSW was evaluated using model developed for creep induced, biodegradation induced settlement [188]. It was observed from the results that the creep and biodegradation settlement for treated waste was smaller than raw MSW. The settlement curves for MBT and raw waste were obtained from model based upon the logarithmic law for creep and exponential decay of biodegradation-induced settlement. The model gives the approximation for settlement data depending upon the degradation rate and Terzaghi's consolidation theory. The parameters obtained from laboratory test conducted provided estimation of settlement for MBT waste.

Summary

The literature survey conducted in developed and developing nations, low income to high income countries, rural and urban communities showed that the management of MSW is chief responsibility of municipal corporation. Municipal solid waste has caused threat to environment and human health and contaminated the natural sources. Therefore, waste management programs have been conducted to minimize the contamination of environment and utilizing the waste as resource by recycling, recovering of recyclable material and energy sources. The enormous growth in the population, increased demand of resources has resulted in high production in MSW. The efficiency of municipality has decreased due to massive growth in waste. The lack of resources, insufficient funds available, inefficiency of recycling and recovering facilities, lack of man power, waste to energy facilities have promoted the trend open dumping of waste. It was observed that segregation of waste in most of communities is absent leading to poor waste management practice in most of regions. In order to have the efficient waste to energy facilities, sorting and segregation of recyclable and non-recyclable waste is necessary to get the maximum energy potential.

The survey conducted in different parts of country investigated that after initial treatment like segregation, sorting of recyclable material, dumping of waste in unsanitary landfill is common method adopted. The disposal of waste in such haphazard manner in open land or unsanitary landfill without provision of liner, leachate collection system, has degraded the environment and quality of water, air and soil. In India, the dumping of waste in open land, burning and unsanitary landfills are most common practices adopted in present days.

The contamination of air, soil and water however depends upon the composition of waste. Thus, the study conducted for analysis of waste characterization showed that the waste in developing countries is having large fraction of organic content and thus tends to degrade with time. The literature study also observed the disposal of mixed waste in landfill and presence of batteries, textiles, cardboard, metal, paint caused the presence of toxic elements in waste. These toxic constituent present in waste thus percolate into ground and contaminates soil and water. Thus, it is mandatory for providing the waste management option for reducing the harmful elements form being dumped in open lands. The study also concluded that present waste management scenario in country needs improvement, awareness among people.

The conclusions drawn from the literature survey also revealed that the characteristic of waste have impact on properties of soil which finally affects the stability of landfill. The studies conducted on the soil showed the presence of waste fraction in upper layers of soil. Some of the studies conducted on the agricultural productivity have observed the presence of harmful chemical in soil which affects the vegetation growth and enters the food chain. Also, the degradation of waste leads to variation in soil properties and organic content, mineral present in waste leads to settlement. Thus, it is recommended that facilities for preventing the percolation of leachate into ground should be provided.

The studies conducted on characteristics showed that the presence of organic matter in waste leads to settlement in MSW. The engineered landfill constructed for safe disposal of MSW thus gets affected due to biodegradation of waste. The stability of landfill depends upon the geotechnical properties of MSW and needs to be evaluated for assessing the stability of landfill. From various studies conducted on settlement analysis observed effect of degradation of waste affected the variation in stability, cracking, settlement. It was concluded that the degradation is function of temperature, pH, moisture content, overburden pressure composition of waste.

In this context, it is concluded from the literature survey that the study of characterization of MSW is essential for sustainable waste management and for the improvement of existing waste management practices. The segregation of waste is of prime importance for adopting the waste to energy facilities and thereby for the reduction of the burden which increases the life span of landfill.

Also, the study area is emerging as an industrial, commercial hub, therefore leading to increased urbanization and industrialization. This will thus lead to increased generation of waste and may cause adverse environmental and health effects. Also, Una is having mostly plain terrain which make it suitable for construction of engineered landfill. Therefore, in present study of characterization and settlement analysis of municipal solid waste in Una, Himachal Pradesh, an attempt has been made for waste characterization, analysis of geotechnical characteristics of waste due to degradation, effect of dumping on soil characteristics and variation in waste settlement characteristics due to degradation over a period of time. The study comprehends the present scenario of waste management practices adopted in the study area. Thus, the study provides a baseline for improving the waste management system and settlement analysis study provides an approximation for the behavior of MSW.

CHAPTER -3

PREVAILING WASTE MANAGEMENT PRACTICES AND MSW MANAGEMENT ANALYSIS IN UNA

3.1 Introduction

India being a large economy is witnessing unabated urbanization and growth in population which are major features responsible for increased rate of solid waste generation and insufficient MSW management techniques or processes [2,192]. The primary purpose of MSW management system is to address environmental, health, economic and aesthetic concern and land-use resources related to improper waste management and waste disposal facilities [193,194]. In India, the disposal of MSW is done in low lying areas or on open dumps unscientifically, without any operational control causing harmful effect on environment and human health [1,195-197]. However, the generation, composition and quantity of waste vary for different places and are reflection of living standard of habitats [1,6,195]. The management of MSW in Indian cities is the responsibility of municipalities and ULB's including management of the waste from its generation to final disposal [1,198,199]. However, in Indian cities, waste generation is increasing about 1-3% annually with per capita waste generation rate of 0.2-0.0.87 kg/day [55], thus challenging the existing waste management practices in the city.

Further, it was reported that about 1.34 billion population is migrating from rural region to urban region thereby increasing the burden on cities which further renders the current MSW management practices to be insufficient and ineffectual [6,192,198**]**. The impact of ineffective waste management practices leads to increased environmental degradation [8,199]. Additionally, the problems in MSW management are escalated due to the amount of waste generated varied nature of waste and reduction in budget provision of municipal authorities [200].

Further, the management of MSW suffers critically due to lack of effective treatment facilities and hence requires a safe and proper treatment before the final disposal of MSW to maintain the serenity of city. The government of India has framed several guidelines and rules at national level to handle and manage the increased waste generation [8,55]. The nature of improvement of SWM system depends upon the economic status of country and available data on different facets of waste generation, collection and its management to facilitate proper waste management systems

[2,19,50]. In this context, the techniques and facilities for providing the better management system in the country is essential to reduce the burden of waste from the cities. The sustainable management of waste for acquiring the zero waste is not feasible. Thus, providing awareness among people about harmful impact of waste disposal, identifying the problems for poor waste management, understanding the current practices of waste management and taking suitable actions for remediation and improvement can reduce the impact to some extent.

Himachal Pradesh is less urbanized state of country having waste generation of 350 TPD [55,201] with the annual rise in waste generation is expected to be 1-1.33% [66, 131]. As per the report, the per capita production of waste in state is around 0.413 kg/day which may rise to 1.33% by 2041 [201]. The rise in generation rate of waste for urban population from 2011 to 2041 is given in *Table 3.1*.

Table 3.1: Waste generation in Himachal Pradesh with population growth [192,201].

Year	**Per capita waste generated (kg/day)**	**Urban Population (×1000)**	**Waste Generated (T/day)**
2011	0.413	736.34	304.3
2021	0.472	883.32	416.6
2031	0.538	1023.43	550.9
2041	0.614	1155.23	709.6

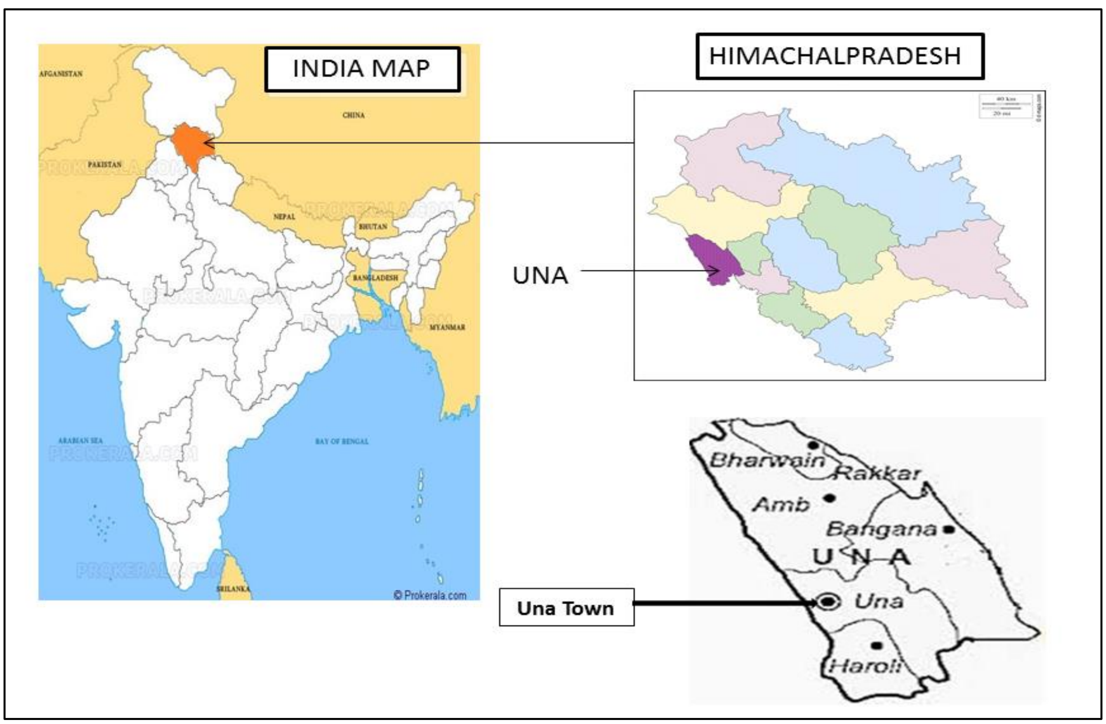
The increased population and growing economy have led to the rise in waste generation in state and inadequate facilities available for treatment and disposal thus make it difficult to manage the waste. Due to the topographical conditions and hilly terrain of Himachal Pradesh, the solid waste management system is facing many challenges [115,131]. The common practice for waste disposal in state is open dumping or the non-engineered landfill sites thus becoming the main source for pollution.

In this context, the current study emphasizes the existing waste management practices carried out in the Una town of Himachal Pradesh. The efficiency of prevailing practices for functioning of existing MSW management system in town, were analyzed using the "*wasteaware*" method which was further quantified using the "*matrix method*" and the results obtained compared with other similar study locations within the state of HP. Additionally, for improvement of current waste management practices in the study region, some appropriate remedial measures have been proposed.

3.2 Methodology

3.2.1 Study Location

The Una town is situated at latitude 31˚48′ and longitude 76˚28′ having area of 1549km^2 in Una district of Himachal Pradesh. The total population of district is about 5,21,173and town has population of 18,722 growing at rate of 8.62% [56]. The increased urbanization led the migration of people from rural to urban area of town results in increased waste generation. The town is subdivided into 11 wards from where the waste is collected. The generation of waste in the town is around 6 TPD and discarded in open dump covering an area of 0.20 hectare which is situated at about 5 km outskirt of town. The location of study area and dump site is shown in *Figure 3.1(a), 3.1(b)*.



(a)

(b)

Figure 3.1 (a): Location of study area. **(b):** Dump site location in study region (Source: Google Earth).

3.2.2 Geological and Climatic Conditions

The Una district has tropical climate and the plain as well as high hilly terrain. The temperature in the district varies from minimum of 4˚C to maximum of 46˚C during summer. The winter seasons starts from the November which continues till middle of March. January month is considered as coldest month with minimum and maximum temperature of 6˚ and 19˚C respectively. The annual average rainfall in the district is about 1040 mm. The area receives rainfall mainly during the monsoon period (June to September) and also some scattered rainfall during non- monsoon period.

3.3 Existing Municipal Solid Waste Management

Management of MSW is an integral part of society and is responsibility of municipal corporation, ULB's and habitats for managing, handling waste. In Himachal Pradesh, all the activities for the waste management practices and rules are monitored by Himachal Pradesh State Pollution Control Board (HPSPCB). The MSW management in study region involve household collection of waste, storage, transportation and final disposal on landfill. However, waste produced from the industries in Una town is not mixed along with the municipal solid waste and thus remains unattended. Present waste management practices adopted in Una are shown in *Figure 3.2*.

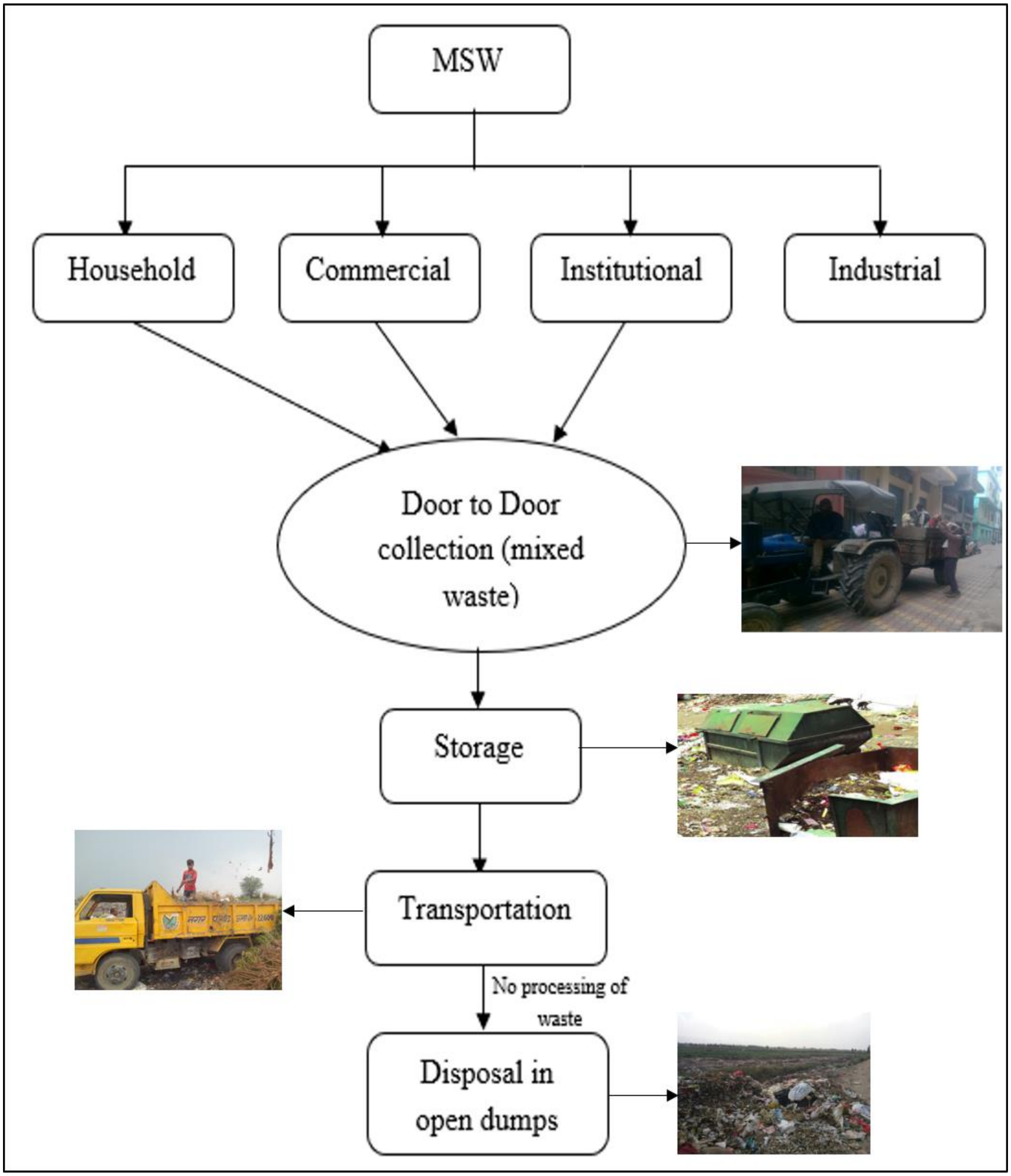


Figure 3.2: Practices adopted for waste management in Una Himachal Pradesh.

3.4 Analytical Framework for Sustainable Waste Management

3.4.1 Wasteaware ISWM Benchmark Indicator

MSW if not managed properly it affects the people health and aesthetic of the city/town. Solid waste management (SWM) is a vital service of municipalities or ULB's upon which community health and also the economic health of the city depends. Thus, the effectiveness, performance of recovery and processing of waste in city is managed by using the indicator of good governance for sustainable waste management [124-126]. The analytical framework for sustainable waste management is designed around concept of Integrated Sustainable Waste Management (ISWM) which differentiate three dimensions of SWM and recycling system for analysis [125,126,202]. The ISWM benchmark indicator is defined for waste management system by including the physical and governance factors [124-125]. To improve and appraise the awareness among the stakeholders of local waste management system is the goal of the benchmarking and it provides the overview of performance of existing waste management practices even because of unavailability of detailed data.

The wasteaware ISWM benchmarking system distinguish into physical and governance factors and it uses the existing data and it provides the basis for assessment of qualitative and quantitative indicators [124,125]. The physical component is a quantitative indicator which involve the public health protection, protection of environment during treatment and disposal of waste and management of resource 3R's i.e. reduce, reuse and recycle. The governance factor is a qualitative indicator which deals with the strategies for delivering a well-functioning system which includes user inclusivity, financial sustainability and sound institutions and proactive policies. The various components of quantitative and qualitative indicators are given in *Table 3.2*.

The physical component of system scales the performance and compared with qualitative indicators using color coding system. Additionally, criteria for both physical and governance factors are utilized for evaluation of quality of collection and cleaning services: 1Q indicator (*Table 3.3*), Environmental protection in treatment and disposal: 2E indicator (*Table 3.4*), Quality of 3R's provision: 3Q indicator (*Table 3.5*) and Financial sustainability: 5F indicator (*Table 3.6*), user and provider inclusivity: 4U and 4P indicator, (*Table 3.7*), sound institution and proactive policies: 6N-National framework, 6L-Local institution (*Table 3.8*).

Table 3.2: Quantitative indicator for physical component of solid waste management system [124,125].

No.	Physical Component	Indicator	Color Coding				
			Low	Low/Medium	Medium	Medium/High	High
1.1	Public health- Waste Collection	Collection of waste coverage: %age of households	0-49%	50-69%	70-89%	90-98%	99-100%
1.2		Waste captured by SWM and recycling system, %age of waste generated that is collected and delivered to an official facility	0-49%	50-69%	70-89%	90-98%	99-100%
2	Environmental control and disposal	Controlled treatment and disposal: % of total MSW destined for treatment or disposal which goes to either state of art, engineered or controlled treatment disposal site	0-49%	50-74%	75-84%	85-94%	95-100%
3	Resource Values- 3R's- Reduce, Reuse, recycle	Recycling rate: % of total MSW generated that is Recycled. Includes Materials recycling, organics, (composting, animal feed, Anaerobic digestion).	0-9%	10-24%	24-44%	45-64%	65% and over

Table 3.3: Criteria to derive Indicator 1Q: Quality of waste collection and street cleaning services [124].

No.	Criteria	Description
1Q.1	Appearance of waste collection points	Presence of accumulated waste around collection points/containers
1Q.2	Effectiveness of street cleaning	Presence of litter and of overflowing litter bins in city centre, along main roads and in popular places where people gather
1Q.3	Effectiveness of collection in low income districts	Presence of accumulated waste/ illegal dumps/ open burning in and around lower income districts of the city.
1Q.4	Effectiveness of supervision and management control	Appropriate service implementation, management and supervision in place
1Q.5	Health and safety of collection workers	Use of appropriate personal protection equipment & supporting procedures.

Table 3.4: Criteria to derive Indicator 2E: Degree of environmental protection in treatment and disposal of waste. [124,125].

No.	Criteria	Description
2E.1	Degree of control over waste reception and general site management	This criterion should be applied to all treatment and disposal sites, whatever the specific process being used.
2E.2	Degree of control of treatment or disposal	The focus here is on the waste treatment or disposal process in use at each site and over any potential emissions. This covers both the presence of the necessary technologies and the operating procedures for their proper use.
2E.3	Degree of monitoring and verification of environmental controls	Includes the existence and regular implementation of robust environmental permitting/licensing procedures; regular record keeping, monitoring and verification carried out by the facility itself and monitoring, inspection and verification by an independent regulatory body.
2E.4	Efficiency of energy generation and use (used for energy recovery facilities only)	Assesses the energy efficiency of those facilities for which a major purpose is energy recovery.
2E.5	Degree of technical competence in the planning	An assessment of the level of technical competence at three points in the system: (i) the authority responsible for service provision; (ii) the management of the treatment and disposal facilities; and (iii) the frontline operational staff

Table 3.5: Measures used to derive Indicator 3R: Quality of 3R's- Reduce, Reuse and Recycle [124,125].

No.	Criteria	Description
3R.1	Source separation of 'dry recyclables	Assessed depending upon the total quantity of material collected for recycling that are collected as clean, source separated materials.
3R.2	Quality of recycled organic materials	A qualitative assessment of the likely quality of the recycled product (i.e. animal feed, compost, and the organic product (digestate) from anaerobic digestion) – assessment guidance based on both separation at source and quality control
3R.3	Focus on the top levels of waste hierarchy	An assessment of the degree of both policy and practical focus on promoting reduction and reuse in higher waste generating cities and on the 3Rs– reduction, reuse, recycling – in lower waste generating cities.
3R.4	Integration of community or informal recycling sector with formal SWM system	An assessment of how far and how successfully efforts have been made to include the informal recycling sector (in low and middle-income countries) and the community reuse and recycling sector (in higher income countries) into the formal solid waste management system.
3R.5	Environmental protection in recycling	Environmental impacts of the recycling chain, from collection through to the separation and processing of the separated materials
3R.6	Occupational and health safety	Use of appropriate personal protection equipment and supporting procedures

Table 3.6: Criteria used to derive Indicator 5F: Degree of Financial Sustainability [124].

No.	Criterion	Description
5F.1	Cost computing	An assessment of the extent to which the solid waste management accounts reflect accurately the full costs of providing the service, the relative costs of the different activities within SWM, and whether the accounts are open to public scrutiny
5F.2	Does the available budget cover the full costs?	Is the annual budget adequate to cover the full costs of providing the service?
5F.3	Local cost recovery– from households	Percentage of the total households both using and paying for the services.
5F.4	Affordability of use charges	Procedures in place to support charges for those who can't affords to pay.
5F.5	Pricing of disposal	Degree to which the final disposal of waste at sites are charged at a rate that covers operational costs of disposal.
5F.6	Access to capital for investment	Adequate provisions for capital investments, to upgrade standards of waste disposal and to replace existing vehicles, equipment and sites at end of their life span.

Table 3.7: Measures used to derive Indicator 4U and 4P: Degree of user and provider inclusivity [124,125].

4U-Degree of user inclusivity			4P- Degree of provider inclusivity		
No.	**Criteria**	**Description**	**No.**	**Criteria**	**Description**
4U.1	Equity of service provision	Assessment for receiving a good SWM service irrespective of income level, which citizen can afford, and protects public health and environmental quality.	4P.1	Legal Framework	Assesses the degree to which law and other legal instruments are in place and implemented at national or local level which enable private sector to deliver stable SWM services.
4U..2	The right to be heard	If authorities have legal obligation, citizen needs to be consulted and involved in decision which directly affects them.	4P.2	Representation of private sector	Organizations in place which represent the private waste sector.
4U.3	Level of public involvement	Evidence of public involvement and the encouragement thereof at appropriate stages of the SWM decision making, planning and implementation process.	4P.3	Role of informal and community sector	Evidence of recognition of the role of informal sectors within formal SWM systems.
4U..4	Public feedback mechanisms	The existence and use of public feed-back mechanisms on SWM services.	4P.4	The balance of public and private sector in delivering services	Degree to which Appropriate checks and balances are in place locally so that Waste services are being delivered.
4U.5	Public education & Awareness	Implementation of a comprehensive, culturally appropriate public education, behavioural change and/or awareness raising programme	4P.5	Bid processes	Degree of transparency and accountability of bid process.

Table 3.8: Criteria used to derive Indicator for sound insulation and proactive policies: 6N-National framework and 6L-Local institutions [124,125].

6N- National framework			6L-Local institutions		
No.	**Criteria**	**Description**	**No.**	**Criteria**	**Description**
6N.1	Legislation and regulations	if there a comprehensive national law(s) in place to address solid waste management (SWM) requirements.	**6L.1**	Organisational structure	The degree to which all SWM responsibilities are concentrated into a single organisation or department, that can be held accountable for performance, or if multiple organisations, the presence of a significant concentration of responsibilities in one named agency
6N.2	Strategy/ Policy	Is there an approved and recent national strategy for SWM, and clear policies in place and implemented?	**6L.2**	Institutional capacity	An assessment of the organizational strength and capacity of the department responsible for SWM.
6N.3	Guidelines and implementation procedures	Are there clear guidelines for local authorities on how to implement the laws and strategy	**6L.3**	City-wide SWM strategy & plan	Is there a recent strategy or plan in place & being implemented at the city (or regional) level for SWM
6N.4	National institution responsible for implementing SWM policy	Is there a single institution at the national level which is charged with the responsibility of implementing, or coordinating the implementation of, SWM strategy/policy	**6L.4**	Availability and quality of SWM data	Is there a management information system in place? Is the waste system performance regularly monitored and measured and data collected
6N.5	Regulatory control	Is there a well organised and adequately resourced environmental regulatory agency	**6L.5**	Management, control and supervision of service delivery	A measure of the strength of control by the city as 'client' for SWM, over the on-the-ground delivery of SWM services
6N.6	Extended producer responsibility (EPR) or Product Stewardship (PS)	Has engagement been made with national and international companies who produce the packaging, electronic goods and other products that end up as municipal solid waste	**6L.6**	Inter-municipal co-operation	Waste collection is often delivered at a local level, while treatment and disposal may require co-operation city-wide or at a regional level. Regulatory control may be organized at regional or national level.

3.4.2 Matrix Method

The quantification method for understanding the valuation of existing MSW management practices has been analyzed using matrix methodology. The parameters in *wasteaware benchmark* have been assigned with grading system as low (L), Low/Medium (L/M), Medium (M), Medium/High (M/H), High (H) and further weights are assigned in matrix method to each of these as L=1, L/M=2, M=3, M/H=4, H=5.

3.5 Result and Discussion

3.5.1 Assessment of existing waste management process in study area

3.5.1.1 Municipal Solid Waste Generation

The waste generation in study area was observed to be increased with growth in population and urbanization in the study area. The amount of MSW generation thus depends upon the food habits, standards of living, cultural habits and seasonal variation of the study area. The waste generation in Una is around 6 tons per day (TPD) with per capita waste generation rate of 0.42 kg/day. About 5.5 TPD is collected out of total waste generated and finally disposed on an open land. The composition of MSW in study area showed presence of higher organic fraction [192] as the area is agricultural and discarding of vegetables, rotten fruits and other biodegradable matters on dump site contributes in the increased organic matter. Also, the fraction of paper and polythene were found to be higher because of small scale industries, educational institutions and government/private sector offices. Despite of plastic ban in Himachal Pradesh, the generation of plastic is higher in the study region as it is in the border of neighboring state Punjab which do not follow the similar legislation.

3.5.1.2 MSW Collection

For the effective and efficient waste management system, the waste collection with collection capacity equivalent or greater than waste generation rate is required. In India the improper waste management system is due to ineffective collection of waste leading the adverse effect on environment and humans. The collection of waste in study region is monitored by Municipal Council Una, employing 58 *karamcharis* for collection of waste from different parts of town and another 50 *safai karamcharis* employed by a private company. The efficiency of waste collection in region is 80-90% with the poor waste collection facilities available (*Table 3.9*). Source segregation of waste or at collection point is absent in study region. Collection of all type of waste in single container is a poor exercise leading to unhealthy and unhygienic condition [85].

Presently, the waste collection from residential and commercial places is done by rag-pickers in handcarts and tricycle along with the waste collection from the streets. The shortage of collection bins in the area causing littering of waste which is due to the indiscriminate collection of waste. Further, it was found that the waste collection in study area was done on mixed basis, without segregating the waste thereby increasing the burden on landfill and lowering the calorific value of waste.

Table 3.9: Municipal Solid Waste collection in Una [192].

Sr. No.	Type	Capacity	Quantity
1	Manual Sweeping	-	90%
2	Mechanical Sweeping	-	Nil
3	Masonry bins	-	10 nos.
4	Covered metal/ plastic container	Up to 1.1 m^3	40 nos.
		2-5 m^3	15nos.

3.5.1.3 Transportation and Disposal

Municipal Council Una has managed the carriage of waste from collection points to disposal sites by trucks and tractors (*Figure 3.3*). Each truck has capacity of about 4 tons (8.3 m^3) and transportation of waste was done with an average efficiency of about 92% [203]. However, the estimated per person collection for the region was 0.0011m^3/day showed that the available vehicles are insufficient for the transportation of waste. The details for the available transportation vehicle in the study area is given in *Table 3.10*.

Table 3.10: MSW Transportation vehicles in MC Una [192].

S. No.	Type of Vehicle	Quantity	Capacity (tonnes)
1	Tractor	1	3
2	Dumper Placer	2	2.5 (single bin system)
3	Tipping truck	4	4
4	Three-wheeler	-	-
5	Compactor	-	-
6	Backhoe loader	-	-
7	Twin lifter	-	-

Figure 3.3: Transportation vehicle of transporting waste to dump site.

The disposal of waste in the study region is being carried out by direct dumping on open land since 2010. The practices adopted for the disposal of waste are haphazard and unscientific. The direct dumping of waste without any prior preventive measures may lead to problems associated with the health, environment pollution. The higher fraction of biodegradable in MSW causes the hazards related to public health and environment. However, waste management practices adopted in study region are not sufficient and lacking in adequate resources for collection, transportation and disposal facilities. Additionally, the lower efficiency of waste collection and management is due to lack of budget provision, inadequate machinery and treatment processes.

3.5.2 Wasteaware Benchmark Indicators

The performance of the SWM in study area is analyzed using ISWM benchmark indicator. Color code were assigned depending upon the indicator score system performance. The conventions used are for low score is 0-20% and coded as red, 21-40% coded as red amber for medium/low, medium- 41-60% coded as amber, 61-80% for medium/high- green amber and 81-100% coded as green for high score. The obtained results for Una town were compared with Baddi, Solan, Mandi and Sundernagar as the nature of waste generated is similar with high fraction of organic matter [115]. The wasteaware benchmark indicators results for the Una town are presented in *Table 3.11*.

Table 3.11: Wasteaware Benchmark Indicator of Una, Himachal Pradesh [192].

Sr. No.	Category	Indicator	Una Town Results
Background Information of city			
B1	Country income level	World Bank income category	Lower-middle
		GNI per Capita	$1,140
B2	Population	Total Population of the city	18722
B3	Waste Generation	MSW Generation (tonnes/year)	2190
Key waste related data			
W1	Waste per capita	MSW per capita (kg per year)	153.3
W2	Waste Composition		4- Key fractions- as % of total waste generated
W2.1	Organic	Organic (food and Green wastes)	56%
W2.2	Paper	Paper and Card	12%
W2.3	Plastics	Plastics	10%
Physical Component			
1.1	Public health waste collection	Waste collection coverage	90% (M/H)
1C		Quality of waste collection service	89% (M)
2	Environmental control- waste treatment and disposal	Controlled treatment and disposal	< 10% (L)
2E		Degree of environmental protection in waste treatment and disposal	0% (L)
3	Resource management reduce, reuse and recycle	Recycling rate	0% (L)
3R		Quality of 3R's- reduce, reuse and recycle- provision	<10% (L)
Governance Factors			
4U	Inclusivity	User Inclusivity	51% (L/M)
4P		Provider Inclusivity	59% (L/M)
6N	Sound institution, proactive policies	Adequacy of national SWM framework	52% (L/M)
6L		Local institutional coherence	55% (L/M)

The *wasteaware* benchmark parameter results showed that the collection efficiency (90%) for study region good as compared to other regions of state (60%). The indexing for collection system is medium to high (M/H) for Una and for Baddi, Solan, Sundernagar and Mandi, it is low to medium (L/M). Though, the indexing for rest of physical factors of regions of Himachal Pradesh is observed to be *Low*. The reasons for low indexing may be because of absence of efficient treatment, disposal facilities and disposal of waste in non-engineered landfills. The migration of leachate due to the degradation of waste is not prevented thus contaminating the groundwater and causing health and environmental hazards. *Figure 3.4* presents the radar diagram for comparison of the indexing of Una, Baddi, Solan, Mandi and Sundernagar. The waste management practices for the cities of Himachal Pradesh showed that the physical and governance factors are very poor (low index).

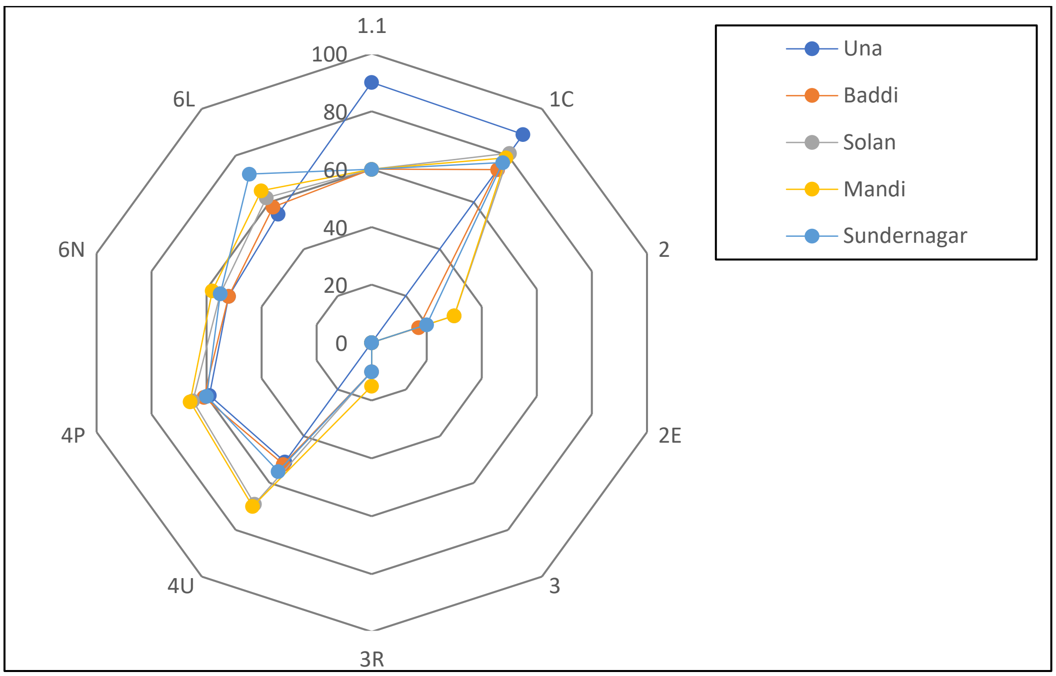


Figure 3.4: Radar diagram for comparison of Benchmark Indicators for Una, Baddi, Solan, Mandi and Sundernagar.

3.5.3 Matrix Method for quantification of indicators

The allocation of weights for the evaluated parameters from the benchmark indicators was done using matrix method. The results obtained have been presented in *Table 3.12* and *Table 3.13* presents overall score obtained using matrix method. The wasteaware indicator has been used to evaluate management system in Una town and consequently appropriate ratings were allocated to the qualitative and quantitative signs depending upon collected data. The benchmark indicators of study region had been compared with other regions of state [115].

Table 3.12: Assignment of weightage using matrix method [192].

Sr. No.	Category	Indicator	Una Town Results
Quantitative Indicators (Public Health, Environmental Control, 3R)			
1.1	Public health waste collection	Waste collection coverage	90% (M/H) (4)
1C		Quality of waste collection service	89% (M) (3)
2.	Environmental control- waste treatment and disposal	Controlled treatment and disposal	< 10% (L) (1)
2E		Degree of environmental protection in waste treatment and disposal	0% (L) (1)
3	Resource management reduce, reuse and recycle	Recycling rate	0% (L) (1)
3R		Quality of 3R's- reduce, reuse and recycle- provision	<10% (L) (1)
Qualitative Indicator (Governance Factor)			
4U	Inclusivity	User Inclusivity	51% (L/M) (2)
4P		Provider Inclusivity	59%(L/M) (2)
6N	Sound institution, proactive policies	Adequacy of national SWM framework	52%(L/M) (2)
6L		Local institutional coherence	55%(L/M) (2)

The standard effectiveness of waste management system obtained from the Una region suggests overall weightage of 38% and for Baddi (32%), Solan (32%), Mandi (36%) and Sundernagar (32%). Analysis discovered that the quantitative parameter of "wasteaware" benchmark has weightage 36% for Una and 30% for Baddi, Solan, Mandi and Sundernagar [115,127]. For Una, qualitative parameters have weightage 40% and 35% for Baddi and Solan and 45% for Mandi and Sundernagar. The benchmark indicator of study region was found to be similar with other regions of state except collection efficiency. The benchmark indicator evaluated in *Table 3.12* exhibit that the collection efficiency and services are good and categorized as M/H for Una whereas for other study locations in the state classified as L/M [131] but the environmental management and management of resource is very poor for the Una town, and categorized in low index (L) similar to those observed for other study locations within the state [131]. The facilities for treatment, disposal and recycling of the waste are negligible in the Una town. The obtained results in the *Table 3.12* and *Table 3.13* using the benchmark indicator and matrix method has been compared with other cities of state having same characteristics of MSW. Therefore, the outcomes from the matrix analysis confirmed that MSW management for study region and other regions of Himachal Pradesh is indexed as low.

Table 3.13: Overall Score obtained using matrix method [192].

Sr. No.	**Category**	**Indicator**	**Una Town Results**
Quantitative Indicators (Public Health, Environmental Control, 3R)			
1.1	Public health waste collection	Waste collection coverage	4
1C		Quality of waste collection service	3
2.	Environmental control-waste treatment and disposal	Controlled treatment and disposal	1
2E		Degree of environmental protection in waste treatment and disposal	1
3	Resource management reduce, reuse and recycle	Recycling rate	1
3R		Quality of 3R's- reduce, reuse and recycle- provision	1
Total Score (Quantitative Indicator)			11
Maximum Score			30
Weightage (%)			**36**
Qualitative Indicator (Governance Factor)			
4U	Inclusivity	User Inclusivity	2
4P		Provider Inclusivity	2
6N	Sound institution, proactive policies	Adequacy of national SWM framework	2
6L		Local institutional coherence	2
Total Score (Qualitative Indicator)			8
Maximum Score			20
Weightage (%)			**40**
Total Score (Overall)			11+8=19
Maximum Score			30+20+50
Overall Weightage (%)			**38**

3.6 Suitable option for Improving Waste Management Practices in Study Region

The results from "wasteaware" benchmark analysis confirmed that the existing MSW management system in study region is not effective and efficient. Despite the absence of environmental control, disposal and recycling of waste, the effectiveness of the collection is good in the study area. The outcomes of the matrix method showed that the efficiency of management system turns into bad condition (much less than 40%) [192]. Thus, the improvement in the MSW management system in study area is of instant need. Therefore, in order to improve the existing solid waste management system, few recommendations are given.

3.6.1 Source Segregation

The study on solid waste management showed that segregation of waste isn't in practice in Una town. Segregation at source for better MSW management is an effective or efficient way to minimize the waste quantity. The recyclable and reusable waste at generation point need to be segregated, which is neither costly nor time-consuming process. This process comprises segregation of selected material and collection into specific containers and additionally, storage of recyclable and normal waste should be done separately. The segregation of waste should be initiated from individual homes by collecting wet and dry waste in separate containers. The segregation may be accomplished as biodegradable and non-biodegradable materials, as the major fraction of biodegradables form an extensive share of the generated MSW at the study area. The organic fraction like food, vegetable wastes are amiable to the generation of energy via anaerobic digestion leading to methane generation. The separation of inorganic materials but recyclable/reusable substances like plastic, paper, glass and metals needs to be done by rag pickers which can also provide an additional source of earning for them, reduces weight of waste from dumpsite and for this reason increasing the existence span of landfill. However, the rag picking from the landfill site affects the health and well-being of rag pickers, thus require welfare activities for upgrading the livelihood and improving the quality of life of waste collector through NGOs, CBOs. Segregation of waste is important for the recycling of reusable materials. Additionally, the segregation of waste may also cause the discount in loads of landfill and provides the higher control of waste within the vicinity for effective and efficient processing/operating of the management system.

3.6.2 Reutilization/recycling of inorganic (plastic, inert and polythene) waste material

Waste generation rate in Indian cities is growing higher [1,6,13] and high content of inorganic material like plastic, polythene and other inert materials is present in waste. Hence, utilization of these materials has become vital in various applications like pavements, construction of roads, as the fill material, admixture, binder and for different other uses. Plastic can be used in pavements, in the embankments as fill material or in cement plants it can be used as admixtures and binders. The possible reutilization of such waste material will notably reduce the weight of landfill [2,52].

3.6.3 Implementation of Material Recovery Facilities (MRF) center

Material Recovery Facilities is a centralized system that receives, segregates and markets reusable and recyclable material from the waste. MRF has an advantage that it allows the municipalities to directly access and process the material uniformly. The design of MRF facility is generally done to manage all types of recyclable materials. The application of an MRF facility depends upon quantity, segregation and collection of waste, market demand, variety of recyclable materials. Due to the accumulation of a variety of recyclable materials, the MRF facility proved to be beneficial for their treatment. For the installation of an MRF facility, it involves large capital and operation cost which can handle a large amount of waste for efficient and effective functioning. The installation of such facilities can be done by cluster formation in collaboration with nearby regions or cities as the feedstock for processing is required in large quantities. Therefore, the installation of MRF in collaboration with other nearby locations will be cost-effective and also will divert about 60-70% the waste from landfills [22,26,45].

3.6.4 Installation of RDF units and Bio-methanation Plant

It was reported from the past studies that high proportions of biodegradable/organic matter in the waste is present in many South-East Asian countries including India [41,42,49]. Thus, for generation of biogas using suitable treatment technology accompanied with the right segregation strategies this organic fraction of waste can be used. The anaerobic treatment of a biodegradable fraction of the waste generate methane which acts as energy source. The installation of the bio-methanation unit in the study area is feasible as the major fraction of waste is organic. However, biogas generation in the study area could be significantly affected all through winter because of low temperatures due to which the microbial activities gets disturbed. Hence proper heat insulation needs to be provided for maintaining the microbial activities in the digestor. Further, the non-biodegradable/inorganic fraction of waste can be utilized to generate RDF and such plants can be installed depending upon the composition and waste generation in study location.

3.6.5 Integrated Solid Waste Management (ISWM)

The ISWM is a contemporary and strategic method to sustainable solid waste management. The efficiency of the ISWM system involves the consideration for reducing, recycling and disposal of waste. It includes various treatment methodologies and methods for successfully dealing with the MSW stream made up of different extracts that can be easily managed and disposed of. The recycling facility of reusable fraction as paper, plastic, steel, glass, etc. provides a source of energy as RDF from fraction of waste having high calorific value, compost or biogas from biodegradable/organic fraction of waste. The ISWM system simulates the advancement of technology for conversion from waste to energy (WTE) and confirms safe working situations by encouraging green jobs. The participation of stakeholders for using techniques with the involvement of community-primarily based enterprise (CBO), non-governmental organization (NGO), personal and residential sectors and business communities with the government is encouraged by the system.

3.6.6 Implementation of 4R's practices and Aiming for "Zero Waste"

Waste minimization may be completed by focusing on 4R's - "reduce" observed by means of "reuse", "recycle" and "recover". The minimum use of raw products is involved in the *reduction* and needs to be adopted in study region and also in the rest of the cities of Himachal Pradesh. The process also involves the "reuse" of recyclable materials which can reduce the waste generation. To minimize the environmental and socio-economic problems various strategies for implementation and growth of waste management are needed. The implementation of 4R's practice is important and the requirement of effective working of a waste management system. The practices for waste management are desirable in developing countries [11] which helps in reducing and managing waste production. The involvement of municipal corporation with NGO's for reprocessing and recovery of resources like paper, glass, cardboard needs to be carried out for reducing the burden of landfill. The workers employed by the MCs, involved in the sanitation works should be skilled by the NGO's. Efficiency of strategies used for management depends on segregation performance at the source and practices of processing and recovery will increase the life span of dumpsite.

Furthermore, the idea of "zero waste" is a technique that pursuits to eliminate waste in preference to its management. This concept aimed to abolish waste and to change the old processes of management. It defines a "whole system approach" to reforming resource streams to limit dangerous discharge and to reduce aid use. The, zero waste is thus the remodeling cycle of useful source extraction, consumption and discards management to reduce the wastage of resources. Therefore, zero waste will help in pollutants discount, useful preservation of resources, waste value discount, reduction in climate adjustments, increase within the life span of a landfill, and effective waste control gadget. *Zero waste* will lead the society, cities to advanced revolutions that may save the environment, lives and expenditure (American Env. Health Studies Project 2010).

Abolishing the waste from residents and business is not feasible because producing anything without generation of waste is impossible. Therefore, the concept of zero waste is to divert at least 90% of total generated waste from landfills, incinerators and the environment [204]. This can be achieved by reusing and recovering the material and not throwing away as garbage. In this context, the waste generated in Himachal Pradesh is rich in organic content which can be directly utilized in bio-methanation, digestion, for composting and left out inorganic content of waste that can be reutilized with the help of recovery facilities. However, the goal for achieving zero waste is not that it can get really but a process which has very clear environmental, economic and social benefits.

3.6.7 Engineered Landfill

The waste which remained after treatment finally get disposed in a landfill or open dumps unscientifically. Therefore, to reduce the harmful impact in the study area, a properly-engineered landfill needs to be constructed. The provision of leachate collection and liner system to minimize infiltration of leachate through waste into the ground therefore stopping pollution of groundwater, surface waste and soil in the instantaneous region. The airing system has to be furnished to stop the accretion of landfill gases.

Summary

The study helped in understanding the present MSW waste management practices involved in Una town, Himachal Pradesh and the factors for inefficient management systems were identified. The waste management system in study area is found to be inefficient depending upon the survey conducted and analyzed using an indicator system. However, the survey conducted showed the collection efficiency of about 90% in the study region but poor treatment and disposal facilities available in town lead to ineffective MSW management. The lack of fund available for installation of machinery, treatment units and transportation vehicles make MSW management a complex process. A systematic travel route for implementing the proper management should be adopted for a better collection of waste. The current practices for waste disposal include direct dumping on open land without providing any preventive measures for leachate migration and gas emission. Additionally, the *wasteaware benchmark indicator* and *matrix method* were used to analyze the management system in study location. Study revealed that the Una shows poor performance of environmentally control waste treatment and disposal system, resource management (3R) system. With universal trends, the systems are focused on sustainability matters mainly through the unification of 3R technologies and degree, nature of improvements toward sustainability are fluctuating thus depending upon the economic status of a country. The study also gives remedial measures for improving the waste management practices including collection, providing an adequate number of bins, transportation, treatment. The municipal corporation of the study region is responsible for providing the proper facilities and better treatment and disposal facilities thereby minimizing the adverse effects of MSW on the environment and human health. The collection, disposal and treatment method adopted for better management of system should be efficient which depends upon the composition and characteristics of MSW. Hence characteristics of waste generated in the study location are of utmost importance for considering the treatment method for proper management of MSW and have been discussed in detail in the next chapter.

CHAPTER -4

CHARACTERIZATION OF MUNICIPAL SOLID WASTE IN UNA, HIMACHAL PRADESH

4.1 Introduction

The sustainability of waste management is essential for providing an efficient service that meets the requirements of end users. As discussed in the previous chapter, the management of waste has become very complex mostly in developing countries due to insufficient facilities for collection, transportation, treatment and reduced budgetary provision of municipal corporations for handling and managing the waste [6,68,80,205]. So, for a better understanding in context of waste management and treatment options, determination of composition of waste and energy recovery potential of waste are discussed in this chapter.

Currently, it has been estimated that the Indian economy will increase till 38% by year 2026 [7,50] and thus will lead to increased generation rate of MSW [2,50]. The massive growth in the population, rapid industrialization and urbanization has led to inadequate, inefficient management causing environmental issues at global and national level [80,88]. The management of waste is complex and cost intensive public service. Hence, it is required to develop a systematic approach for improvement of waste management practices, policies and rules for legal framework in developing countries [2,8,198]. The disposal management of waste, gathering information and reliable data regarding waste generation, quantity and characterization are essential factors for sustainable waste management. These factors depend upon the food habits of people, living standard, seasonal variations, socio-economic condition of the area [1,8,68,88,157]. Thus, for better and sustainable waste management it is mandatory to collect the data and information for generating a baseline regarding the characteristics of waste which helps in improving the MSW management system. Thus, identification of composition and nature of MSW is necessary for adopting adequate treatment measures.

In India about 1,45,626 MT/D of waste is generated daily with per capita generate rate of 0.2-0.87kg/day. The characteristics study of MSW in India has generally reported a higher proportion of organic matter about 35-60%, about 6-10% recyclable and rest are inert material in various parts of country [1,2,13,54,55,80,206]. The generated waste mainly includes biodegradable and non-biodegradable fraction which include organic matter, paper, plastics, metals, inert and others like cardboards, textile, leather, thermocole [18,80,207,208]. The larger fraction of organic content in MSW of developing country is due to food habits, economic conditions than developed countries [69] The utilization of biodegradable waste in terms of energy source can be one of useful method for minimizing the quantum of waste. However, the common practice adopted for waste collection is without the segregation process which effectively reduces the energy value of waste. In India, the various waste to energy and treatment facilities like RDF, incineration, gasification and composting etc. are facing problems due to mixed nature of waste which is result of poor waste segregation [18,81]. Now-a-days the requirement of environment friendly processing, treatment and disposal techniques are the need for the sustainable management of MSW.

Nevertheless, in Himachal Pradesh the waste generation rate has increased with time and growth in population. The major composition of MSW is organic as HP is primarily an agricultural state. The waste generated in state and study area is classified as mixed waste as no facilities for segregation of waste were adopted at collection points. The disposal method for MSW leads to the evolution of dumpsites in different cities of state. The proper characterization of waste is an essential factor for designing an efficient, cost effective waste management system [80,209]. Presently, the lack of data availability regarding generation, characteristics, nature waste makes it difficult to develop an ISWM system.

In this context, the present study focuses on the MSW characterization in Una town of Himachal Pradesh, a Tier-IV city. The characterization of waste involves the identification of different components of waste to be utilized for suitable treatment methods thus reducing the quantity of waste on land. The potential energy content from the MSW generated from the study location using experimental conditions was validated using empirical models. The characterization outcomes had been carried out for the generated MSW as no such outcomes exist and consequently has been compared with similar research carried out at different locations in Himachal Pradesh. Statistical analyses were carried out to determine the significances of the characterization results. The physical and chemical characterization of waste was done to observe the nature of waste and suitable treatment facilities were suggested to utilize the energy value by contributing to energy supplies and alleviating energy poverty.

4.2 Material and Methods

4.2.1 Sampling Procedure

The collection of samples from the dump site was done as per guidelines of ASTM-D-5231-92 [210]. The MSW samples were collected from vehicles unloading waste from residential, commercial and institution at the dump site. The sampling was done randomly for 10 days (n=10) for each season to obtain representative sample. The waste collection was done on a plastic sheet while unloading trucks to avoid mixing of soil, dust particles. The quartile method was used for sampling and determination of composition of waste [211,212]. Total of 1000 kg of waste was unloaded from the trucks during 10 days sampling period and out of 1000 kg representative sample of 100 kg was obtained for physical characterization. For all three seasons, total of 30 samples (n=10 for each season) were collected. After collection of samples, segregation and sorting was done with the help of rag-pickers to differentiate the components of MSW.

For the chemical characterization, waste samples from the different locations were collected during the three seasons. The collected samples were mixed to get a representative sample of 5 kg and was taken to the laboratory in tight plastic containers for analysis. The sample was tested for proximate and ultimate and heavy metal analysis.

4.2.2 Characterization of Municipal Solid Waste

4.2.2.1 Physical Characterization

Physical characterization of MSW is done to classify the different waste components like biodegradable and non-biodegradable and others (cardboards, thermocole, leather, textile etc.). The categorization of MSW components is important for adopting the suitable treatment technologies for sustainable waste management system [75]. The physical characterization of waste was done on wet basis without prior drying of samples and then segregation for different components like organics, paper, plastic, wood, metal, leather, textile and inert was done. The inert materials are classified as those which are chemically non-reactive, can’t be degraded biologically, composed material from street sweeping, construction material. Each segregated component was weighed separately to determine the percentage of contribution in waste generated. Samples were then immediately transported to laboratory for the moisture content determination. The density of the waste was determined in field using wooden box of capacity 1m^3. The composite sample of waste was filled in the box, compacted and then weighed. Thus, the density of the waste was determined on basis of mass per cubic meter of box [37,213].

4.2.2.2 Chemical Characterization

The chemical characterization of waste sample was done as per the guidelines of ASTM -D 5231-92,2008 [210]. The proximate analysis was done as per the ASTM standards including ASTM E790, E830 and E897 [214-216] for determining moisture content, ash content, volatile matter, fixed carbon, calorific value of the waste [211]. For the determination of gross calorific value of waste, bomb calorimeter was used. The heavy metals in the MSW was determined as per the method given in ASTM 2003, using flame Atomic Absorption Spectrometer (AAS). The elemental analysis including determination of C, H, N, S and C/N ratio of waste sample. Analysis of the samples were carried out as per ASTM D 3176-09, 2002 [217] and CHNS elemental analyser (*Make - Thermo Electron Corporation Flash EA 1112*) was used to carry out the test.

Moisture Content

The moisture of MSW was determined in laboratory by heating waste in oven at temperature of 105-110 ˚C until constant weight is obtained [4,211].

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \tag{4.1}$$

Ash Content

The waste is heated in a muffle furnace at 750˚C for about 1 hour till the waste is completely turned into ash.

$$\text{Ash Content (\%)} = \frac{\text{Weight of Ash} \times 100}{\text{Initial weight}} \tag{4.2}$$

Calorific Value

A pellet of known weight was prepared and fired in bomb cell in bomb calorimeter to analyze the calorific value of waste. The gross calorific value is amount of heat produced from the burning of unit weight of sample. It is expressed in kcal/kg [4,211].

$$\text{Gross Calorific Value (kCal/kg)} = \frac{\text{Rise in temperature of sample} \times \text{Water equivalent}}{\text{Weight of sample}} \tag{4.3}$$

Volatile Matter

The sample is heated in crucible at temperature of 950˚C for seven minutes and remained fraction is weighed and expressed as

$$\text{Volatile Matter (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \qquad (4.4)$$

Fixed Carbon

The amount of combustible matter left after the volatile matter is removed is termed as fixed carbon.

$$\text{Fixed Carbon (\%)} = 100 - \text{moisture (\%)} - \text{Ash content (\%)} - \text{Volatile Matter (\%)} \qquad (4.5)$$

4.2.3 Energy potential of Municipal Solid Waste

The energy recovery is an integral part of MSW management system and determination of energy content in terms of calorific values is important for utilizing energy value of waste. Energy content in terms of calorific value of MSW is determined by using bomb calorimeter in laboratory and obtained results were compared using the empirical methods [118,134,218-222]. The experimental determination for analysis of calorific value require small amount of waste i.e. 1g for bomb calorimeter, 1-10mg for elemental analysis and 1-5g for proximate analysis [221,222] which is insufficient for vast variance in MSW. These methods require precision and skilled worker to carry out experiments. Therefore, mathematical models were developed based upon physical, elemental and proximate analysis to give approximately accurate estimation of calorific value.

Physical Composition Analysis

The conventional model and model developed by [219] and uses the characteristics having plastic, paper, garbage present in MSW for determining the calorific value. The model based on physical composition were created depending upon weight percentage of plastic, food, paper in MSW.

Ultimate Analysis

The elemental composition-based models Dulong's model, Steuer's model and Scheurer-Kestner model were developed depending upon the presence of carbon, sulphur, oxygen, hydrogen present in MSW [219,220]. The weight percentage of elements present in MSW depending upon the water content present is used for analysis of calorific value.

Proximate Analysis

The proximate analysis models were created to determine the calorific value based upon the weight percentage of volatile matter and fixed carbon in MSW. Bento's model and Traditional model uses the presence of combustible volatile matter in waste.

The empirical models used for energy content determination have been summarized in *Table 4.1*.

Table 4.1: Empirical model for energy content determination.

Physical Composition Analysis	**Ultimate Analysis**	**Proximate Analysis**
Conventional Model H_n = 88.2 R + 40.5 (G+P) - 6W where H_n= net calorific value (kcal/kg) R = plastic content (% wt. on dry basis) G = garbage content (% wt. on dry basis) P = paper (%wt. on dry basis) W = water content (% wt. on dry basis)	***Dulong's model*** H_n = 81C +342.5 (H- O/8) +22.5S-6(9H+W) where H_n= net calorific value (kcal/kg) C = carbon (wt.%) *H = Hydrogen (wt.%)* O =Oxygen (wt.%) S = Sulphur (wt.%)	***Traditional Model*** H_n = 45B-6W where B = combustible volatile matter W = water (% dry basis)
Khan and Abu Ghrahah Model E = 23[F+3.6(PA)] +160(PL) where PL = %age of plastic by weight F= %age of food waste by weight Pa = %age of paper waste by weight	***Steuer's model*** H_n = 81(C-3O/8) +57(3O/8) +345(H-O/16) +24S-6(9H+W) **Scheurer-Kestner's model** Hn = 81(C-3O/4) + 342.5H +22.5S + 57(3O/4)-6(9H+W)	***Bento's Model*** H_n = 44.75B-5.85W+21.2

4.3 Results and Discussion

4.3.1 Physical Characterization

The results of the physical characterization of MSW from the Una town are presented in *Table 4.2*. The average density of municipal solid waste was determined to be 428 kg/m^3. The MSW from the Una town was observed to be rich in organic content (56%) contributing in major proportion of total generated MSW. The major constituents of biodegradable waste include fruits, vegetables, paper and kitchen waste. The higher proportion of organic content (40-70%) in MSW is supported by studies conducted in India and other developing countries [2,6,13,18, 131,223].

The physical characterization of MSW was done for three seasons summer, monsoon and winter to observe any seasonal variations. It was observed from the results that during the summer season the organic fraction in MSW was higher (58.6%) which is due to greater abundance and consumption of fruits, vegetables than winter season (53.4%). This variation is also due to climatic conditions and cultural variations as reported in other studies as well [19,75,131,207]. The Una town is also a transient place for tourists to hill stations like Dharamshala, Mcleod Ganj etc. and high flow of tourists during summer seasons leads to increase in the waste generation. The presence of higher organic content (50-55%) was also observed in studies conducted for nearby areas Baddi, Mandi, Solan, Sundernagar [131].

Table 4.2: Physical characterization of MSW from Una town.

Sr. No.	Components	Summer	Monsoon	Winter	Average
1	Organic matter	58.6±2.23	56.3±1.28	53.4±3.44	56.1±1.08
2	Paper	10.6±0.35	13.9±1.85	12.12±1.26	12.2±0.76
3	Polythene/Plastic	10.3±1.77	10.1±0.80	10.61±0.69	10.3±0.59
4	Glass	0.9±0.21	1.1±0.21	1.09±0.15	1.0±0.03
5	Metal	1.4±0.94	0.9±0.18	1.13±0.54	1.2±0.38
6	Inert	10.0±2.67	10.0±1.30	11.2±2.36	10.5±0.72
7	Others	8.2±1.44	7.7±1.07	10.45±1.23	8.7±0.19

Note: All component values are in percentage (%).
Number in the parentheses is standard deviation.
Other includes leaves, wooden matter, polystyrene etc.

The results also showed the presence of paper and plastic in higher fraction in the study area. The fraction of paper is higher about 12.2% owing to the existence of many educational institutes (schools, colleges), govt. and private sector offices etc. The results of physical characterization have been presented graphically in *Figure 4.1*. The inorganic fraction of waste includes plastic/polythene, metal, glass and other miscellaneous materials. The amount of total inorganic fraction in waste was observed to be 31.7% for study area. Plastic/polythene is major component of inorganic waste which was found in higher proportion about 10.3% despite of the fact that Government of Himachal Pradesh has banned the use of plastic bags, packets and pouches since 2003.

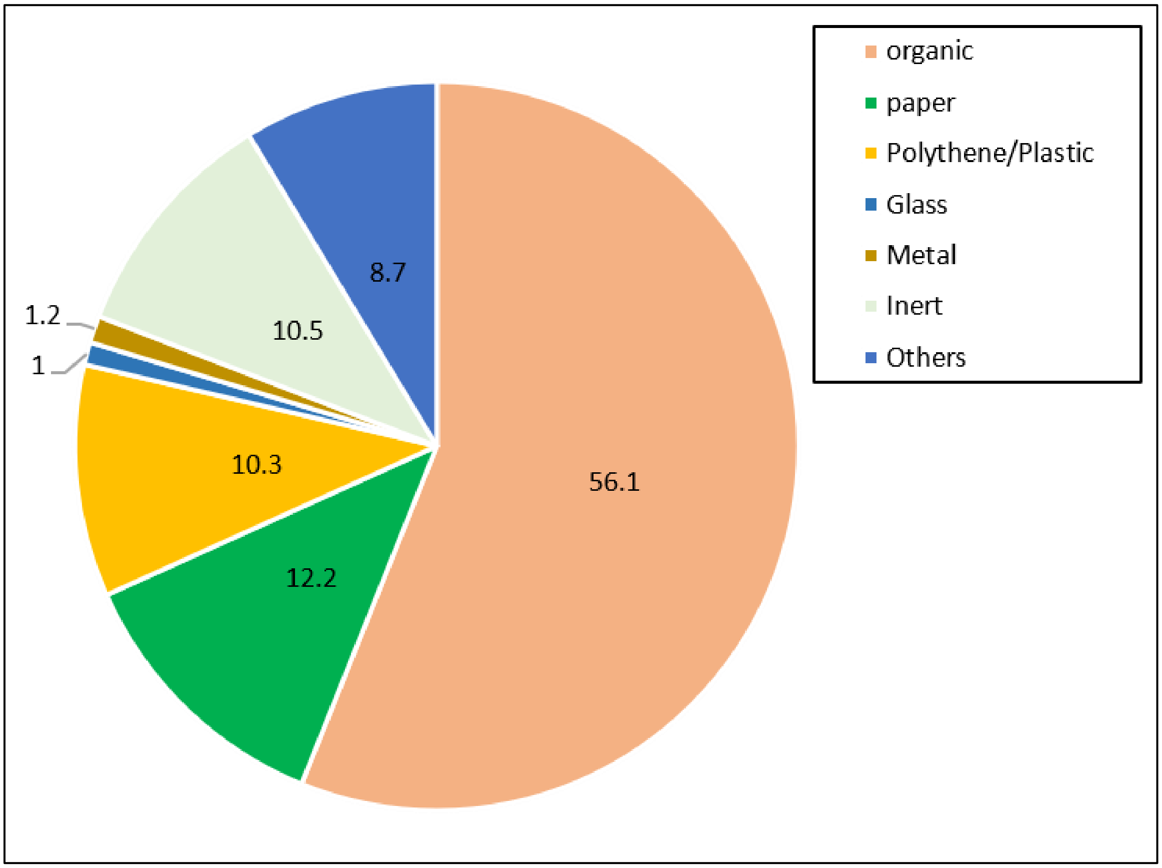


Figure 4.1: Physical characterization of MSW in Una town.

Additionally, the studies conducted in other cities of Himachal Pradesh [131], the plastic was found to be in lesser fraction except Baddi (14.40%) which is also a border region with Punjab and Haryana. The consumption, carrying of goods and services, transient population from the adjoining and nearby cities or state, contributes in generation of waste. The plastic waste generation in other regions like Mohali (6.6%), Chandigarh 97%) Jalandhar (9%), Bhopal (10%) was found to be significantly less [18,19,114]. Metal and glass were in very small fraction (about 2%) in waste due to lack of large-scale industries producing such materials.

The informal recycling by rag pickers was observed during the sampling, which reduced the fraction of such materials from waste. However, the inert fraction of waste was in higher proportion about 10.5% in waste due to waste coming from street sweeping, construction and demolition operations. The presence of inert fraction in waste reduces the calorific value of waste and thereby increasing the density of waste [18,223]. Miscellaneous materials in category *others* (8.7%) like wood, thermocole, textiles etc. were also found in waste generated from commercial, institutional sectors in study area.

4.3.2 Chemical Characterization

For the implementation of treatment units, waste to energy facilities like gasification, pyrolysis, bio-methanation, incineration, vermicomposting, RDF by utilizing the energy value of waste, chemical characterization is important method to be adopted. The chemical analysis includes ultimate, proximate and heavy metal analysis of municipal solid waste for three seasons summer, monsoon and winter. The results obtained from chemical analysis (proximate and ultimate analysis) of waste have been presented in *Table 4.3*.

4.3.2.1 Proximate and Ultimate characterization

The results obtained from the proximate analysis of MSW showed that the average moisture content of waste was about 50% which varied between 40-61% for the three seasons. In comparison with literature for developing nations, moisture content varies in range between 20-65% [9,69,79,131]. Further, the studies revealed that moisture content in Indian cities Chandigarh (35-59%), Jalandhar (25-34%), Bhopal (28%) are slight less [18,19,75]. However no significant difference in moisture content was observed for seasonal variation in other cities like Baddi, Mandi, Solan of Himachal Pradesh [131].

Table 4.3: Chemical characterization of MSW from Una town for three seasons (summer, monsoon, winter).

Parameters	Unit	Seasons			Average
		Summer	Monsoon	Winter	
Proximate Analysis					
Moisture Content	% by wet weight	40.2±3.59	61.3±5.19	48.22±5.15	49.9±4.64
Ash content	% by dry weight	27.34±5.68	20.24±1.37	27.02±3.52	24.87±3.52
Volatile Matter	% by dry weight	29.57±5.50	16.43±3.25	20.60±1.18	22.2±3.31
Fixed carbon	% by dry weight	2.89±0.73	2.03±1.02	4.16±0.64	3.03±0.80
Calorific value	(kcal/kg)	2543±176.55	1953±104.73	2292±102.16	2263±127.82
Ultimate Analysis					
Carbon	% by dry weight	28.59±1.24	37.29± 2.20	31.51±1.29	32.46±1.58
Hydrogen	% by dry weight	4.90±0.10	2.66±0.55	3.97±0.29	3.84±0.31
Nitrogen	% by dry weight	1.36±0.11	1.56±0.51	1.39±0.13	1.44±0.25
Sulphur	% by dry weight	0.08±0.001	0.10±0.003	0.14±0.001	0.11±0.002
Oxygen	% by dry weight	16.55±4.02	11.62±2.11	13.83±1.03	13.99±2.39
Potassium	% by dry weight	0.67±0.08	0.63±0.08	0.52±0.04	0.62±0.07
Phosphorous	% by dry weight	0.45±0.06	0.37±0.05	0.39±0.06	0.40±0.06
Mineral Content	% by dry weight	47.40	45.77	48.28	47.15
C/N ratio	-	21.02	23.90	22.7	22.72

Further, the ash content of the MSW were almost similar for both summer (27.34%) and winter season (27.02%) because of the increased burning of waste on dump site during summer season and use of wood, coal for heating purposes during winter which increased the amount of ash content in waste. The presence of inert material significantly affects the ash content in MSW [18,70,223]. It was recommended that MSW having ash content in range of 5-15% is suitable for incineration [224]. The volatile fraction for three seasons varied in range of 16-30% having the highest percentage in summer (29.57%). The higher percentage of volatile matter (average 22.2%) in waste due to high fraction of biodegradable matter present in MSW. These results were observed to be in same range with other cities like Baddi, Solan, Mandi and Sundernagar wherein the values lie in range of 23-28% and for tricity of Chandigarh 17-28% [75,131]. Thus, higher fraction of volatile matter indicates that the waste can be utilized for energy generation. The fixed carbon in study region varied in range of 2.03-4.16% having higher value in winter seasons because of burning of coal, wood for heating purposes. The value of fixed carbon in study area was less during monsoon season due to higher moisture content and comparison with reported literature showed similar such reported value 1.68% to 4.86% for Himachal Pradesh, higher values 6.7% to 8.3% for Jalandhar and 1.0% to 7.6% for tricity region of Punjab [18,75,131]. Consequently, the average calorific value of waste was observed to be 2263 kcal/kg with highest value reported in summer season (2543 kcal/kg). Similar studies carried out in cities of state and nearby region showed that the calorific value of waste in Himachal Pradesh varied between 2327-2667 kcal/kg and for Chandigarh 2508 kcal/kg, Mohali 2208 kcal/kg [75,131]. Reported studies for metropolitan cities like Mumbai, Delhi, Chandigarh showed high calorific value of waste as 7477 kcal/kg, 4498 kcal/kg, 1929-2508 kcal/kg respectively which the waste suitable for energy generation [1,75,118,209].

The analysis of elemental composition of MSW was done using ultimate analysis (*Table 4.3*). The results revealed that carbon content in waste varied between 28.59-37.29% for three seasons with average 32.46% which is higher due to high organic content present in the MSW. Similar results were observed for the other cities of state and country [9,18,19,69,75]. However, presence of oxygen (11.62 to 16.55%) was high in waste followed by hydrogen (H) (2.66 to 4.90%), nitrogen (N) 1.36-1.56% for three seasons. The studies conducted in Baddi, Solan, Mandi, Shimla also showed the similar trend. The values observed for carbon, oxygen, nitrogen, hydrogen was found to be within the range observed for Jalandhar, Chandigarh, Solan, Baddi [18,75,131]. Presence of trace elements like sulphur, potassium, phosphorous were observed in MSW with average values 0.11%, 0.62%, 0.40% respectively. The average C/N ratio of waste 22.72% showed suitability of waste for composting process. The slight variation in C/N ratio was observed during the three seasons. The obtained results showed the same characteristics as Baddi, Solan, Mandi and other Indian cities having C/N value in range of 20-40% which indicate its amenability for composting [19,67]. The presence of elemental composition is observed to be useful in deciding the treatment potential of MSW. The variation in proximate and ultimate analysis for three seasons have been shown in *Figure 4.2* and *Figure 4.3*.

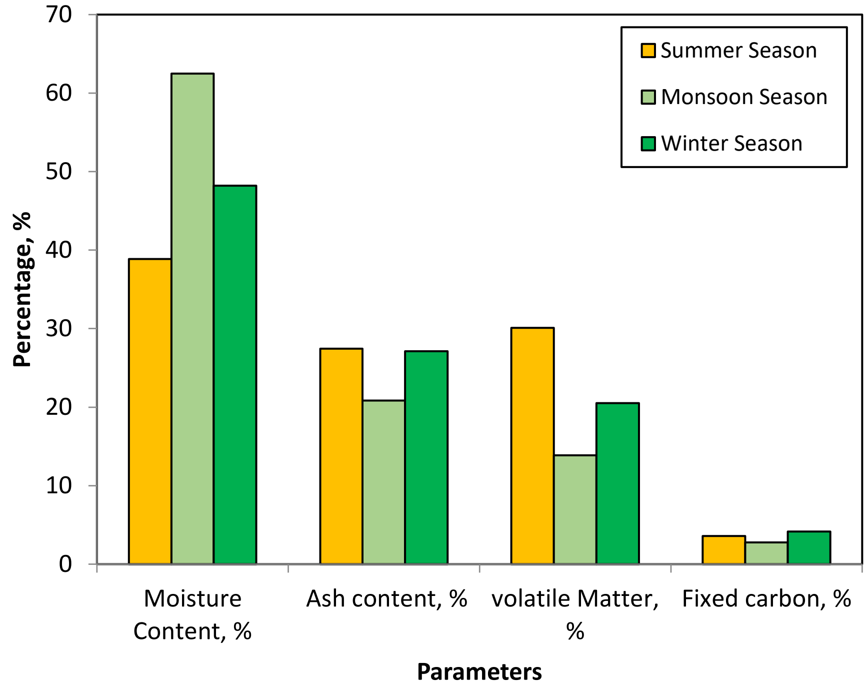


Figure 4.2: Variation in components from proximate analysis.

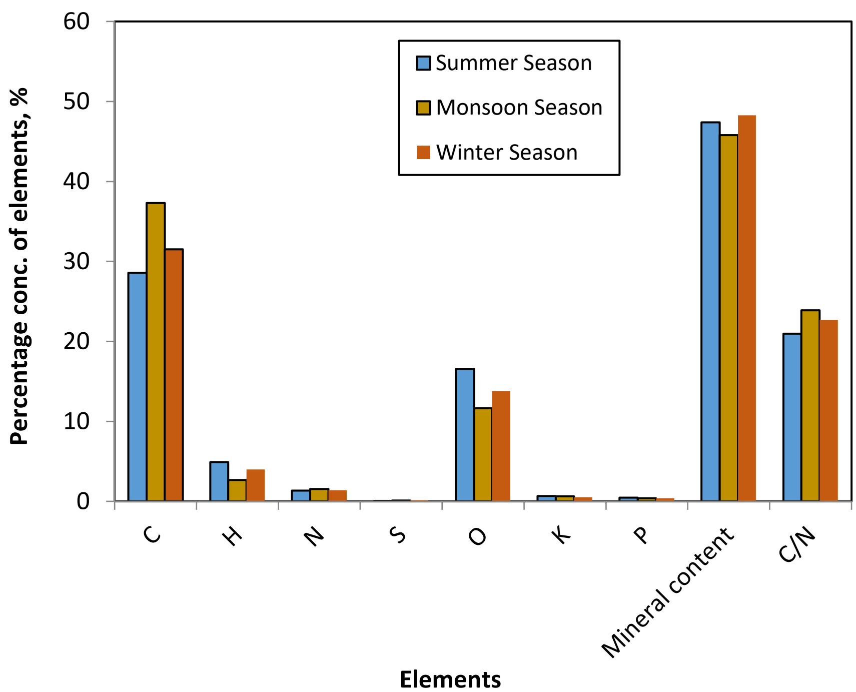


Figure 4.3: Variation in elements composition for three seasons.

4.3.2.2 Heavy Metal Characterization

The presence of heavy metals in MSW have been presented in *Table 4.4*. The results showed that heavy metals present in MSW were within the permissible limits prescribed by US Environmental Protection agency [225] and MSW Rules [72]. *Figure 4.4* showed variation in heavy metals for three seasons.

Table 4.4: Heavy metal concentration in MSW for three seasons.

Parameters (mg/kg)	Seasons			Average	Permissible Limit [65]
	Summer	Winter	Monsoon		
Pb	0.01	0.01	0.01	0.01	100
Cu	156.04±7.88	127.37±9.18	139.97±1.74	141.13±0.58	300
Cd	0.001	0.001	0.001	0.001	5
Fe	882.13±65.49	715.47±41.09	726.47±75.32	774.69±25.11	-
Ni	0.01	0.01	0.01	0.01	50
Cr	22±1.41	17.16±4.15	19.02±2.85	19.39±0.95	50
Zn	23.86±5.1	22.65±5.27	21.50±7.44	22.67±2.48	1000
Mn	12.13±1.82	9.35±4.73	11.63±1.33	11.04±0.44	-

Note: Number in the parentheses is standard deviation.

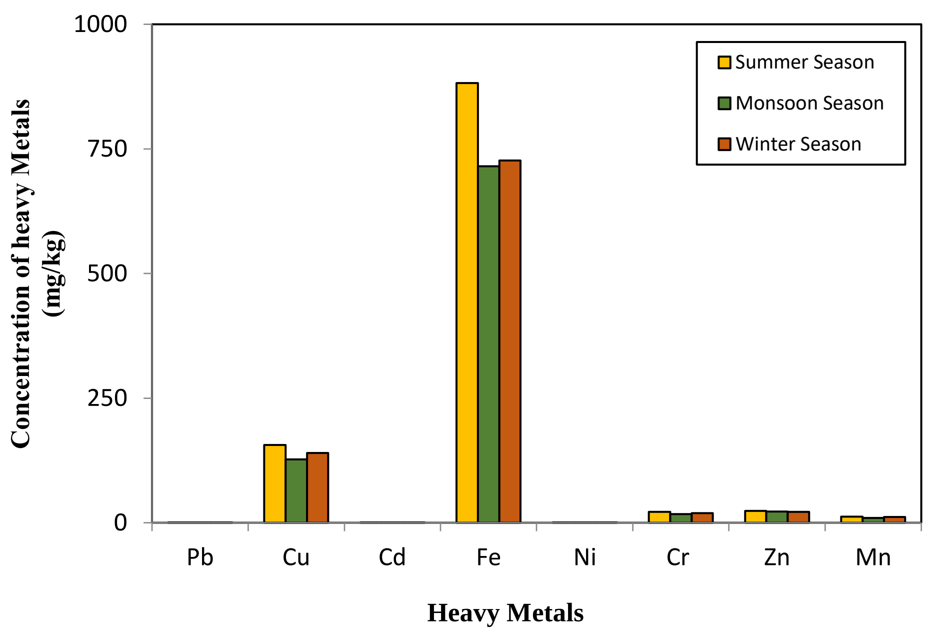


Figure 4.4: Variation in average heavy metal concentration of MSW.

The presence of copper (Cu), chromium (Cr), zinc (Zn) found in MSW could be attributed to the water-cooling industries, leather and paint industries in the study area. The presence of heavy metals like lead (Pb), cadmium (Cd), nickel (Ni) in MSW was in very small fraction but require consideration because small concentration of these metals could be harmful. However, because of the growing fertilizers, leather, paint industries in the study area, increases the influx of harmful chemical and substances to the landfill will result in the presence of harmful and toxic metal in the waste. The migration of metals and toxic substances from waste can thus leads to the contamination of groundwater and surface water bodies. Thus, the results obtained from the analysis are used for selecting the different treatment and processing facility for MSW and utilizing the energy value of waste.

4.3.3 Energy Generation Potential: Mathematical Validation

The energy content of MSW was determined in terms of calorific value of waste collected from the town during three seasons. The laboratory analysis showed the calorific value of waste about 2543 kcal/kg for summer, 1953 kcal/kg for monsoon and 2292 kcal/kg for winter season. The analysis revealed that during the summer season the calorific value of waste is higher due to less moisture content than in monsoon and winter. The experimental values were correlated with the use of the empirical equations for estimating the calorific value or energy content of waste depending upon the physical and chemical characterization of waste as presented in *Table 4.1*.

The physical analysis of energy content by Khan and Abu Ghrahah and model developed by Dulong's using elemental composition showed the almost similar values as determined in laboratory analysis. The obtained results indicate that presence of paper, food, plastic has positive effect for energy generation. The proximate analysis of showed a weak correlation between measure and predicted energy content values of MSW. The higher variation in energy content was observed may be due the effect of moisture content variation [218,219,226].

4.4 Suggested alternatives for better management of MSW depending upon the Characterization and Energy Content Potential

Improvement in waste management practices are essential for study region and energy content could be one of intensive idea for such progress. The implementation of various treatment and waste to energy units depends upon the waste characteristics and the management methods adopted for collection, segregation and transportation of waste. The facilities for energy recovery require the installation of waste to energy plants, solid waste management system for recovering and utilizing energy value of waste before final disposal in landfills. The waste that comes to dumping site in the study location is mixed waste which significantly reduces the energy generation potential of waste. For waste to be used as source of energy, segregation is important before it is used for any further processing. The segregation helps in differentiating the organic and inorganic fraction of waste which further can be used for suitable biological and chemical processing. However, the waste generation in study area is less therefore the waste to energy units can be provided in cluster formation with rest of cities of Himachal Pradesh and nearby region of other state like Punjab, Haryana. Thus, depending upon the composition, characteristics of waste the suitable treatment facilities were suggested and WTE facilities that can be provided for the study region are discussed.

4.4.1 Biological Treatment Processes

4.4.1.1 Aerobic and Anaerobic Digestion

The treatment of organic waste generated by aerobic and anaerobic digestion for converting it into a stabilized product. The organic fraction of waste in study area was found to be 56% which showed high efficiency for treatment using both aerobic and anaerobic methods. The treatment using aerobic digestion uses the MSW from kitchen, agricultural activities which is converted into compost [227]. This process involves the growth of micro-organisms through aeration and ventilation for maintaining the effective decomposition of waste [89,228]. These micro-organisms convert the waste into a stabilized product having good water holding capacity and can be used as fertilizer for increasing the fertility of soil.

The treatment of MSW in anaerobic condition involves conversion of organic waste into digestate and biogas in absence of oxygen [90]. Biodegradable fraction of waste is used to generate biogas in bio-methanation plant and is utilized as green fuel. The biogas generated during the digestion process is having concentration of methane (CH_4) and carbon dioxide (CO_2) in higher proportion. The concentration of biogas generation depends upon pH, temperature and moisture content during the anaerobic digestion which can affect the degradation rate of MSW. The pH level in acidic phase reduces the generation of methane leading to acetogenesis in MSW. The production of methane in mesophilic condition is more, therefore anaerobic digestor during winter seasons needs the precaution for maintaining the temperature by proving heat blanket or hot water bath system to sustain the methane production rate. This is of particularly concern for usage in HP as winter months in the state experience low temperatures which can reduce the functioning of the anaerobic process. The pathway for biological treatment of MSW is shown in *Figure 4.5*.

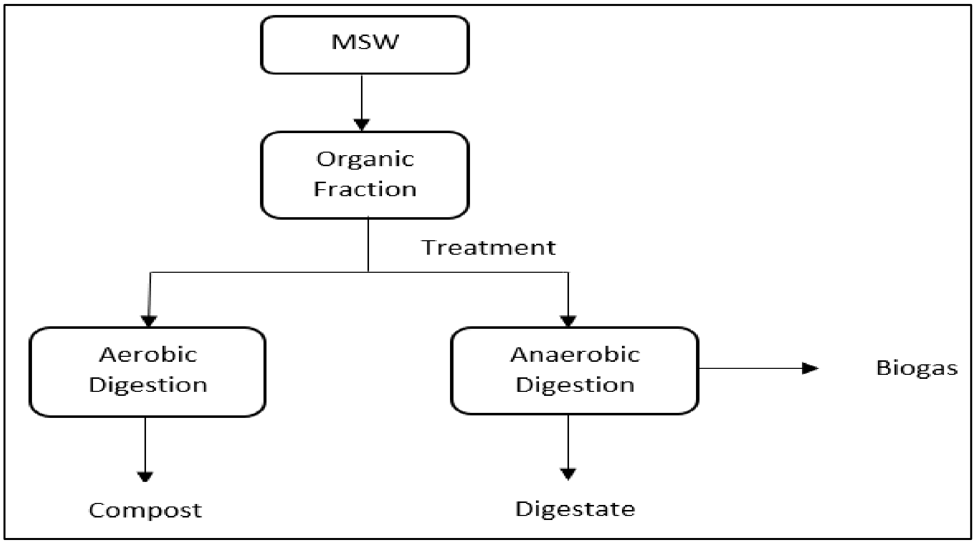


Figure 4.5: Biological treatment of MSW.

However, the anaerobic digestion requires consideration of temperature and collection of biogases properly. Waste generated for study area is not enough for treating it anaerobically at large scale which is also not cost effective. In this context, if availability of resources from nearby areas the treatment of waste can be done using the anaerobic digestion. biogas Alternatively, if the waste generated is of same quantity then aerobic digestion is a feasible option for treating and converting it into compost.

4.4.1.2 Vermicomposting

Vermicomposting is procedure of converting waste into humus like material by use of micro-organisms and earthworms. It is a manure restoring microbial populace which incorporates nitrogen fixers, phosphates and so forth making it suitable for vegetation. Vermicomposting of MSW is cost effective, economically feasible procedure which accelerates the stabilization of biodegradable fraction in waste [91]. However, the vermicomposting facilities are not in exercise in study area but were in existence at a few areas of Himachal Pradesh [131] and presently not in operation due to loss of professional labour, blended nature of waste and presence of heavy metals. The presence of heavy metals in the waste is much less at present however required to be eliminated from the waste prior to vermicomposting.

4.4.2 Thermal Treatment Processes

4.4.2.1 Pyrolysis

Pyrolysis is process of combustion of waste in absence of oxygen at temperature of 300-800˚C in heating chamber. Prior to the pyrolysis, segregation of waste for removal of glass, metals, inert material needs to be done [88]. The final product of pyrolysis process after suitable treatment of removing NO_x and SO_2 can be reused and thus increasing the performance and economic value of process [92,135,229]. The product of pyrolysis 'syngas' has high calorific value of 20 MJ/Nm3, containing gases like methane (CH_4), carbon dioxide (CO_2), hydrogen (H), carbon mono-oxide (CO) [230]. Both the organic and plastic fraction of waste is utilized in pyrolysis system which convert plastic into fuel of high calorific value.

4.4.2.2 Refuse Derived Fuel (RDF) Unit

The characterization of MSW showed higher fraction of paper, plastic, garbage, wood etc. shows the viability for installation of RDF facility. The RDF plant in the study area is considered as one of alternative solution for energy recovery. The results of MSW characterization showed that average calorific value of waste 2263 kcal/kg and can be utilized for the energy generation potential. Currently, only one RDF plant exist in North India situated in Chandigarh with capacity for generating 3100 kcal/kg calorific value of fuel with daily intake of waste about 500 TPD [57]. The average calorific value of waste in Chandigarh city was estimated to be 2208 kcal/kg showed similar value for study area. Thus, based upon the amount of generation of waste and characteristics, one RDF plant can be established for Himachal Pradesh to derive the RDF fuel to produce electricity.

4.4.2.3 Gasification

Gasification is the chemical process for generating fuel rich and gaseous products. The MSW is heated in boiler for steam production to generate electricity (*Figure 4.6*). The process is complex and breaking down waste into simple molecules and substances like dioxins [231]. The product syngas is produced during the process can be used as fuel for various large industrial applications. During the process of gasification, the large volume and mass of waste is reduced by 50-90% of initial volume or mass. The process is less expensive and environmentally compatible because of their higher chemical to electrical efficiency than combustion plant [88,92].

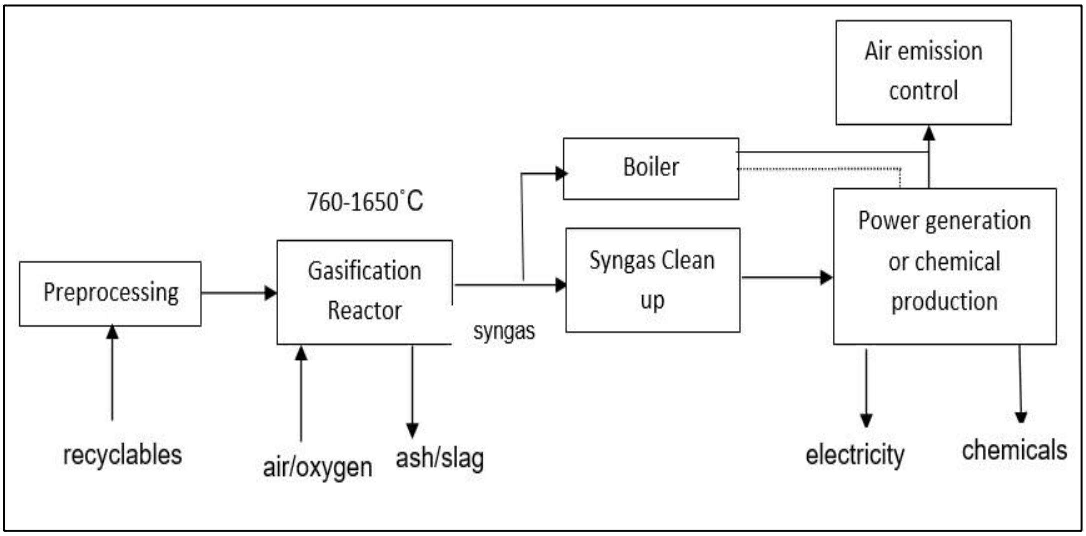


Figure 4.6: Gasification process of municipal solid waste.

The comparison of thermal treatment facilities suggested for treatment of MSW in study area has been given in *Table 4.5*.

Table 4.5: Thermochemical conversion technology: advantages and disadvantages [135,229,232].

Thermochemical Conservation Process	**Advantages**	**Disadvantages**
Gasification	Reduction in volume of waste by 50-90% Uses all type of waste No emission of greenhouse gases	High capital and operational cost Production of dioxins and other persistent organic pollutant (POPs) causing air pollution Corrosion of metal tube during reaction
RDF	High calorific value of RDF pellets (~4000 kcal/kg) Alternative energy source for fossil fuels Lower pollutant emission	Needs safe disposal of produced fly ash High energy consumption. Coke formation from liquid products. Highly inefficient in higher moisture content
Pyrolysis	Smaller emission of NO_x, SO_2 Less land requirement Up to 80% energy recovery rate High calorific value of product (~38MJ/kg) Lesser volume production of flue gas per kg of waste, reducing treatment capital cost	Greater capital cost Oily liquid product has high water content resulting due to moisture in feedstock

The WTE facilities for treating the waste and utilizing the energy value require sufficient amount of waste for efficient running of the treatment unit. The waste generation in the study town is 6 TPD which is less for treating the waste in treatment unit. Hence installation of WTE unit for study area is not a feasible option which thus increase the operation, installation and maintenance cost. However, the entire district generates about 20.4 TPD of waste and the with the collaboration with the nearby cities and districts, WTE units can be installed thus making it economically efficient option. The fraction of different components of MSW for different treatment processes at Una is shown in *Figure 4.7*.

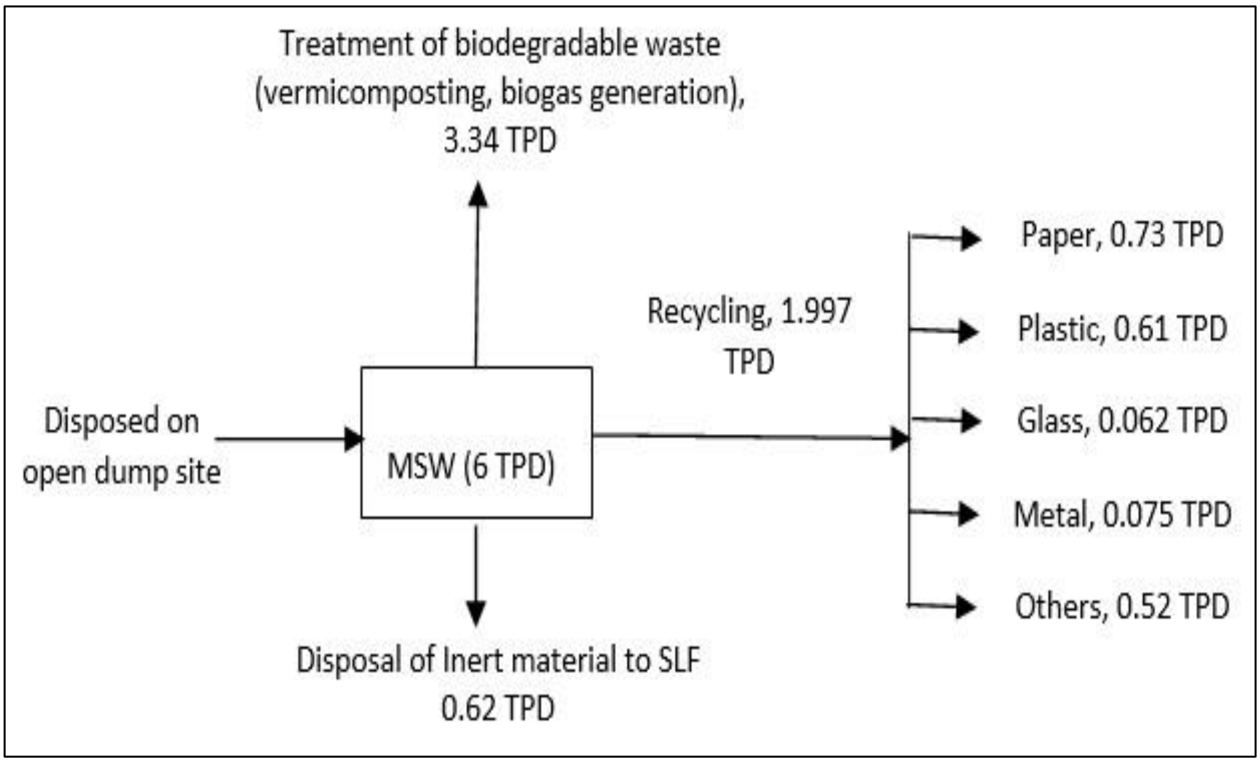


Figure 4.7: Treatment of different fraction of MSW in Una.

The study conducted in Himachal Pradesh revealed that the major fraction of waste is organic and suitable technique for converting waste to energy in Una district is aerobic and anaerobic treatment. The inorganic fraction of waste is treated in thermal treatment facilities for generating heat, electricity, fuel for large scale industries, machineries etc. However, the installation of WTE plant requires professional labour, availability of land, suitable PPP arrangements with the government and personal industries and other practical difficulties. The requirement of land for establishing the separate treatment plant for organic and inorganic waste can be the largest constraint in putting in place. In this context, Combined Treatment Systems (CTS) are frequently desired which includes treatment of each natural and inorganic fraction in a single WTE unit. This is regularly completed by using use of bio-refineries where organic waste is treated to produce biofuels and inorganic waste to produce syngas (*Figure 4.8*). The syngas produced in both the processes from pyrolysis and gasification can be utilized for heat and electricity generation and for power sources for boilers and turbines in nearby industries.

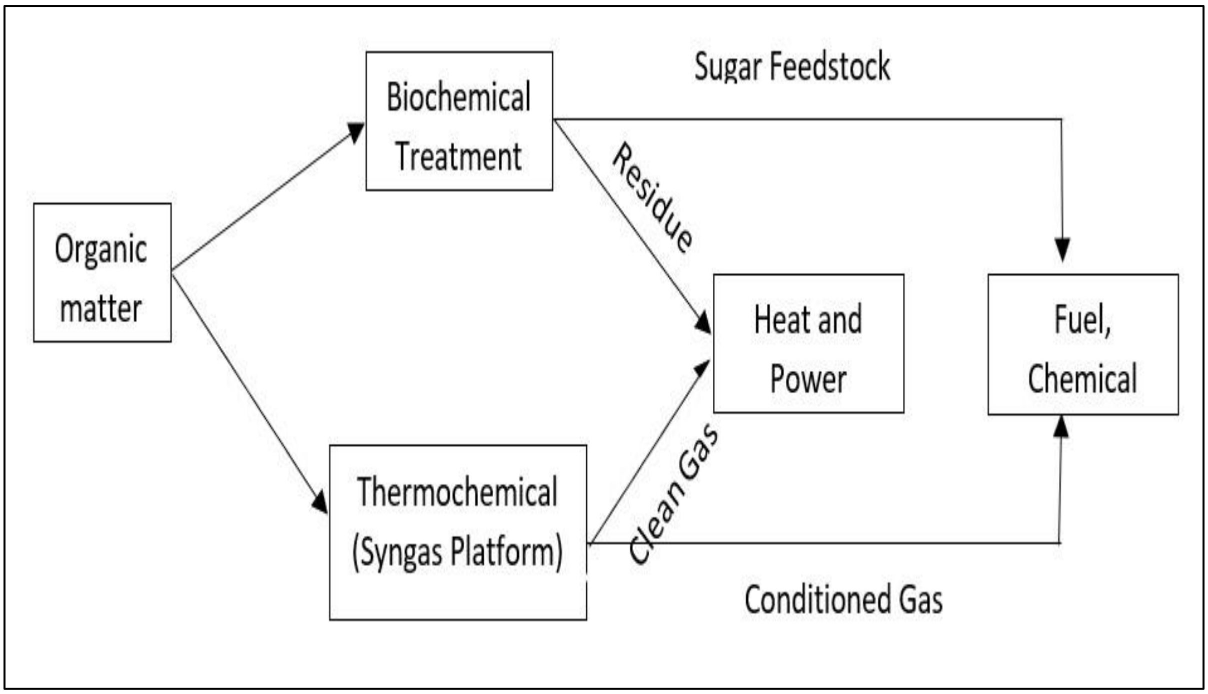


Figure 4.8: Utilization of Biomass in Bio-refinery platform.

Considering the practical location, the economy of the state and the district, land availability and the calorific value of the waste generated, the utilization of biorefinery as a possible WTE facility proves to be best suited for study area as it utilizes both organic and inorganic fraction of MSW to produce biofuels and syngas enhancing the value derived from biomass. Further, biological treatment processes could be used individually for organic waste and for inorganic waste RDF facilities could be provided.

4.4.2.4 Engineered Landfill

The construction of engineered landfill is considered as one of the effective MSW disposal method for reducing its harmful effect on environment and human health. Before final disposal of waste on the landfill segregation, recycling of biodegradable fraction should be done which thus reduces the burden of landfill. The engineered landfill for disposal of waste generated in Una district ought to be built for service life of approximately 20-25 years. The dumping of waste in landfill should be done for construction and demolition waste and at end of day the waste should be covered with layer of soil having minimum thickness of 10 cm. The leachate collection system and liner should be designed for the collection and prevent migration of leachate into sub soil. To minimize the price of construction, alternative drainage materials (tire derived aggregates, C&D waste aggregates) can be used [233]. Finally cover soil layer (0.5m depth) for flora boom must be supplied on top, covering drainage layer, which will be used for recreational activities like gardens, parking vicinity etc. However, after the final closure of landfill settlement of MSW needs to be taken into consideration because of degradation of MSW. Considering the generation rate of MSW in Una, a separate engineered landfill site may not be an effective option. Therefore, the disposal of waste should be done in collaboration with other districts of the state. Presently, construction of engineered landfill is being proposed for Shimla to ensure the safe disposal of waste. So, waste can be dumped in engineered landfill in Shimla city after initial treatment of segregation and recycling of waste. However, the transportation may cause additional burden on municipalities due to distances incongruity in distances.

Summary

The waste characterization is important for consideration of management methods and selection of suitable WTE facilities, suggesting the appropriate treatment methods for final disposal of waste. The characterization of MSW in study area showed that the MSW is rich in organic content (56%) with average moisture content of 49.57% which make it suitable for biological treatment. The generation of methane is a distinct possibility due to higher fraction of organic matter in waste. The chemical characteristics of MSW specified the higher ash content because of inert fraction in waste. The variation in the ash content and fixed carbon content in MSW during winter season is due to burning of coal, wood for heating purposes. The average C/N ratio of waste varied in optimum range for the study location. However, the heavy metal analysis revealed that the concentration of heavy metals in waste are within permissible limit but may be of concern because even small fraction may cause harmful effects on health. Additionally, the calorific value (2263 kcal/kg) determined for study region showed waste potential for energy recovery. The energy content estimated using the model analysis showed correlation of physical composition and ultimate analysis with the measured values in laboratory. Different methods for converting waste to energy have been discussed for utilizing the energy from organic and inorganic fractions of waste.

The remaining fraction of MSW need to be disposed in the landfill and thus require construction and designing of engineered landfill for minimizing the harmful effect on soil and environment. The stability and designing of landfill get affected due to degradation and settlement of MSW. The properties of MSW vary with the moisture content, organic matter present and rate of degradation. Thus, analysis of geotechnical characteristics of waste is required for ensuring the stability and structural integrity of landfill. In this context, geotechnical properties of MSW have been analyzed and discussed in next chapter.

CHAPTER -5

DEGRADATION EFFECT ON GEOTECHNICAL PROPERTIES OF MUNICIPAL SOLID WASTE

5.1 Introduction

Growth in waste generation is occurring at a faster rate due to rise in population, urbanization and industrialization and has made it difficult to in handling the waste generated efficiently. The most common practice adopted for management of waste across the world is landfilling which is considered to be an effective and inexpensive method for disposing the waste. The inadequacy of waste management practices comprised of poor collection, treatment and disposal facilities has already been discussed in earlier chapters. In summary, the present practices adopted for the management of waste in India are inadequate and quite unsatisfactory. From the total generated waste, about 10-20% is disposed in engineered landfill and remaining fraction of waste is disposed of unscientifically [6,234]. Hence as mentioned earlier proper management of MSW needs the designing of an engineered landfill. However, construction and operation of landfill depends on the characteristics and composition of MSW as well as other specific physical and engineering properties. In designing of landfill, the analysis of mechanical behavior is essential along with determining the water content, organic content of MSW. Hence, the present chapter deals with determining the geotechnical properties of the MSW generated at the study location.

The characteristics of MSW are complex which vary in size having various materials with different mechanical and geotechnical properties. The mechanical behavior depends upon fibrous and paste fraction (soil like materials) present in MSW which changes with time [37,235]. The complex geotechnical and mechanical characteristics of MSW causes problem in stability, cracking, settlement and slope stability of landfill [38,146,148,213]. The parameters which are important for considering the engineering aspects of landfill for settlement analysis, stability, cracking under static and dynamic conditions are given in *Table 5.1*.

The rate of degradation of waste is affected by many factors including composition, moisture content, pH, temperature and results in breaking down of MSW into finer particles. The properties of MSW thus gets affected due to degradation of organic material and increased moisture content thereby affecting the stability of landfill [36,37,105]. However, the presence of water content and organic content in MSW increased the degradation of waste and thus affects the long-term mechanical response due to disintegration of particles [105]. The degradation of waste results in reduction in volume and the settlement of waste occur about 30-50% of initial height of waste due to increased compression and overburden pressure [111,169].

Table 5.1: Parameters for designing and stability analysis of landfill [37,138].

Parameters	Unit Weight	Hydraulic Conductivity	Shear Strength	Lateral Stiffness	Compressibility
Leachate collection and removal system	✔	✔	✔	✔	✔
Drainage System integrity	✔				
Waste slope stability	✔	✔	✔		✔
Cover System Integrity	✔		✔		✔
Subgrade stability	✔		✔		
Subgrade integrity	✔		✔	✔	
Steep slope liner stability	✔	✔	✔		
Steep slope liner integrity	✔		✔	✔	✔
Shallow slope liner stability	✔	✔	✔		
Shallow slope liner integrity	✔		✔	✔	✔

Thus, properties of the waste were observed to get affected from fresh to degraded state of MSW. The particles of waste get finer with decomposition and results in variation in properties by converting organic component to inorganic. The determination of effect of degradation for landfill stability is function of unit weight, moisture content, organic content, compressibility, shear strength [105,141,145,213]. In the initial stage, the stability of landfill depends upon the unit weight and developed pore water pressure which thus results in decrease in strength characteristics [105]. The unit weight, compaction increases with degradation rate while the permeability of MSW decreases because finer fraction in MSW results in closed packing [36,141]. The compressibility due to degradation of fresh waste increased due to organic content present which changes the volume and composition of MSW. The strength characteristics of waste which is considered as most critical parameter for the stability of landfill, gets affected with degradation of MSW [140,144,145,149,236,237].

Various studies showed that there is no trend in variation of the shear strength characteristics of MSW due to degradation [143,145,238]. Many studies showed that the degradation results in increase in soil like material, fines due to which cohesion of MSW increased from 12 to 67 kPa and friction angle decreased from 38° to 24° [105,140,141,145,239,240]. The engineering properties of MSW affects the distribution of leachate and slope stability in landfill. The analysis of geotechnical characteristics provides a basis in designing a landfill and are however important in considering the stability during operation and after the closure of landfill. To avoid the catastrophic failure of landfill, evaluation of the effect of these changes on the geotechnical properties of MSW is important.

5.2 Material and Methods

5.2.1 Sample Collection

The samples of fresh and decomposed MSW were collected from the dump site as per the recommendations laid in ASTM D 5231, 2008 **[**18,241,242]. The sampling of fresh waste was done for a week and representative sample of 100 kg was obtained. The samples were collected on a plastic/polythene sheet and the components of waste like organic, paper, polythene/plastic, wood, metal, inert and miscellaneous were analyzed by segregating and were weighed for physical characterization. Using dry gravimetric method, moisture content was determined and shredding of samples was done for the gradation. Sample collection points in the dump site for degraded samples have been shown in *Figure 5.1*.

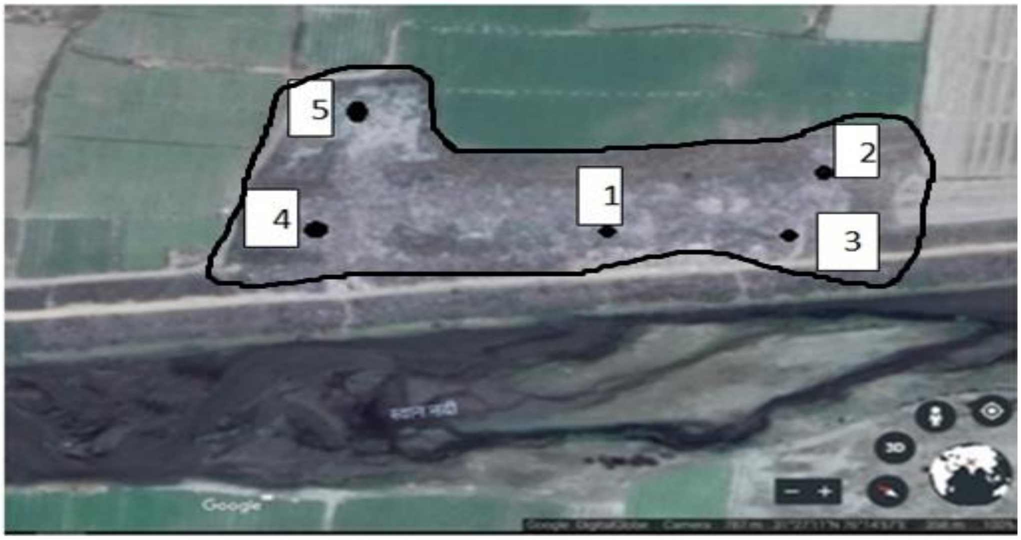


Figure 5.1: Sampling location (1,2,3,4,5) for degraded samples on dump site.

Waste samples of age between 0.5 year to 6 years were collected at variable depths from 0.5m to 6m to understand the effect of degradation on characteristics and strength properties of waste. The points of sampling were identified with help of MC Una personnel and workers at dump site. Depending upon the age of waste, representative samples covering MSW degradation period of 0.5-year, 1 year, 2 years, 4 years and 6 years were collected and the collection points were marked as 1 to 5 respectively in *Figure 5.1*. The samples were collected with help of auger and the *in-situ* unit weight was determined. The collected samples of fresh and degraded waste were then packed in poly bags and transported to the laboratory.

The moisture content of fresh and degraded waste was determined as ratio of water mass to mass of dry waste after heating at 60˚C, as per *ASTM D 2216, 2010* using dry gravimetric method [243] (*Figure 5.2*). The organic content of MSW was determined using loss on ignition method (LOI) by heating sample in muffle furnace at 440˚C for 72 hours. The degradation rate depends upon the presence of organic matter in fresh and degraded waste and was determined using following equation,

$$DOD = \left(1 - \frac{X_{fi}}{X_{fo}}\right)\frac{1}{(1- X_{fi})} \times 100 \quad \ldots\ldots\ldots\ldots (5.1)$$

where X_{fo} is initial organic content and X_{fi} is organic content at any stage of degradation.

Figure 5.2: Moisture content determination of fresh and degraded MSW.

5.2.2 Geotechnical Properties of Waste

The collected samples from the landfill site were shredded for determining composition, organic content, moisture content and particle size distribution. However, the degraded samples have the smaller particle size due to disintegration over a period of time. The laboratory testing of MSW for physical and geotechnical parameters was conducted as per ASTM standards [241-145].

The geotechnical parameters specific gravity, unit weight, hydraulic conductivity, shear strength and compressibility of MSW were determined as per the codal provision of American standards for testing and Material ASTM D 698, ASTM D 3080, ASTM D 2435 and as used by many researchers [105,130-141,143,239,246].

5.2.2.1 Physical properties

The physical properties of MSW from a geotechnical perspective include determination of organic content, specific gravity, particle size distribution. The determination of specific gravity of samples was done using a 1000 ml capacity pycnometer as per ASTM as used by many researchers [141,239].

The segregation of waste sample was done manually (*Figure 5.3*). However, the large particles of fresh waste were found to be unsuitable for testing, so representative samples of waste should be obtained for the geotechnical testing after shredding the waste to average size of 0.075mm to 40 mm. The samples were analyzed for particle size distribution (PSD) having sieve size openings from 0.075 mm to 100 mm after drying at a temperature of 60°C. The moist waste samples were sieved using a set of three sieves 100mm, 50mm, 20mm [245]. The larger particles of MSW were measured manually. The MSW was shredded using low-speed torque shredder to obtain the representative sample because of difficulty to use larger sized particle for laboratory testing [143,239,245]. The shredded samples varied in size between 0.075mm to 40 mm. The wet sieve analysis of waste was done on a weight basis as per ASTM D 422 [245].

The gradation, unit weight, water content, depends upon the composition of MSW collected from the site and were determined based upon volume and weight of the material. The unit weight of waste is used for analysis of the stability of slopes, leachate collection and removal system designing, settlement prediction and structural integrity of pipe systems [138, 213]. The unit weight of MSW samples depends upon the composition of waste, placement conditions, environmental conditions and stress conditions (overloading condition) [241].

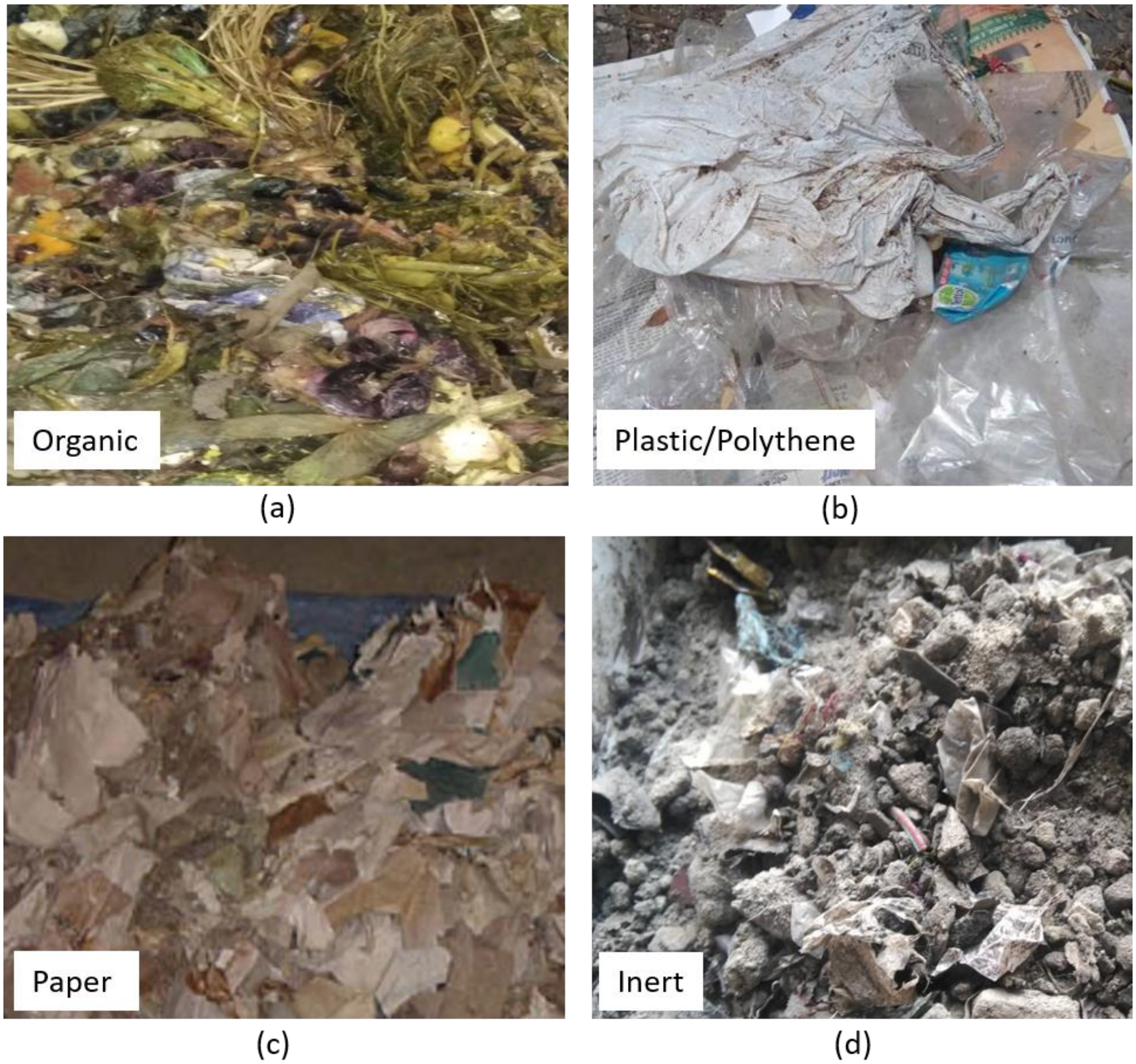
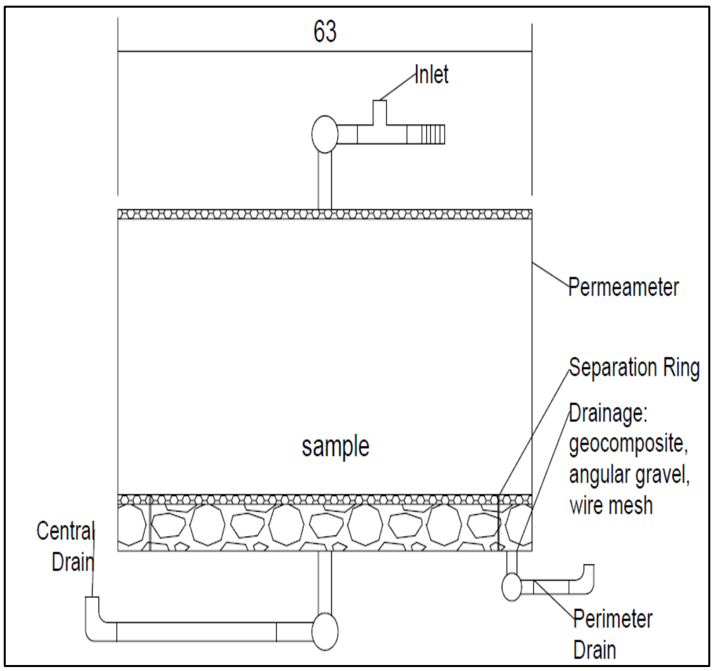


Figure 5.3: Segregation of waste samples for particle size distribution.

5.2.2.2 Hydraulic Conductivity

The constant head permeability tests as per ASTM Standard [241,247] was performed for determining hydraulic conductivity of MSW. The hydraulic conductivity of waste varies significantly with the composition of waste, degree of compaction; overburden stress applied but also depends upon the degradation process which changes the composition, size distribution of waste [36, 37]. The permeability of the MSW sample varies with the amount of plastic fraction present, which obstructs the flow of liquid through the sample.

The fresh and landfilled samples were compacted at dry density in small scale rigid wall permeameter of diameter 63 mm and height of 100 mm (*Figure 5.4*). The shredded fresh MSW samples (8-10 kg) were compacted in layers of 6-8 cm thickness using 15 blows per layer by a hammer. The samples were then tested under zero confinement and gradually increased normal stresses (0, 50, 100, 150, 200, 276 kPa). After saturation of the sample, the flow rate through the sample was determined using Darcy's law under constant hydraulic gradient [36,239].



(a) (b)

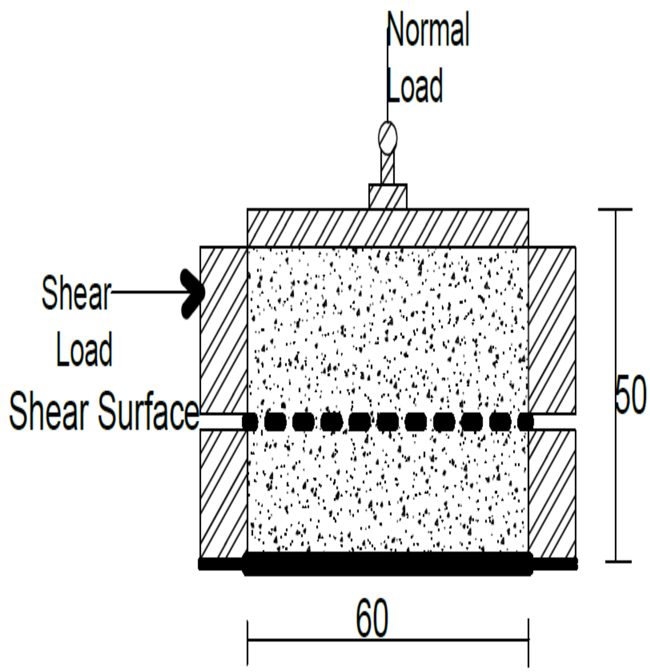
Figure 5.4: Schematic diagram and photograph of hydraulic conductivity apparatus.

5.2.2.3 Direct Shear Strength

The determination of shear strength of waste was done in the laboratory using a direct shear test as per ASTM D 3080 [248]. Laboratory testing for shear strength evaluation is the most appropriate method used by many researchers [138,140,143,145,146,237,239], so a direct shear test was conducted on MSW samples. The samples were placed in the shear box of size ($60\times 60 \times 50\ mm$) (*Figure 5.5*), subjected to the vertical stress (σ) of 50-300 kPa and sheared at a horizontal displacement rate of 1 mm/min at OMC of waste [36,148,149]. The fresh samples were collected during 5 days sampling period and degraded samples were collected within the dump site from a varying depth of 0.5 to 6 m having age between 0.6 to 6 years.

The large metal, glass particles were removed from waste and shredding of the sample was done before placing in the shear box. Each layer of the sample was compacted by a hammer to the pre-determined unit weight. The friction between the two surfaces in the shear box is reduced by polishing and below the lower box, steel balls were provided to reduce the friction. The samples were tested under different normal stress levels and the effect of MSW particles on strength was accounted. Initially, the loads were applied (50 kPa, 100 kPa, 150 kPa, 200 kPa, and 300 kPa) and each vertical load on the sample was sustained for at least 2 hrs for ensuring that no further settlement occurs before shearing [36,148].

(a)



(b)

Figure 5.5: (a) Photograph of direct shear test apparatus. (b) Schematic diagram of shear box ($60 \times 60 \times 50\ mm$).

5.2.2.4 Compressibility

Compressibility testing of MSW samples was determined using oedometer test for evaluating compressibility of fresh and degraded waste samples under different moisture content as per ASTM D 2435 [249]. The samples were placed between porous stones in an oedometer with dimensions 63mm diameter and 25 mm thick circular ring. The waste samples were prepared at OMC and compacted with the tamping device. Initially, 48 kPa load was applied on the sample and for about 24 hrs, the compression was measured at different time intervals. The load was increased to 96 kPa after 24 hrs or when compression ceases and again compression at different time intervals for the next 24 hrs was measured. The compression of samples was measured for normal stresses (σ) of 150, 250, 300 and 400 kPa. Thus, strain variation with normal pressure was plotted and the compression ratio was evaluated.

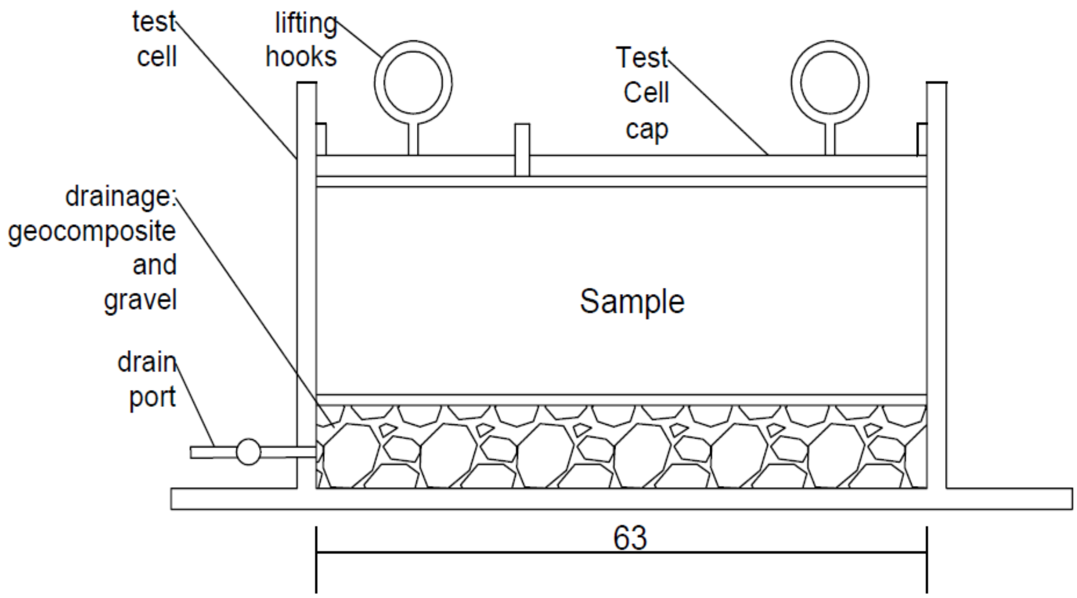


Figure 5.6: Schematic of consolidation apparatus.

5.3 Results and Discussion

5.3.1 Physical Characterization

The component of fresh and degraded waste samples was determined for physical characterization as per US EPA, 2010 [250]. The characterization of waste showed that the fresh waste comprised of 68.3% of biodegradable fraction and 37.7% of non-biodegradable fraction. It was also observed that the with the increasing age of waste the biodegradable fraction reduces due to degradation which turns organic fraction to inorganic. The degree of decomposition (DOD) of fresh MSW was absent and for degraded waste it varied from 78.1% to 90%. The obtained results showed that with degradation of waste, inert fraction of waste increases. The biodegradation of waste results in the disintegration of particles into fine and soil like material. The variation in metal and glass content of degraded samples is owed to the disparities among the sampling, collection and handling of the waste practices. The various components of fresh and degraded MSW are summarized in *Table 5.2*.

Table 5.2: Components of fresh and degraded waste collected from the dump site.

Sr. No.	Components	Composition (%)					
		Fresh Waste	Degraded Waste				
			0.5 year	1 year	2 year	4 year	6 year
1	Organic matter	56.1±1.08	41.8±2.03	32.9±1.94	27.6±0.93	21.5±1.11	16.5±0.97
2	Paper	12.2±0.76	2.23±1.32	1.27±0.87	1.04±1.04	0.89±0.98	0.68±1.43
3	Polythene/Plastic	10.3±0.59	3.34±0.36	2.78±0.47	2.18±0.29	1.98±0.52	1.12±0.73
4	Glass	1.0±0.03	0.6±0.14	1.2±1.06	1.5±1.04	0.89±0.13	0.2±0.09
5	Metal	1.2±0.38	0.93±0.15	1.04±0.42	1.45±0.59	0.51±0.1	0.16±0.02
6	Inert	10.5±0.72	46.04±9.58	53.51±6.38	60.3±6.54	67.81±8.63	74.21±10.27
7	Others	8.7±0.19	5.06±0.21	7.3±0.56	5.93±0.42	6.42±0.24	7.13±0.28
	Total	**100**	**100**	**100**	**100**	**100**	**100**

Note: All component values are in percentage (%).

Other includes leaves, wooden matter, thermocol, coconut etc.

Inert includes soil particles from street sweeping, after degradation of waste.

The properties of MSW evaluated have been presented in *Table 5.3*. From the table, it was clear that organic waste reduces from 41.8% to 16.5% and increase in inert fraction from 46.04% to 74.21% from the 0.5 year to 6 years old waste. On wet basis, determined moisture content for fresh was 49.5±1.05 % and 39.8 to 51.6% for degraded waste respectively.

The variation in moisture content did not follow any pattern with depth *Figure 5.7*. It was observed that initially moisture content increased from 0.5 to 2 years old waste and then decreased with further increasing age of waste. The specific gravity of MSW increases with degradation owing to disintegration of particles into fines and soil like material. Also, it was observed that the obtained results showed similar pattern with the literature.

Table 5.3: Properties of Fresh and degraded waste.

Sample	Age (years)	Moisture Content (%)	Specific Gravity (Gs)	Organic Content (%)	Comparison with literature	
Fresh sample	0	49.5	1.83±0.05	58.4	Gs= 0.85 Moisture content = 44% O.C = 76-84%	Reddy et al., 2009c
					Gs= 1.89-1.95 Moisture content = 35%	Feng et al., 2016
					Gs= 1.34 Moisture content = 46%	Breitmeyer 2011
Landfilled (old) Sample	0.5 year	44.3	1.85±1.97	41.8	0.3 year, Gs-1.83-2.27, m/c- 42.5-47.9	Feng et al., 2016
	1year	51.6	1.93±2.04	32.9	2 years, Gs – 1.88-1.93, m/c- 58.5-68.9%	
	2 years	48.9	1.91±2.24	27.6	2-2.5 year, Gs -1.95, m/c- 43.9, O.C- 33.1%	Ramaiah et al. 2017
	4 years	46.4	2.15±2.28	21.5	3-4 year, Gs -2.00, m/c- 35.8, O.C.- 21.1%	
	6 years	39.8	2.14±2.23	16.5	4.5-6 year, Gs -2.40, m/c- 20.1, O.C.- 15.9%	
					Gs - 1.51(S), 1.88(M), 2.14 (D)	Wu et al., 2012

S= Small depth, M= Medium Depths, D= Large depths

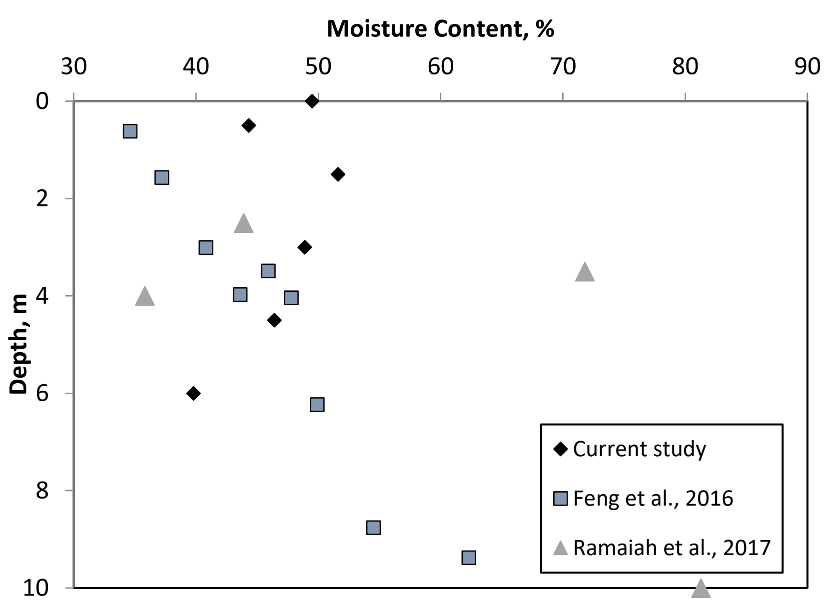


Figure 5.7: Moisture content variation of MSW samples.

5.3.2 Geotechnical Properties

5.3.2.1 Particle Size Distribution

The specific gravity of waste samples was determined as presented in *Table 5.3*. For fresh samples of waste, it ranges between 1.83±0.05 and for degraded samples it ranges from 1.85 for 0.5-year old waste to 2.15 for 6-year old waste. The results depict that the specific gravity of degraded sample is more than fresh sample. This may be due to degradation of organic content present in waste and these values were found to be similar with reported literature [36,138,239,246]. However smaller variation in the value may be due to fibrous content and composition of MSW [143,239].

Further, an increase in unit weight of waste was observed with progressive age of the waste. The unit weight of MSW was also observed to be increased with depth and degradation from 6.97 kN/m^3 to 10.4 kN/m^3 (*Figure 5.8*). The degradation of waste converts the organic fraction into inorganic thereby increasing the fines content, thus resulting in the denser or closer packing of particles.

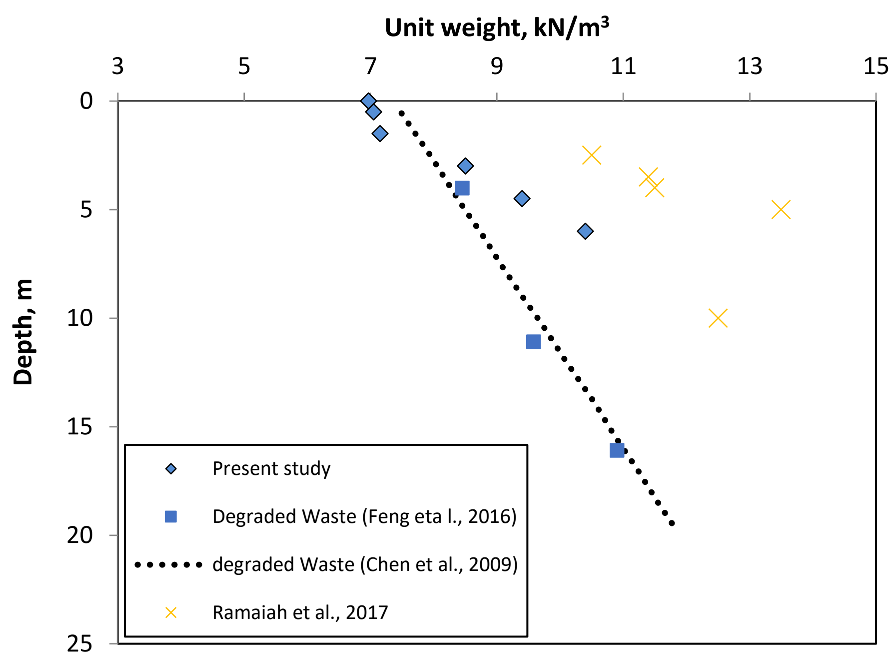


Figure 5.8: Variation in unit weight of MSW with depth.

The MSW was sieved through sieves of size 100mm, 50mm, 20mm and about 57%, 14.5%, 10% of fresh and 51%, 17%, 14% of old waste was retained on sieves. The gradation showed the percent fines passing 20mm sieves in degraded waste is more than fresh waste due to degradation of MSW.

The gradation curves for MSW samples have been presented in *Figure 5.9.* With the decomposition of waste, the presence of fines in waste increases due to disintegration of particles.

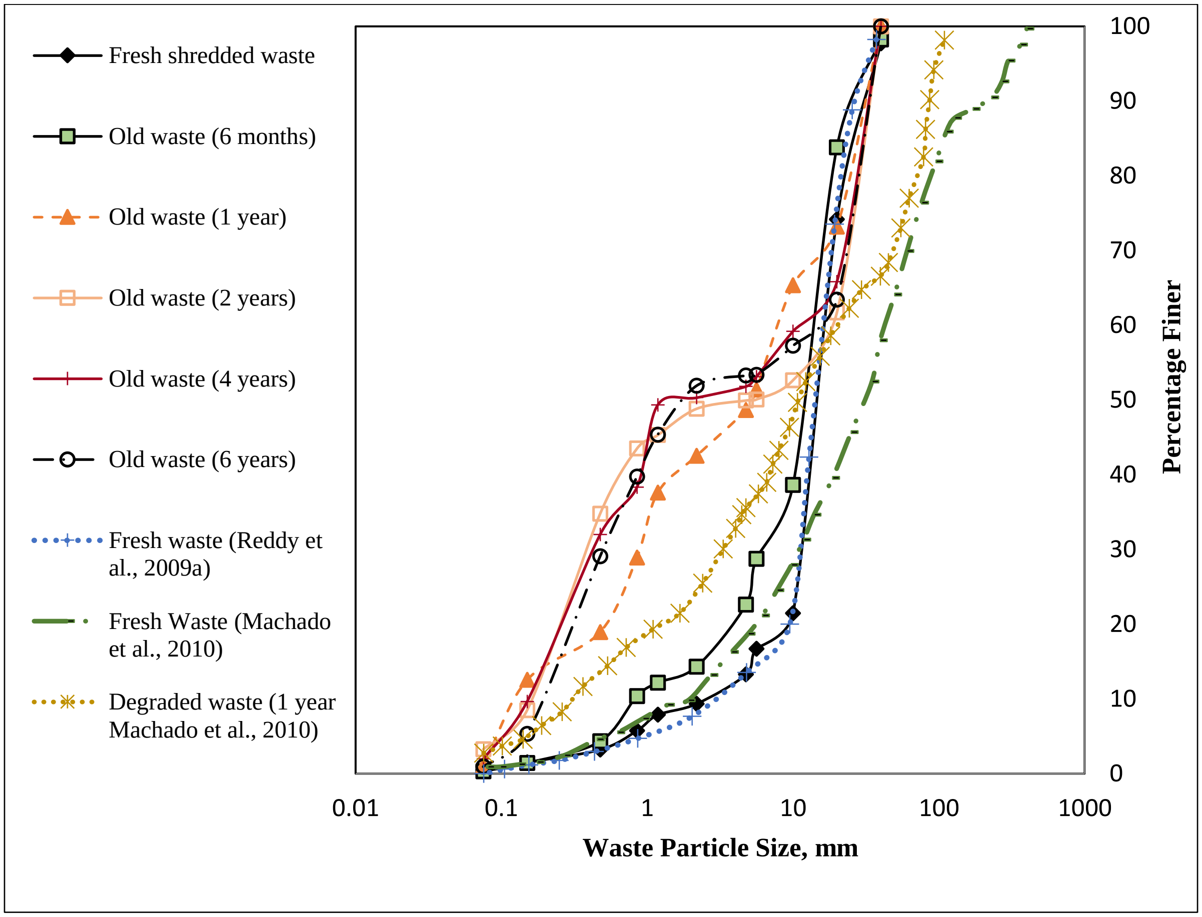


Figure 5.9: Comparison of gradation for collected waste samples with literature.

5.3.2.2 Hydraulic Conductivity

The hydraulic conductivity of waste samples was determined as in rigid wall permeameter at zero confinement pressure and then pressure was increased [247]. Results depict that the fresh sample of waste were having a higher rate of hydraulic conductivity than degraded samples because of higher void ratio present in fresh waste. However, disintegration of particles due to degradation of waste results in closer packing and reduces the voids in waste and hence reduces the hydraulic conductivity of degraded waste. *Figure 5.10* showed the variation in hydraulic conductivity of waste samples with applied pressure. The increase in the vertical stress led the hydraulic conductivity to vary from 1.30×10^{-4} m/sec to 1.4×10^{-7} m/sec for fresh waste and for old samples it varied from 1.34×10^{-5} m/sec to 8.90×10^{-8} m/sec.

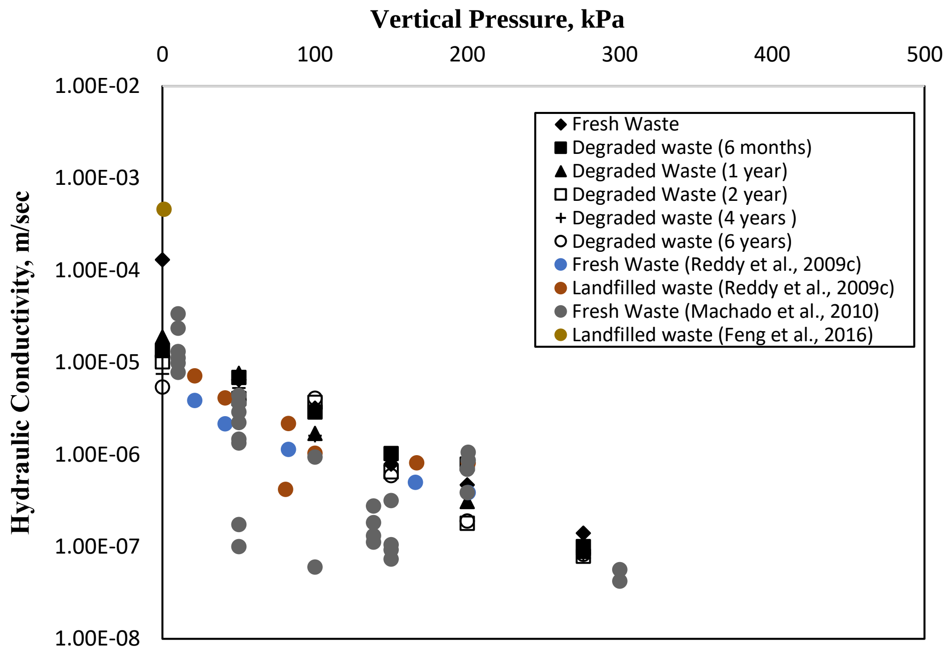


Figure 5.10: Comparison of hydraulic conductivity of fresh and degraded waste with reported literature.

It was clear from the figure that with increase in the vertical stress the hydraulic conductivity decreased. The degradation of particles results in closer packing and the plastic fraction reduces the hydraulic conductivity of MSW [142]. *Figure 5.11* showed the variation in hydraulic conductivity with depth.

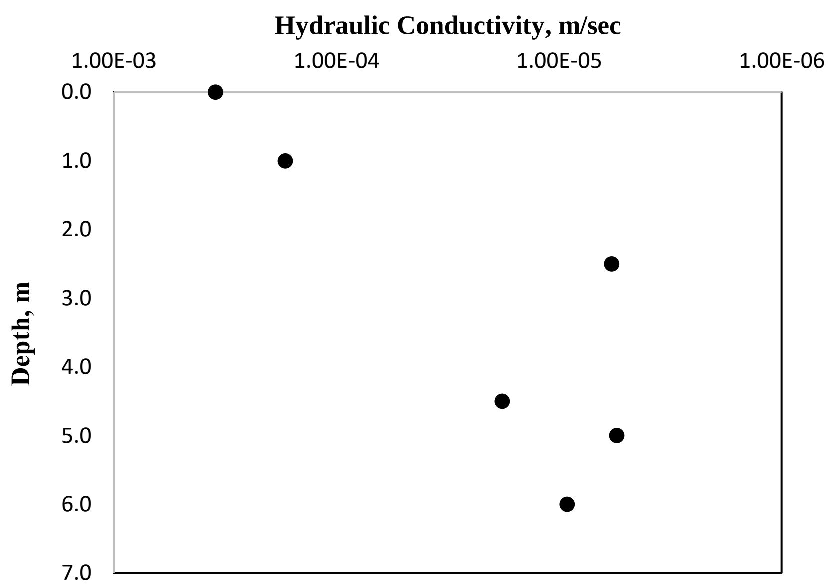


Figure 5.11: Hydraulic conductivity variation of MSW with depth.

5.3.2.3 Direct Shear Test

As per ASTM D3080, 2004, the direct shear testing of samples was done [248]. It was observed from the results that with increase in the vertical stress, shear strength also increased. It was found that the shear strength of fresh samples of waste is less than degraded samples. The presence of fines and fiber content in the samples increases with degradation results in increased shear strength of MSW [235]. However, the difference in shear strength of waste at 4m and 6m depth is very less because of same degradation rate of sample. The results of direct shear test have been presented in *Figure 5.12*.

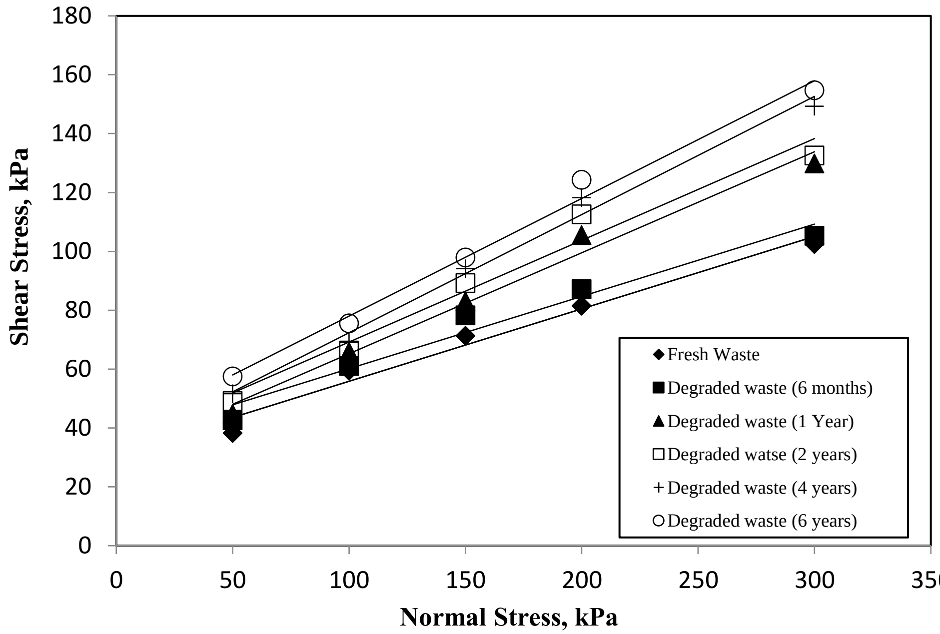


Figure 5.12: Direct Shear test result for fresh and degraded waste samples.

The angle of internal friction and cohesion (φ, c) for fresh waste was 13°, 31.2 kPa and for old sample of waste φ varies from 14° to 22° and c varies from 30.9 kPa to 38 kPa. It was found that angle of internal friction increases with depth while cohesion did not follow any pattern with depth as observed by many researchers [143,145,238]. The variation may be due to the change in composition, presence of paper, wood and fiber content in MSW which thus results in low shear strength waste [140,143]. The stress versus horizontal displacement curves for fresh and degraded waste under different normal stresses have been presented in *Figure 5.13* and *Figure 5.14* respectively.

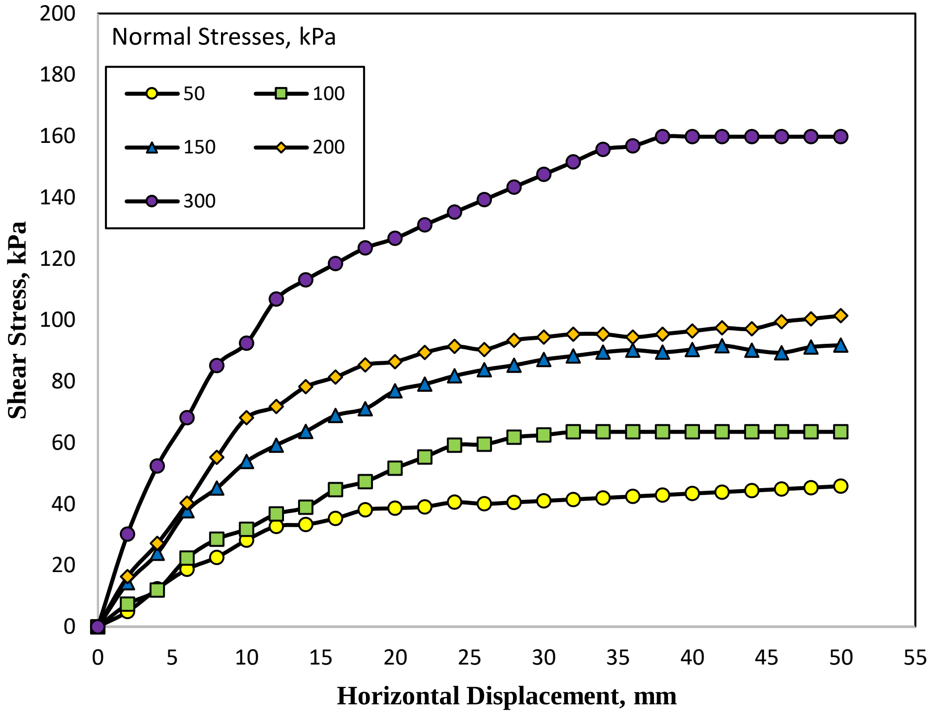


Figure 5.13: Shear stress versus horizontal displacement for fresh waste.

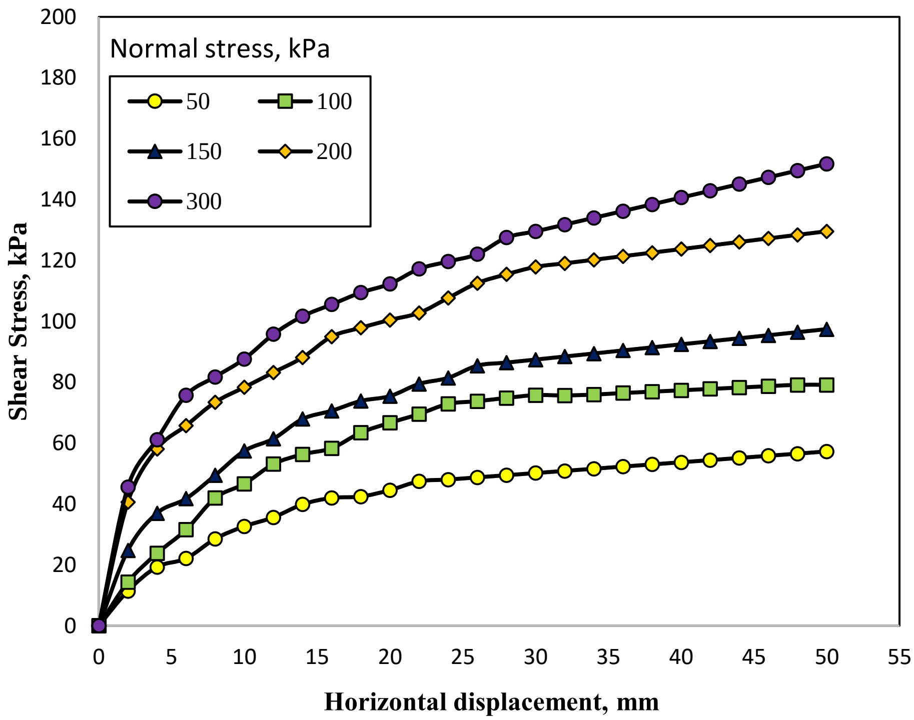


Figure 5.14: Shear stress versus horizontal displacement for degraded waste.

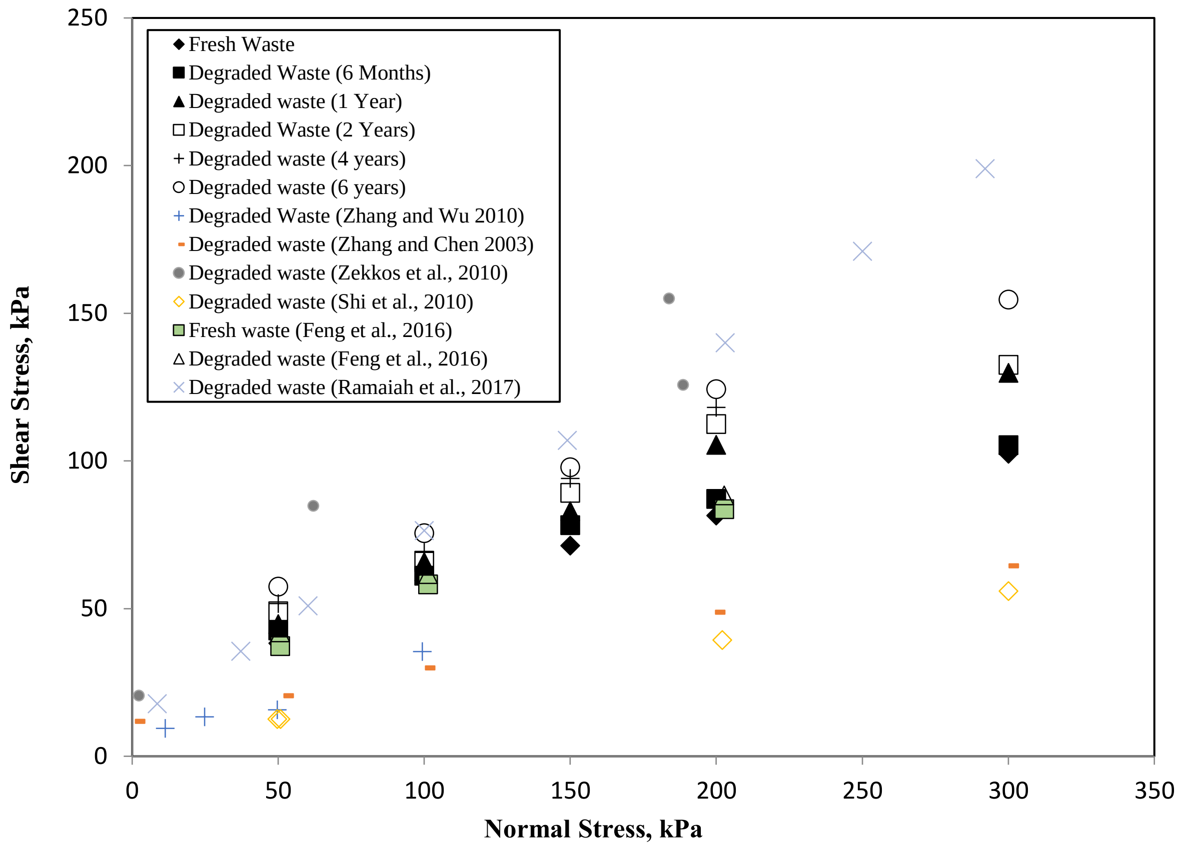


Figure 5.15: Comparison of direst shear test results of present study with reported literature.

The results obtained from the test were compared with reported literature as shown in *Figure 5.15*. The sample showed gain in shear strength with shear displacement. It was clear from the results that with degradation, cohesion decreases and friction angle increases for our study location.

5.3.2.4 Compressibility

The compressibility of waste was determined in oedometer as per ASTM D 2435 [249]. The vertical load was applied on waste samples for determining the immediate compression. The variation in the compressibility of fresh and degraded samples has been presented in *Figure 5.16* and compared with literature [105,239,240,251]. The observed results showed that the compression index for fresh waste varied from 0.19-0.29 and for degraded waste, it ranges between 0.12-0.17 under the different load increments. The observed result showed that the compression index values for fresh waste was more than older waste because of degradation of MSW and fines, soil like material present in waste [108,246].

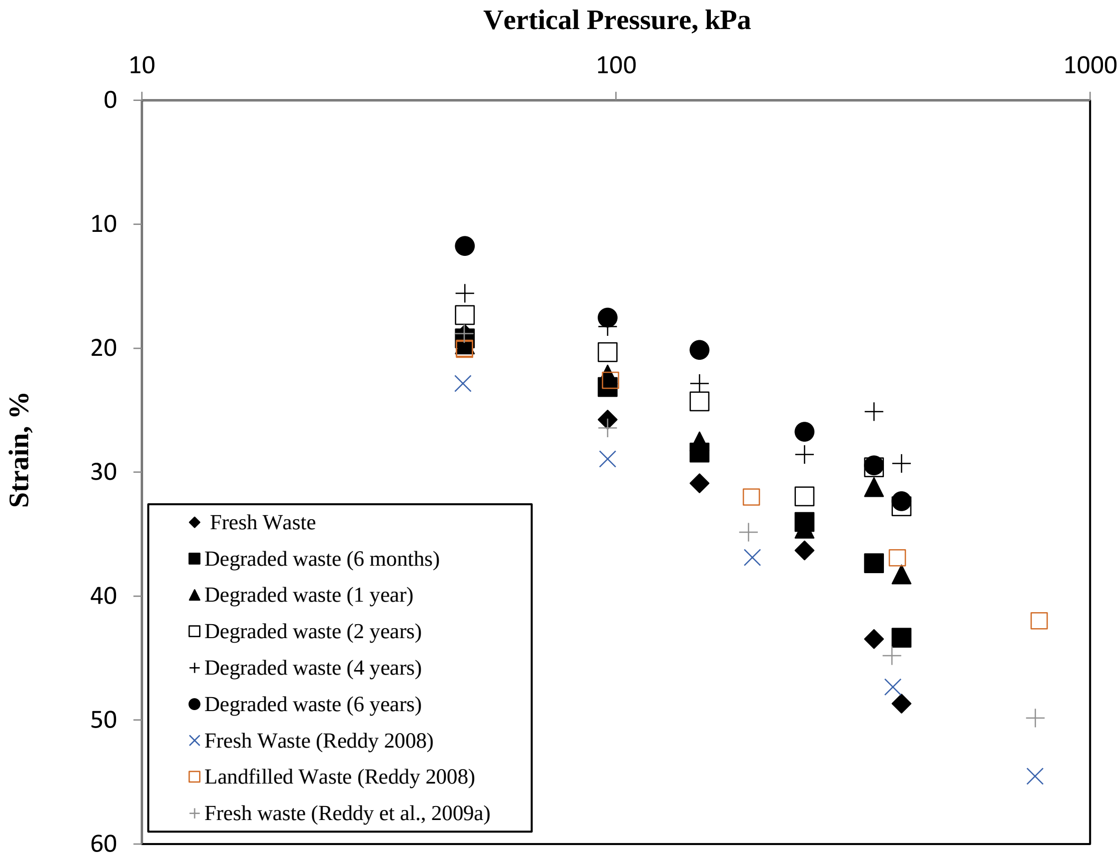


Figure 5.16: Comparison of compressibility behavior of fresh and degraded waste with literature.

The results depict that geotechnical properties of MSW gets affected due to rate of degradation. The moisture content in MSW increases significantly with degradation and then decreases and organic content decreases with degradation. The unit weight of waste sample increased from 6.97 kN/m^3 to 10.4 kN/m^3 with increased depth and age of sample.

The vertical pressure applied on the waste samples caused close packing of the particles reducing the hydraulic conductivity of fresh waste from 10^{-4} m/sec to 10^{-7} m/sec and for degraded waste it ranges between 10^{-5} m/sec to 10^{-8} m/sec respectively. The cohesion of waste increases from 31.2 to 38 kPa and angle of internal friction increased from fresh to highly degraded waste respectively with increase in density.

The obtained results of geotechnical testing of MSW have been presented in *Table 5.4*.

Table 5.4: Results of geotechnical testing of fresh and degraded waste.

Parameters	Fresh Waste	Degraded Waste				
		0.5 year	**1 year**	**2 years**	**4 years**	**6 years**
Unit Weight, kN/m^3	6.97	7.05	7.15	8.5	9.4	10.3
Hydraulic Conductivity (m/sec)	1.3×10^{-4} - 1.4×10^{-7}	1.34×10^{-5} -1.0×10^{-7}	1.9×10^{-5} - 8.9×10^{-8}	1.2×10^{-5} - 7.9×10^{-8}	7.5×10^{-6} - 8.2×10^{-8}	5.4×10^{-6} - 8.3×10^{-8}
Cohesion, c (kPa)	31.2	31.5	30.9	34.6	33.5	38
Angle of internal friction, φ	13˚	14˚	18˚	19˚	22˚	22˚
Compressibility index	0.19-0.29	0.16	0.17	0.13	0.13	0.12

The variation in evaluated parameter for fresh and degraded waste with literature has been presented in *Table 5.5*.

Table 5.5: Percentage variation in results of present study with reported literature.

Sr. No.	Parameters	Comparison of average percentage variation of results of current study with literature			
		Ramaiah et al. 2017	Feng et al. 2016		Reddy et al. 2009a
Type of waste		**Degraded (%)**	**Fresh (%)**	**Degraded (%)**	**Fresh (%)**
1	Specific Gravity	5.4-8.6	1.6-3.2	0.44-1.1	1.2
2	Moisture Content	10-28	37-65	6.7-33.5	12.5
3	Organic Content	12-26	-	-	2.5
4	Unit weight, (kN/m^3)	1-9.6	3.2-7.6	4-16.8	-
6	Hydraulic conductivity, m/sec	-	9.3	13.2	9.09
7	Cohesion, c (kPa)	29.4	24.3	35.4	5.2-29.6
8	Angle of internal friction, φ	37	12	17.8	15-60
9	Compression index, C_c	3.5	-	-	9.25

The evaluated results from the testing showed that there is slight variation in parameters with literature which may be due to variation in composition, characteristics and nature of waste. The variation in specific gravity of waste was about 1.2-3.2% for fresh and 0.44-8% for degraded waste. However, smaller difference in unit weight, hydraulic conductivity and compression index was observed. The large variation in the shear strength parameters about 5-25% of angle of internal friction and 17-37% of cohesion values were observed. This may be due to reason that waste from the study area has lesser fiber content and causes slower degradation as compared to literature [36,105,239]. The presence of fines due to waste degradation tends to closer packing of waste thus reducing the hydraulic conductivity, compressibility and increasing unit weight, shear strength of MSW.

Summary

Characterization of MSW for the study location showed presence of high organic fraction in fresh waste (58.6%) which decreased with degradation rate. The degradation of waste changes the properties of waste which are important for designing the different components of landfills. Additionally, with increasing depth, unit weight increases due to conversion of organic content to inorganic material. The moisture content present in waste is high due to organic content in fresh waste which accelerate the growth of micro-organism in waste. The hydraulic conductivity of landfilled waste is less than fresh waste attributed to increased finer particles in degraded waste. Also, the shear strength of waste samples increased with application of stress and the compression index of waste reduces with degradation. These evaluated parameters showed significant variation in properties with degradation and age of MSW.

It was observed that weak correlation between degree of decomposition and geotechnical properties of MSW exist due to heterogenous nature of MSW. The degradation of waste results in the differential settlements and thus it is necessary to assess the stability of landfill. The accumulation of leachate in waste results in build-up of excess pore water pressure resulting in the seepage failure. Thus, the investigation of geotechnical properties is important to assess the changes with degradation and to avoid catastrophic failure.

Depending upon the geotechnical analysis, the effect of MSW dumping on soil is determined and its preventive measures for reducing the harmful effect along with the recreation of soil needs to be done. Thus, assessment of geotechnical properties of MSW is important parameters for the designing, operation and stability of landfills. The construction of engineered landfill for efficient disposal of MSW further require the settlement and slope stability analysis which in turn can be evaluated depending upon the shear strength and compressibility characteristics of waste. Therefore, in designing the engineered landfill and for considering the strength and stability characteristics, stress stain behavior of MSW obtained from a large-scale DST for our study location is discussed in next chapter. Further, these evaluated parameters were used for analyzing the settlement of MSW within the landfill.

CHAPTER -6

SHEAR BEHAVIOR OF MUNICIPAL SOLID WASTE

6.1 Introduction

The disposal of MSW in landfill is one of most common, economical and attractive method as compared to other techniques like incineration, composting, pyrolysis. It is estimated that about 90% of the waste in India is disposed in open land unscientifically [197] which causes environment and health hazards. In order to minimize the harmful effects from un-engineered MSW dumping, it is necessary to dispose the waste scientifically in engineered landfills. Therefore, construction of landfill requires the analysis of mechanical behavior of MSW as discussed in the previous chapter.

The complex behavior of MSW and unknown aspects of geotechnical properties are considered as the source of problem in designing the landfill. The characteristics of waste are important factors in analyzing the stability of landfill and thus depends upon the degradation of waste [144,145]. The MSW are normally studied as composite material which contains paste fraction (soil like material) and fibrous fraction which acts as reinforcement element. However, the geotechnical characteristics of waste such as shear strength and compressibility are important in designing and maintenance of landfill [172]. The stability and integrity of landfill should be ensured during its operation period and after post-closure. Thus, in the slope stability analysis, shear behavior of MSW has an important role for landfill stability [140,146].

Due to heterogeneous nature of municipal solid waste, the stress behavior of MSW is complex. It depends upon the different factors like waste composition, density, degradation and drainage condition. The properties and composition of MSW in a landfill changes with time, due to biodegradation, compression and creep. It is clear that the variation in shear strength of waste occurs with time which can thus disturb the long-term stability of landfill. The response in shear of MSW is considered to be important in designing landfill, evaluating the static and seismic stability, stability of foundation and slopes and designing of cover system [138,140].

The stability of landfill vary with characteristics of waste and these properties of waste varies with time, moisture condition, temperature, composition and seasonal fluctuations [252,253].

The maximum storage height and safe slopes of MSW landfill can be ensured by evaluating the shear strength of MSW. It was observed that the stress strain behavior of MSW is non-linear and time dependent [144,240]. The shear behavior of MSW observed to show the gradual increase in stress with increase in the shear displacement which may be attributed to fibrous and compressible nature of waste [143,148]. The anisotropic nature of waste was observed by many researchers in direct shear test due to different orientation of fibrous material [140,143,148].

The studies of shear behavior analysis have been conducted using large scale laboratory shear test apparatus for evaluating the physical properties, strength, stiffness of solid waste for stability analysis by many researchers [140,143,146,148]. Various methods have been used for determining the shear strength of waste including: i) back analysis of failed and stable slopes, ii) large scale in-situ testing, iii) Laboratory testing of intact or reconstituted MSW. However, direct shear testing of MSW is considered to be one of most prevalent method employed for estimating the shear strength. The shear strength of waste is evaluated using direct shear test, by Mohr-Coulomb failure criterion as given by Equation (6.1):

$$\tau = c + \sigma_n \tan \phi \tag{6.1}$$

where τ is shear strength of MSW, c is cohesion, σ_n is applied normal stress, ϕ is angle of internal friction.

The direct shear test performed by [213] identified a significant difference shear strength parameter of MSW. As observed by many researchers, cohesion of waste sample varied between 0 to 80 kPa and friction angle varied between 0° to 60° [140,148,213,238,240]. However, the effect of degradation and age of the waste on the shear strength parameters was observed to be contradictory. The study carried out [144] observed an increase in ϕ value with increase in decomposition of waste, and no correlation was observed between cohesion and waste decomposition. However, other researchers observed an increase in ϕ value with decreasing cohesion with age and degradation of municipal solid waste [237,238]. Thus, the contradictory observation in shear strength parameters requires further investigation of shear behavior of MSW.

Therefore, this study presents a large-scale direct shear testing of fresh sample and degraded MSW samples of different age. The study was carried out to analyze the effect of composition, waste age or degradation, fibrous fraction, normal stress and unit weight on shear strength parameters of MSW.

6.2 Material and Methods

6.2.1 Sampling

The sampling of waste was carried out as per the recommendations of ASTM D 5231 [242]. The fresh sample of waste were collected from the trucks at time of unloading. The degraded samples of MSW were collected from the dump site at different depths (0.5m to 1.5m) from various locations as discussed in previous chapter. The collected samples of waste were packed in plastic sheets and brought to laboratory for testing.

Figure 6.1: Sample collection of degraded waste from landfill site.

6.2.2 Characterization of MSW

The fresh sample of waste were characterized for different components like organic, paper, plastic, wood, steel, glass. It was observed from the physical characterization of fresh waste the higher fraction of organic matter (56%) is present in waste followed by paper (12.2%), plastics (10.3%). The fresh sample of waste were shredded to obtain the representative sample for testing.

The degraded samples of waste collected from the different location showed the decrease in organic fraction with depth and age of sample. It was observed that the organic fraction of waste reduces from 41.8% for 0.5-year-old waste to 16.5 % for 6-year degraded sample. The details of constituents like metal, paper, glass, wood have been provided in Chapter 5.

The waste samples were air dried and sieved through large set of sieves for separating the particle having size >20mm and <20mm. The degraded waste sample collected from the site from different locations consists of material <20mm generally composed of soil like fraction and >20 mm is bulky and fibrous material is generally paper, plastic, wood, gravel and miscellaneous materials. The percentage fraction by weight or volume of steel, glass, metals are lower as rag pickers plays an important role in recycling such materials and other usable items having economic value in markets. Based upon the characterization of MSW the fresh and degraded waste samples, laboratory testing was conducted.

6.2.3 Large Scale Direct Shear Apparatus

A large-scale direct shear test apparatus with box dimensions 300×300×150 mm (*Figure 6.2*) was used to determine the shear strength parameter of MSW. The displacement rate can be controlled up to 5 mm/min. A rigid steel loading plate connected to hydraulic system is used for application of constant vertical stress on sample. The constant vertical load of 50-300 kPa was applied and specimen were sheared at horizontal displacement rate of 1mm/min. The shear load is applied on the lower shear box placed on steel balls. The lubrication was done to reduce the friction between surface of steel plates sliding against each other. The horizontal displacement and vertical loads were recorded using load cells.

The samples were prepared for the testing by compacting through a standardized method developed [213]. The maximum size of particle employed in this study was as adopted by [140]. The maximum particle size for the granular material was 40mm and for the fibrous material the maximum particle size was limited to 80mm. The fibrous material is soft, supple and can be folded during the specimen preparation. The sample in shear box is compacted in three layers using drop hammer of ~8 kg weight from height of 0.8m above surface of sample.

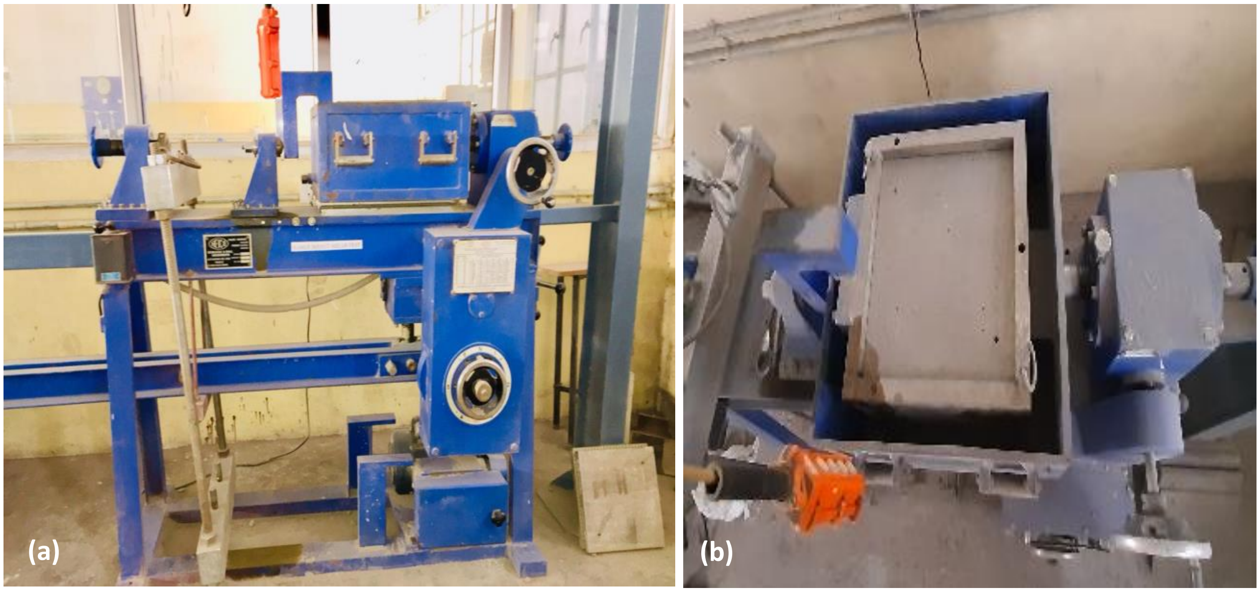


Figure 6.2:(a) Large Direct Shear Test Apparatus **(b)** Shear Box of size (300×300×150) mm.

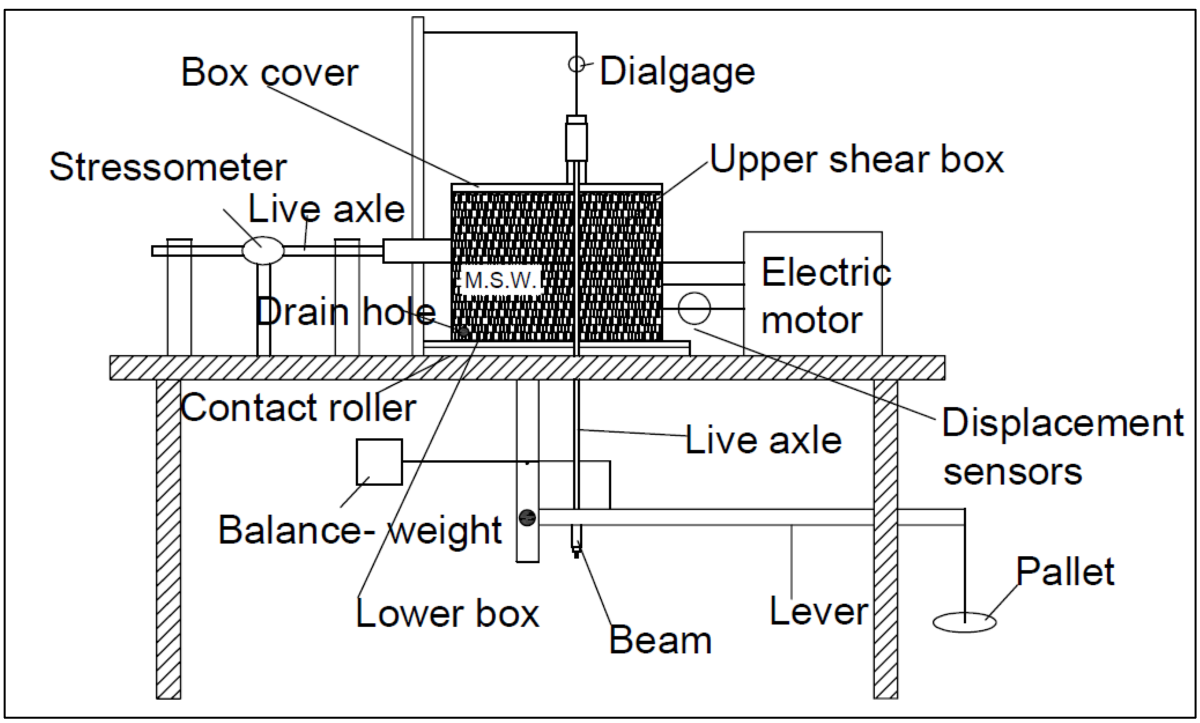


Figure 6.2 (c): Schematic diagram of direct shear apparatus.

The specimens were prepared at target water content (20-25%), because the sample preparation at in-situ moisture content became slushy and difficult to compact. The MSW samples of different age haven been presented in *Figure 6.3*.

Figure 6.3: Municipal Solid Waste samples **a)** Fresh Waste **b)** 0.5-year **c)** 1-year **d)** 2 years, **e)** 4 years and **f)** 6 years.

6.3 Results and Discussion

6.3.1 Shear Stress-Shear Displacement behavior

The results from the test showed that the behavior of stress-displacement of waste is consistent with other studies [36,143,238]. However, the variation in the shear stress of MSW differs from the previous studies. The difference in magnitude of shear stress of present study may be due the difference in characteristics, composition of waste, density, unit weight and applied normal stress. It was observed that the shear strength of waste sample increases with normal stress (*Figure 6.4*).

The friction angle and cohesion for fresh sample were observed to be 15°, 29.4 kPa and with age of degradation of waste it varied from 17°, 30.8 kPa to 24°, 35.5 kPa. It was observed from the test results that angle of internal friction increases with degradation of waste and cohesion did not follow any pattern as observed by [143,144].

The results of direct shear test for the fresh and degraded waste samples have been shown in *Figure 6.5* (a-f). The MSW sample exhibit continuous gain in shear stress with increasing horizontal displacement. They do not exhibit ultimate stress up to end of test at 55 mm displacement. The shear stress at 50 mm displacement was adopted for defining the peak stress as the not much variation was observed after this displacement.

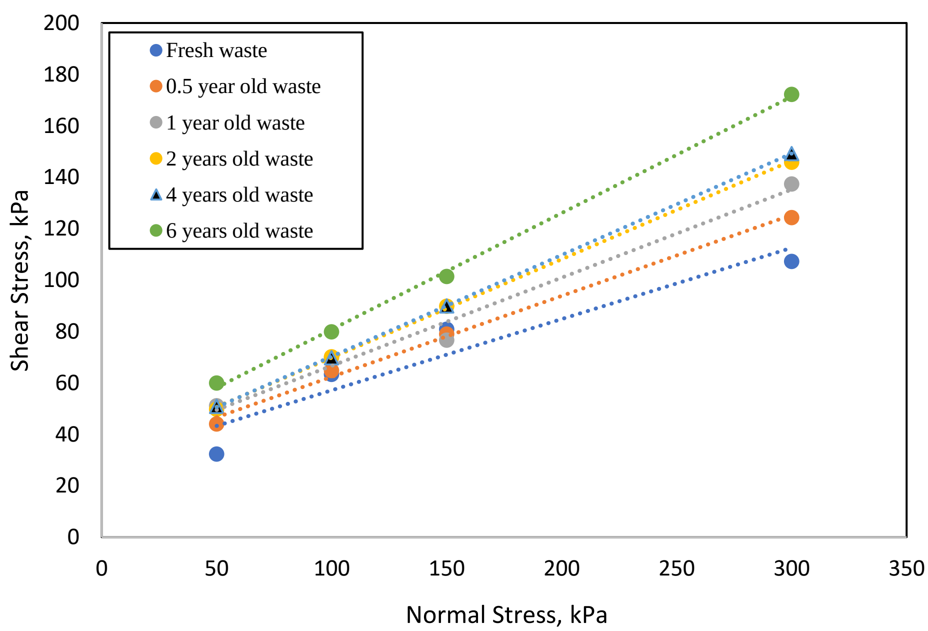


Figure 6.4: Shear strength of fresh and degraded MSW.

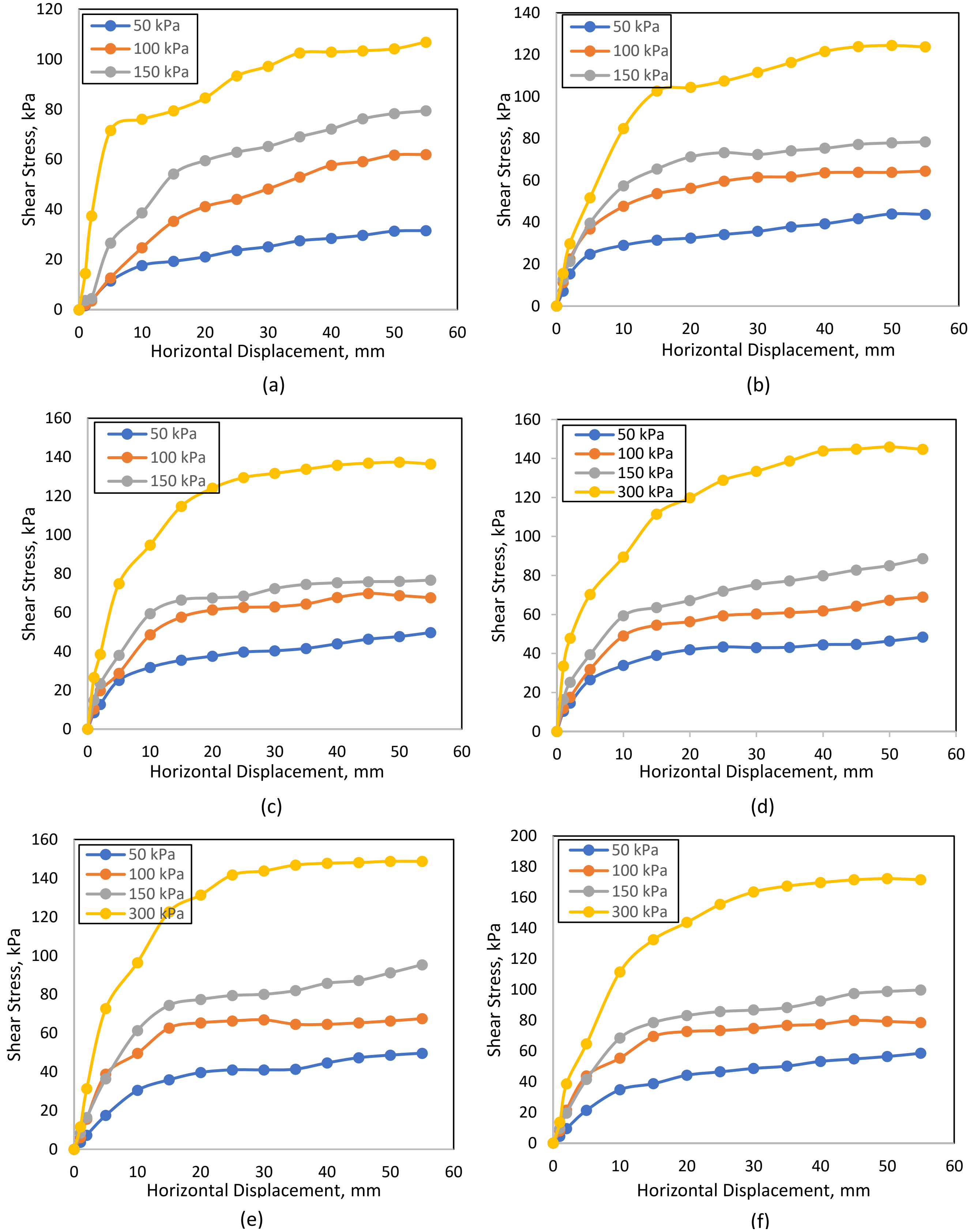
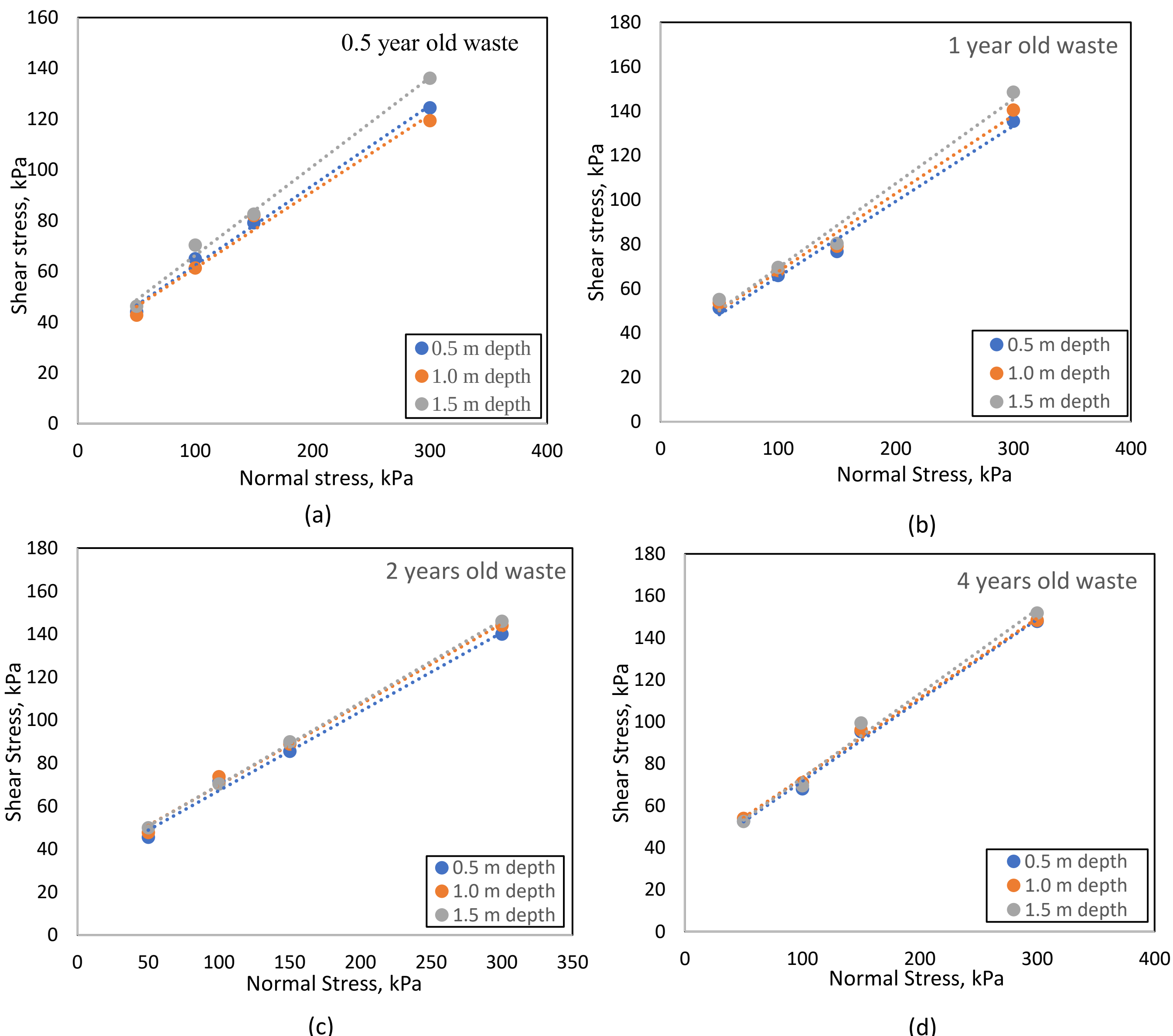
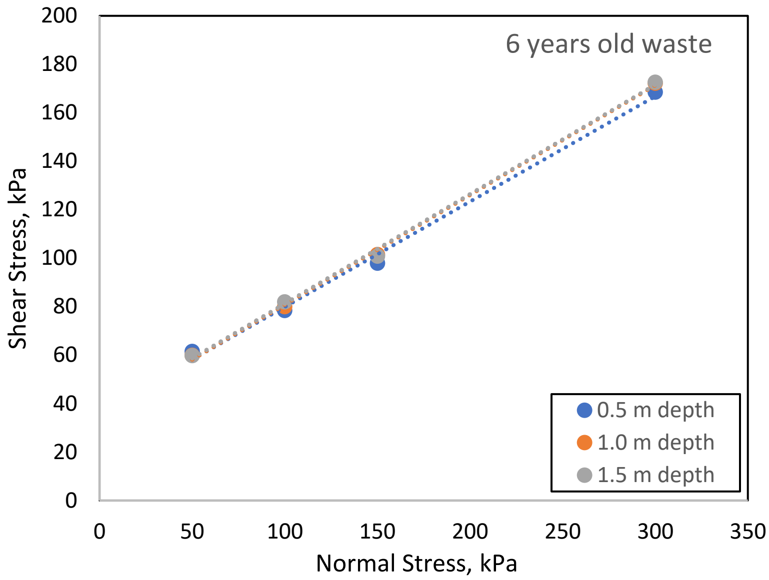


Figure 6.5: Results of shear stress versus shear displacement response of MSW sample, **(a)**Fresh Waste, and Degraded Waste **(b)** 0.5-year **(c)** 1 year **(d)** 2 years **(e)** 4 years and **(f)** 6 years.

6.3.2 Effect on shear strength with depth

The degraded waste samples of varying age were collected from different depth (0.5 m, 1.0 m and 1.5 m) also showed the significant variation in shear strength parameters (*Figure 6.6 (a-e))*. However, the collected sample showed slight increase in the friction angle and cohesion did not follow any trend. The cohesion of the sample varied from 30.8 to 35.5 kPa and angle of internal friction varied from 16° to 24°. The variation in the shear strength parameters with depth showed slight increase in friction angle. This variation in the friction angle may be due to the presence of soil or inert like material and cohesion value changes due to reduction in fibrous content with age or depth. It was observed from the results that shear strength changes slowly with depth.





(e)

Figure 6.6 (a-e)**:** Variation in shear strength of degraded waste sample with depth.

The results obtained from the present study showed variation in the shear strength than reported literature [36,140,143,144,237,238]. The variation in the parameters may be due to composition of waste, lesser fibrous material like paper, wood than other countries. This was reported that the with increase in the age of waste sample and depth, the physico-chemical biodegradation of waste in landfill changes the properties of waste and results in increased inert content.

6.3.3 Mobilized Shear Strength Parameters

The samples were observed to exhibit an unremitting increase in shear stress without obtaining a failure stress. Thus, as per the recommendation [36,140], the shear strength parameters were evaluated at 50 mm displacement because after this value the variation in shear stress is almost negligible. Therefore, the mobilized shear strength parameters were obtained for the degraded waste samples from the best fit linear envelope for each specimen for respective depth.

The mobilized shear stresses for waste sample at shallow depths indicates no significant difference at given displacement as shown in *Figures 6.7 (a-c)*. The composite failure envelope was fitted for the waste samples of different age at depths of 0.5 m, 1.0 m and 1.5 m depth.

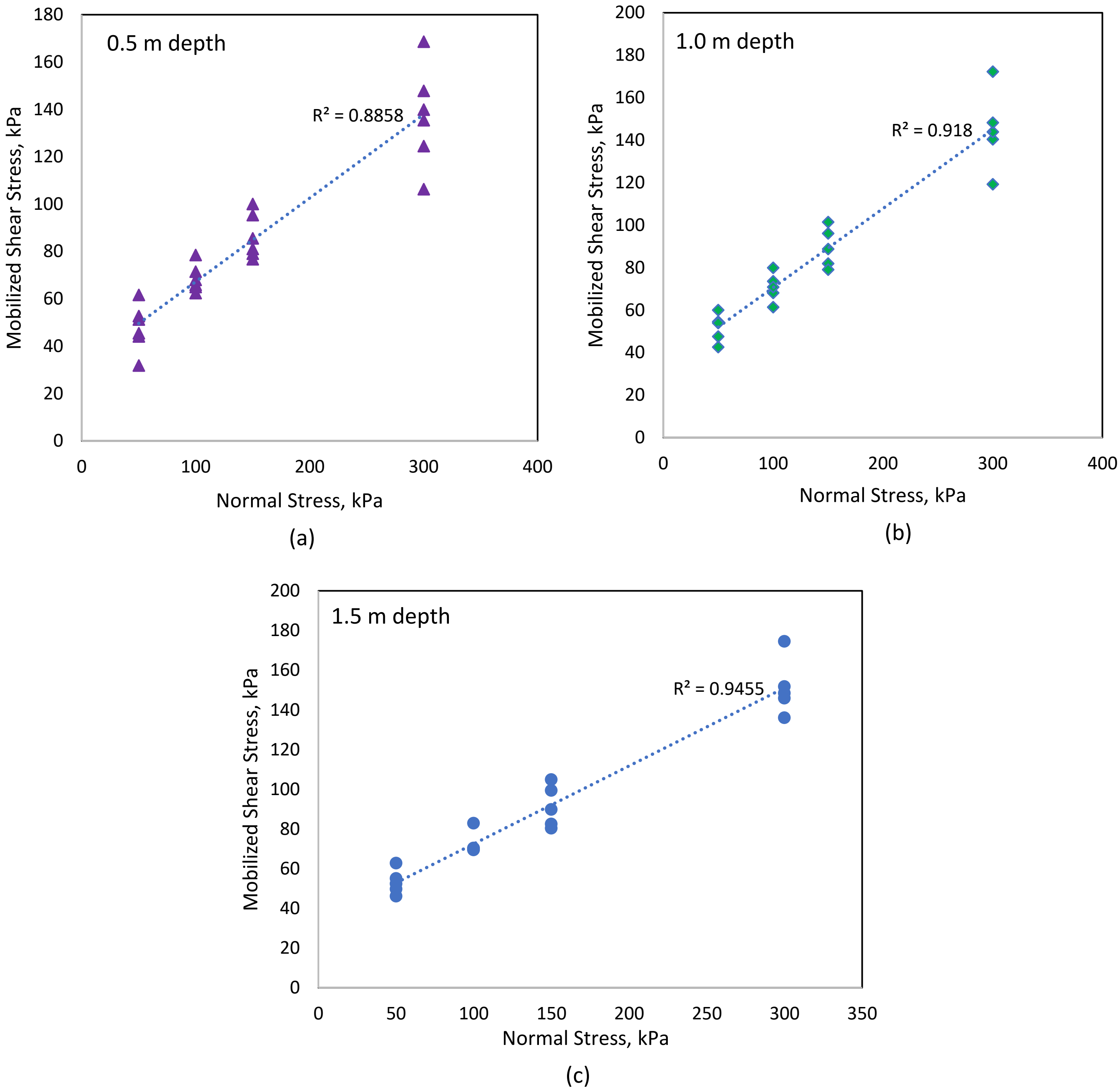


Figure 6.7: Mobilized Shear Strength in MSW samples at different depths.

The shear strength parameters cohesion and angle of internal friction obtained from the shear failure envelop for 0.5m, 1.0m and 1.5m depths are (31.9 kPa, 19°), (33.4 kPa, 20°) and (33.2 kPa, 21°) respectively. The variation in cohesion and friction angle of waste with depth has been shown in *Figure 6.8*. It was observed from the test results that the obtained shear strength parameters were observed within the range of reported literature as shown in *Figure 6.9*.

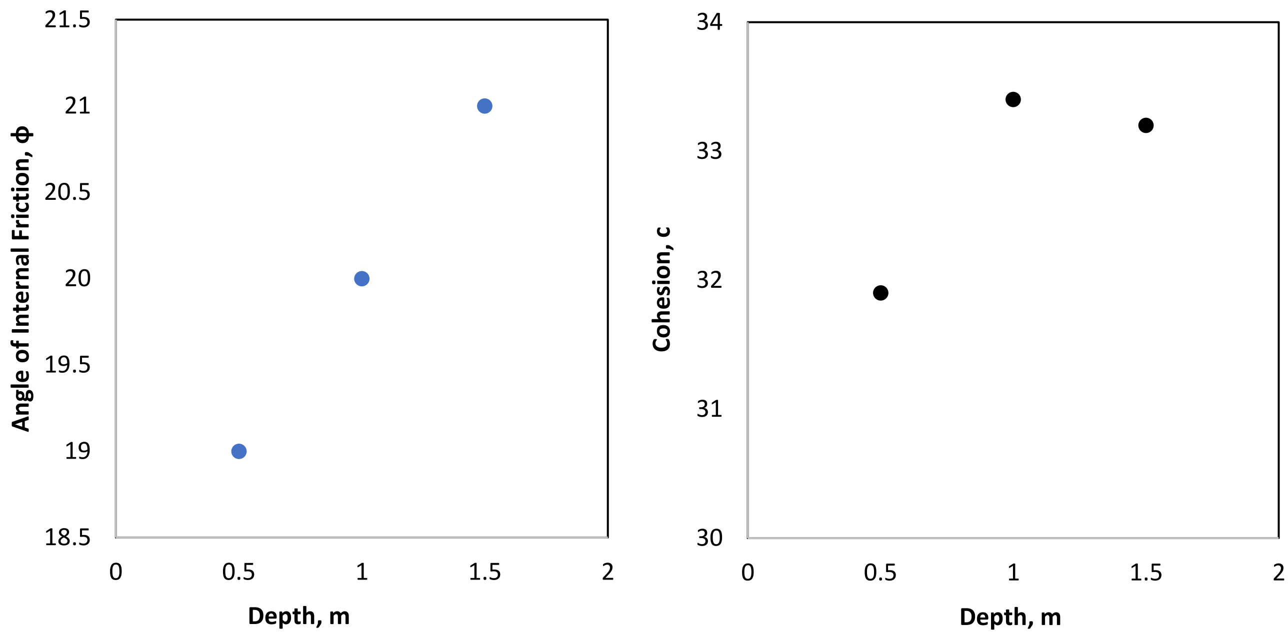


Figure 6.8: Variation in angle of internal friction and cohesion with depth.

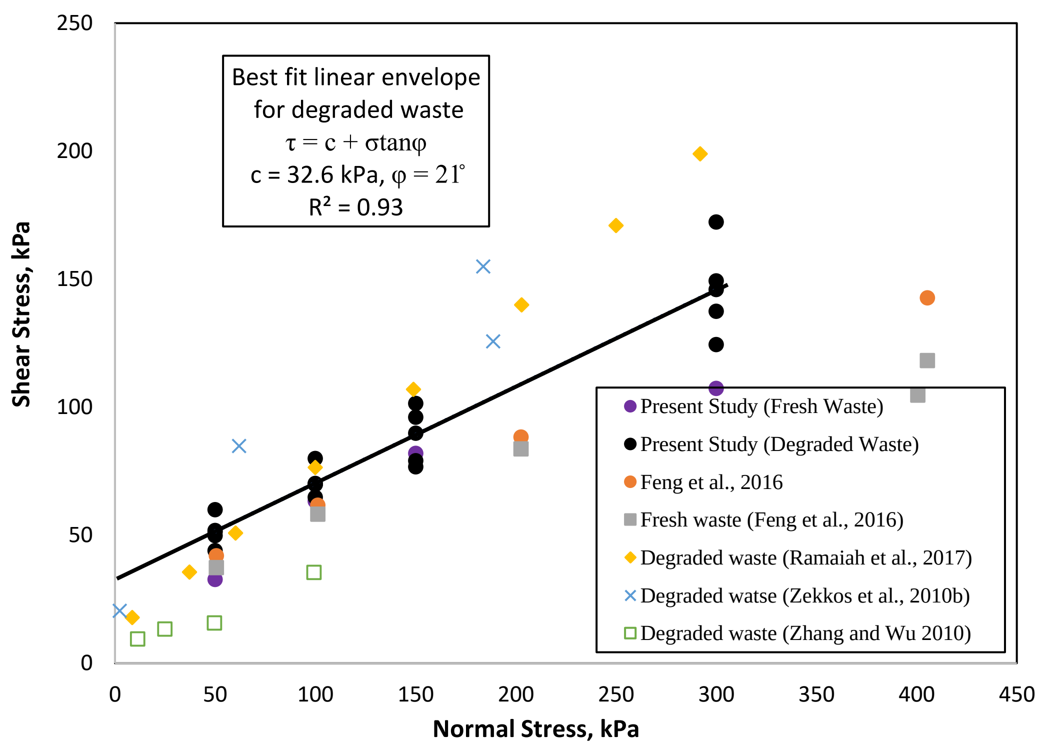


Figure 6.9: Comparison of obtained shear strength parameters with reported literature.

The obtained parameters of shear strength for the present study however showed smaller values than literature. The best fit shear strength parameters for testing of degraded waste were determined as c= 32.6 kPa and φ = 21°. The most of data points are close to recommended shear strength envelope and some of data points are above or below the recommended failure envelope showed variation in parameters with literature.

This variation in the cohesion and angle of internal friction may be due to the variation in composition, amount of fibrous material present in waste (*Figure 6.9*). However, the fiber orientation in the waste sample also affects the shear strength as reported by [140]. The fibers oriented parallel to direction of shear displacement exhibit lower shear strength than firers oriented perpendicular to the direction of shear stress. Thus, the interaction of fibrous material within the waste affects the shear strength of waste sample.

Summary

The effect of characteristics, composition, age or degradation and type of waste on the shear behavior of waste was studied by conducting the large-scale direct shear test. The test performed on the fresh and degraded waste showed significant variation in angle of internal friction with shear displacement. The test results showed that with degradation of municipal solid waste and age of waste, angle of internal friction increases significantly, while no defined pattern was obtained for cohesion values. The analysis revealed that degraded waste sample consisting of more soil like fraction which resulted in an increased friction. The presence of fiber content in waste, however affected the waste properties. As a result of which, degraded waste depicted an increased shear strength as compared to fresh waste. Additionally, degradation of waste results in disintegration of particles into fines and therefore increasing the density and unit weight of waste. The observed results for shear strength of the waste also showed that with increasing age, the density of waste, shear strength increases with increase in friction of waste. However, the effect of fibers orientation on the strength of waste is beyond the scope of the present study and thus requires further investigation.

The stress-strain response of MSW was observed to increase with horizontal displacement, indicating that the shear stress is increasing without obtaining a peak stress up-to 55 mm. Therefore, the failure stress was observed at 50 mm for defining the shear stress of waste. The response of stress-strain behavior of waste is closely related to deformation and stability analysis of landfill. The stability of landfill due to change in waste properties can results in failures like cracking and settlement.

Moreover, at the time of landfill closure, effects of degradation on geotechnical properties of MSW are important. Therefore, the analysis of geotechnical properties and variation with degradation of MSW has been of paramount importance for stability and structural integrity of landfill. In this aspect, landfill settlement analysis is important for overall landfill stability condition. The MSW settlement due to mechanical compression and biodegradation is discussed in the next chapter.

CHAPTER -7

EFFECT OF OPEN DUMPING ON GEOTECHNICAL CHARACTERISTICS OF SOIL

7.1 Introduction

Enormous amount of MSW produced across the country due to exponential increase in the population and urbanization has caused serious problem of management and disposal of MSW in developing countries [1,47,207]. The difficulties in waste management occurs due to rapid increase in generation of waste, poor collection, transportation and treatment facilities available. The unavailability of land has encouraged the uncontrolled waste dumping on outskirts of town or cities causing adverse impact on environmental and public health. However, the most common method adopted for disposal of waste in the country is landfilling without any prior treatment and precaution for minimizing its adverse impact [1,9].

The studies reported that the total waste generation in Himachal Pradesh was estimated to be 350 TPD [201] out of which about 85% of waste is illegally dumped in open land, 10% is recycled and 5% of waste is incinerable [131]. The dumping of waste directly on the land contaminates the soil and groundwater. The MSW in Himachal Pradesh is rich in organic fraction which on degradation produced toxic brown colored liquid called leachate. This liquid contains toxic compounds, metal which migrates through soil thereby contaminates soil and groundwater. The mixed waste coming to the dump site contains harmful chemical, compounds which migrates into soil and groundwater, causing harmful impacts on environment and human health. However, soil and groundwater contamination control largely depend upon the characteristics of soil where waste is being dumped. Waste dumping on the open soil results variation in the mechanical as well as geochemical properties of soil.

In this context, the present study focuses on evaluating the effect of dumping on geotechnical characteristics of soil and comparison was done with the uncontaminated soil for estimating the level of contamination. Due to degradation of MSW, the effect on the characteristics, nature of soil have been analyzed. In addition, the geochemical analysis of soil characteristics was also done to observe the elemental composition of soil.

7.2 Material and Methods

7.2.1 Collection of samples

The samples of soil were collected within the landfill site from different points and about 1 km outside the periphery of dump site for comparison. The depth of dump site varies from 5-8 meters which accepts the waste coming from households, institution, commercial areas etc. The contaminated soil from the landfill site (dump soil) and natural soil samples were collected with augur to obtain representative sample from the various points at depths of 0.5 m, 1.0 m and 1.5 m from the dump site. The sampling was done during the months of March-April, prior to rainy season to avoid alteration in properties due to rain. The collected sample were packed in plastic bags and brought to laboratory for moisture content determination.

The collection points of samples of dump soil (contaminated soil) and natural soil have been presented in *Figure 7.1*.

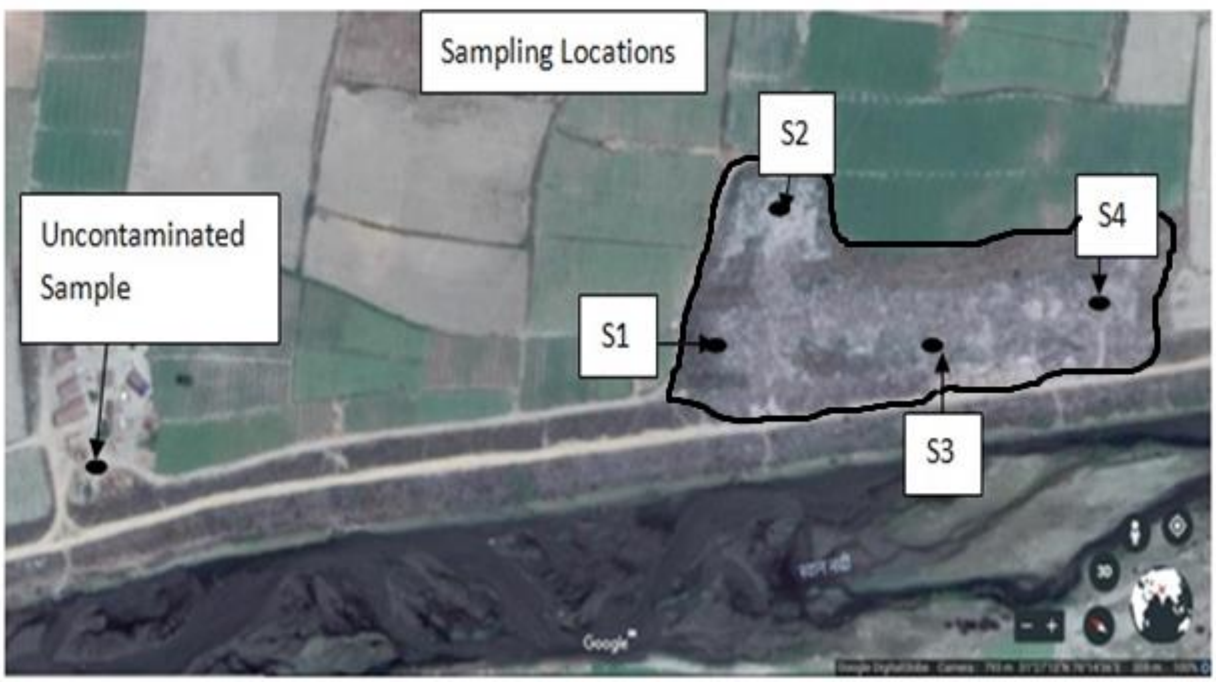


Figure 7.1: Collection of soil samples from dump site.

7.2.2 Geochemical Analysis

The composition of soil minerals and morphology of soil were determined using Scanning Electron Microscopy (SEM) and Energy Disperse X-ray Spectroscopy (EDX) analysis.

Instrumentation Analysis

Scanning Electron Microscopy (SEM) and Energy Disperse X-ray Spectroscopy (EDX or EDS)

SEM is morphological and topographical analysis and it provides a beam of electron to deliver high resoluion image for analysing the surface of material. The SEM provides structure and physical features of material by the magnified images.

EDX or EDS is a chemical microanalyis technique which is used in combination with SEM. It characterize the elemenal composition by detecting the X-ray emitted from the sample during bombardment of electron beam. EDX provides the information regarding the elements and composition of material by heating the samples at 500-550°C for about half an hour.

7.2.3 Laboratory Analysis

The collected samples of soil were tested for determination of geotechnical parameters. The laboratory examination of these samples included the determination of specific gravity, dry density, particle size distribution, hydraulic conductivity, shear strength (c,ϕ values) and CBR of contaminated and uncontaminated soli samples. The testing of samples have been performed according to the guidelines of Indian Standards (IS: 2720:1983) [254-261] for different geotechnical parameters as

Table 7.1: IS Codes for testing of geotechnical properties of soil.

Sr. No.	Parameter	IS Code
1	Specific Gravity, G_s	IS:2720 (Part 3/Sec 1)-1980 (Reaffirmed 2002)
2.	Particle Size Distribution	IS:2720 (Part 4)-1985
3.	Compaction	IS:2720 (Part 7)-1980
4.	Permeability	IS:2720 (Part 17)-1986
5.	Direct Shear Strength	IS:2720 (Part 13) -1986 (Reaffirmed 2011)
6.	California Bearing Ratio	IS:2720 (Part 16) -1987

7.3 Results and Discussion

7.3.1 Geochemical Analysis for dump and natural soil samples

The SEM analysis of soil sample showed the structural behaviour, geometric arrangement of particles and whereas EDX analysis showed composition of elements of dump soil and natural soil. The SEM micrographs for the soil samples were analyzed at four different magnifcations (5000, 10000, 15000, 25000) and images of magnifications of both contaminated and uncontaminated samples has been shown in *Figure 7.2(a)* and *Figure 7.3 (a)*.

The elements observed in the dump soil and natural soil samples were summarized in *Table 7.2* and *Table 7.3*.

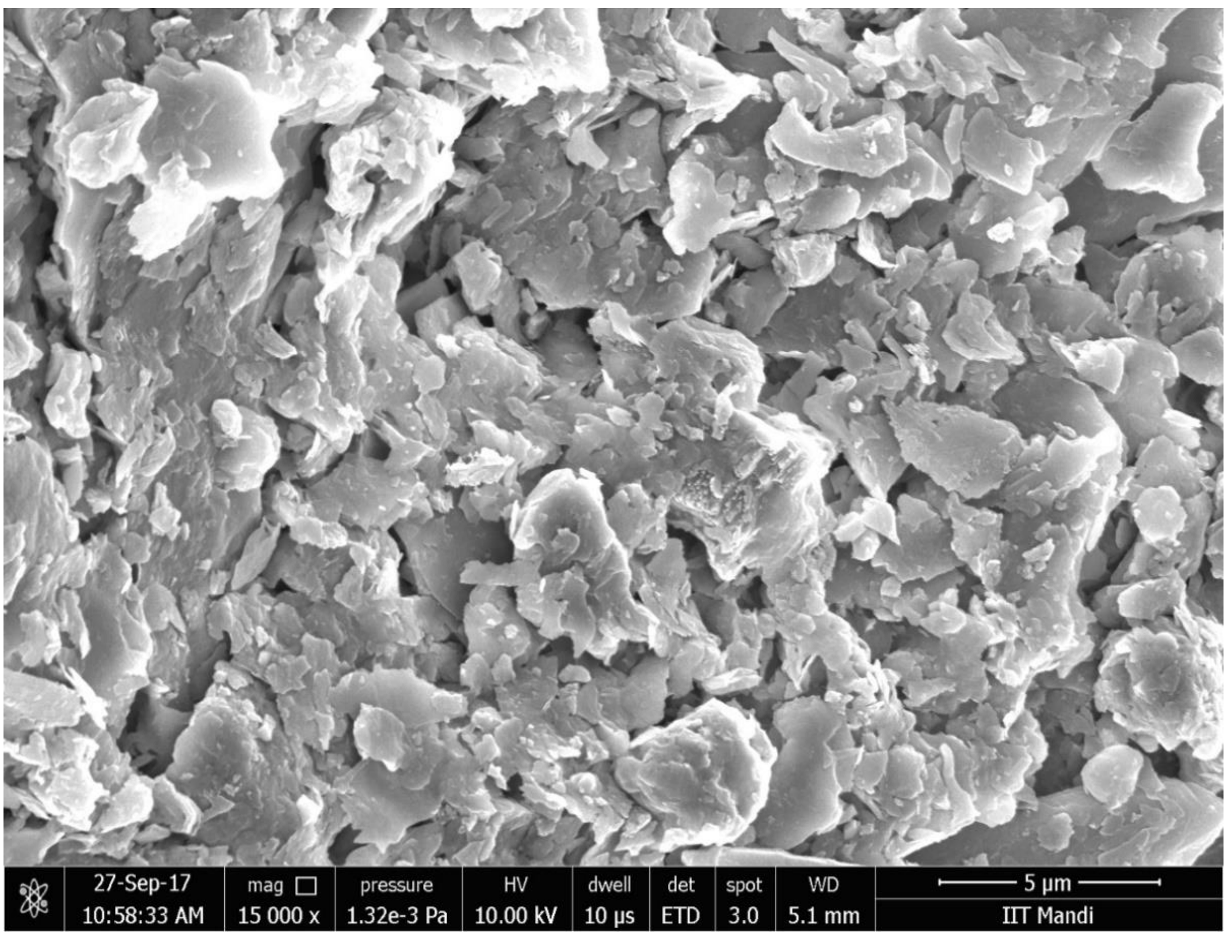


Figure7.2(a): SEM Micrographs of dump soil with different magnifications.

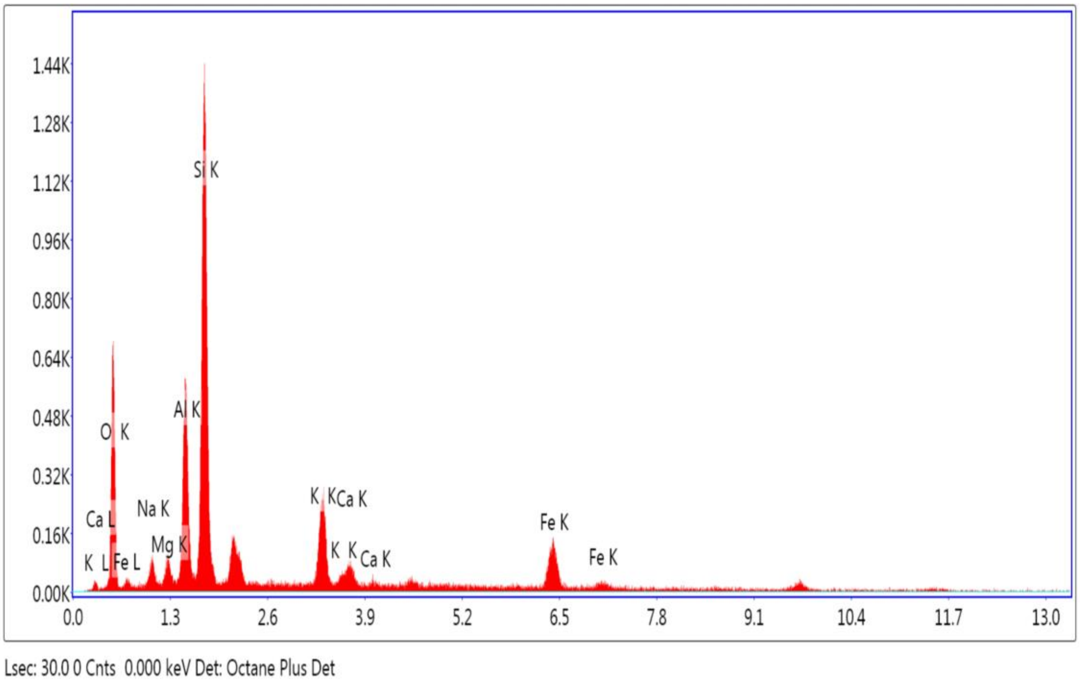


Figure 7.2(b): Elemental analysis of dump soil by EDX analysis.

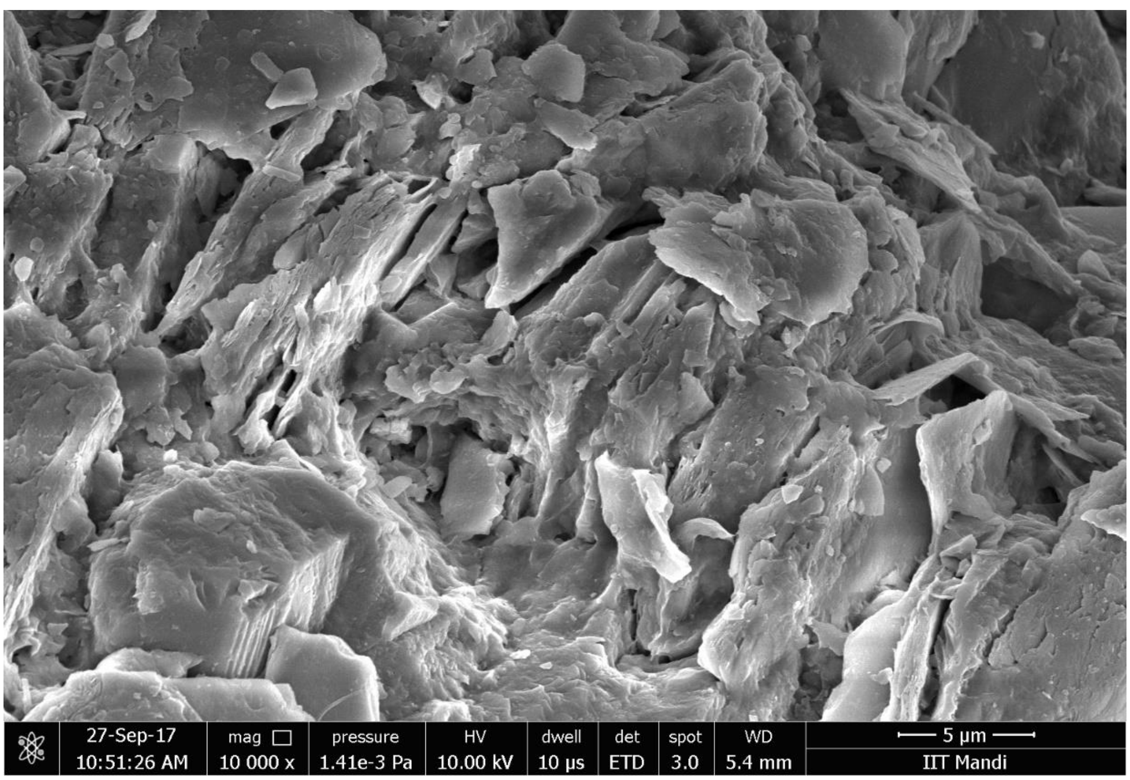


Figure 7.3(a): SEM Micrographs of natural soil with different magnifications.

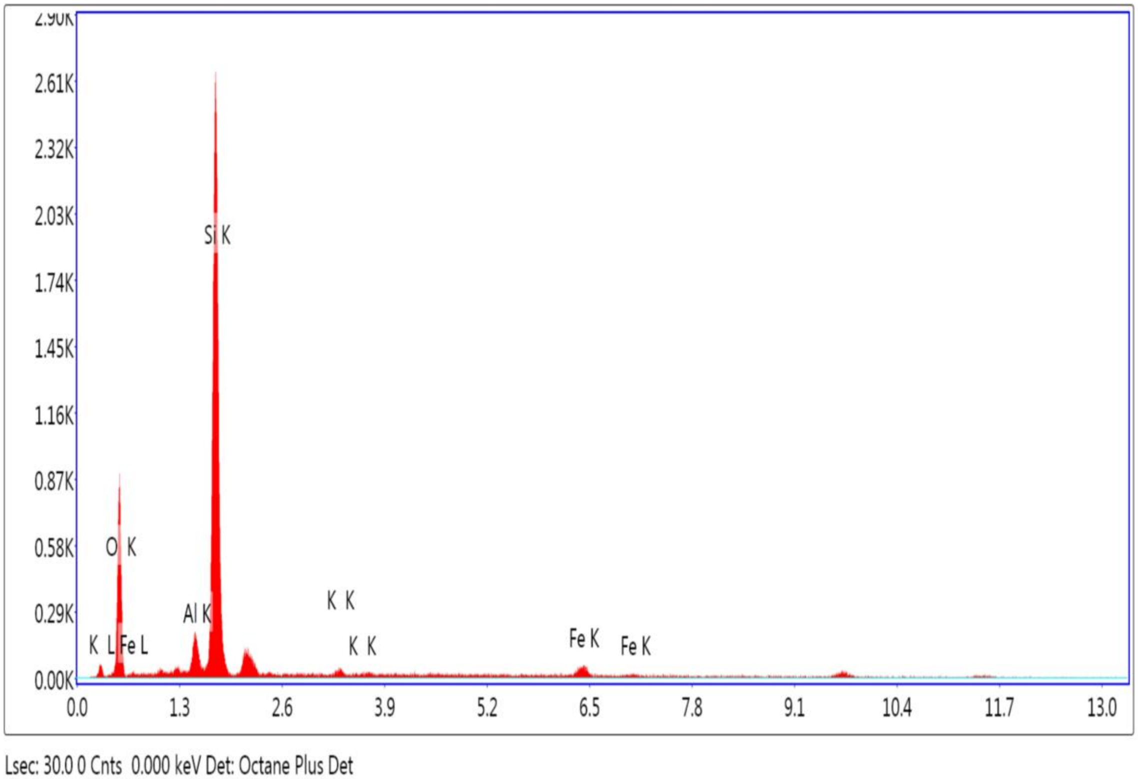


Figure 7.3(b): Elemental analysis of natural soil by EDX analysis.

Table 7.2: Quantitative analysis of detected elements in dump 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 7.3: Quantitative analysis of detected elements in natural 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

The composition of elements in soil samples were observed by EDX analysis. The major elements observed in dump soil were oxygen, sodium, magnesium, aluminium, silica, potassium, calcium and iron. The presence of Mg, Na, Ca in soil may be due to dumping of waste but in smaller concentrations, however the large concentration of these elements can affect the soil structure and permeability. The excess of sodiun can results in excess of alkaline salt and become toxic to plants. The natural soil sample showed presence of oxygen, aluminum, silica, potassium and iron. The results revealed that the presence of oxygen in both sample was more followed by silica and alumina. However the concentration of silica is more in natural soil which showed presence of quartz mineral.

7.3.2 Analysis of Geotechnical properties for dump soil and natural soil

7.3.2.1 Specific Gravity

The specific gravity of samples was determined using pycnometer (500 ml flask) as per IS:2720, (Part 3/sec-1- 1980) [255]. From the obtained results it was clear that the specific gravity of contaminated soil was less than natural soil. Due to dumping, MSW fraction gets mixed with subsoil majorly in upper layer. Thus, decrease in specific gravity of sample may be due to organic content in soil which disintegration of particles [27,262]. The presence of organic content in soil is due to dumping of waste and it varied from 1.255 to 0.385% from shallow to deeper depths (0.5 to 1.5 m). Further, the lowest specific gravity of soil was observed at depth of 0.5 m and it increased significantly with depth because of reduced effect of MSW dumping on lower layers. The obtained results for dump soil and natural soil were summarized in *Table 7.4*.

Table 7.4: Specific gravity of soil samples.

S. No.	Sample	Depth (m)			Average value over 1.5 m depth
		0.5	1.0	1.5	
1.	S1	1.98	2.28	2.46	2.24
2.	S2	2.04	2.36	2.45	2.28
3.	S3	1.91	2.41	2.49	2.27
4.	S4	2.08	2.37	2.47	2.31
5.	Natural Soil	2.59	2.63	2.64	2.61

7.3.2.2 Particle Size Distribution

The sieve analysis of the samples was done as per IS:2720, (Part 4), 1985 to observe the gradation of contaminated (dump) and uncontaminated (natural) soil [257]. The gradation curve of soil sample showed that both the sample dump soil and natural were mainly composed of sand. It was observed from the results that the dump soil collected at depth of 0.5m depth has finer fraction of particles. This may be due to the organic content present due to dumping of waste [151,152]. The particle size distribution curves for all dump and natural samples have been presented in *Figure 7.4(a-e)*.

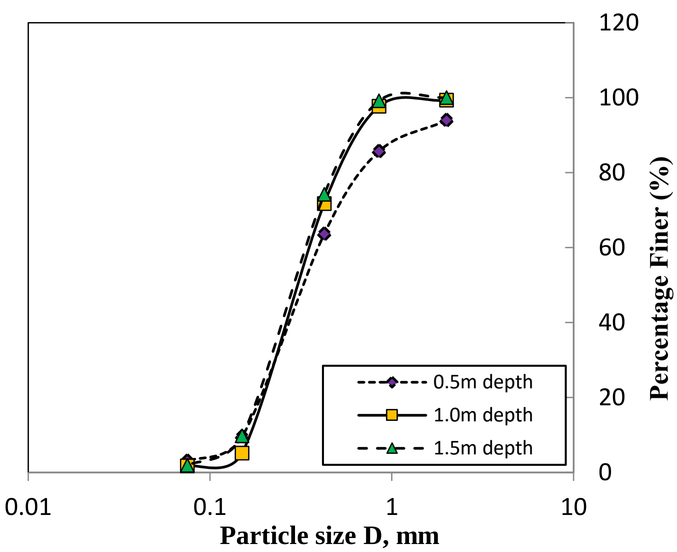


Figure 7.4(a): Particle Size Distributions for dump soil S1

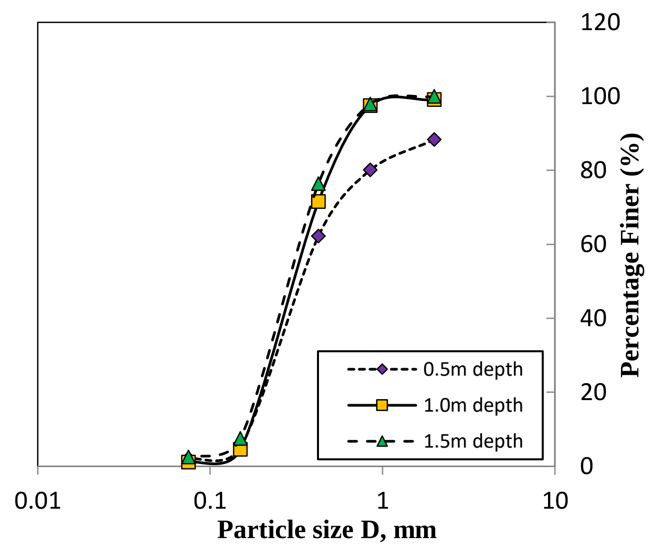


Figure 7.4(b): Particle Size Distributions for dump soil S2

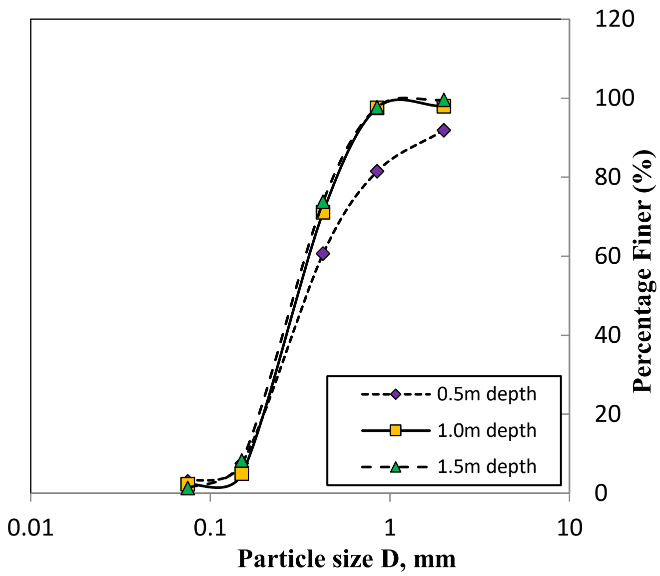


Figure 7.4(c): Particle Size Distributions for dump soil S3

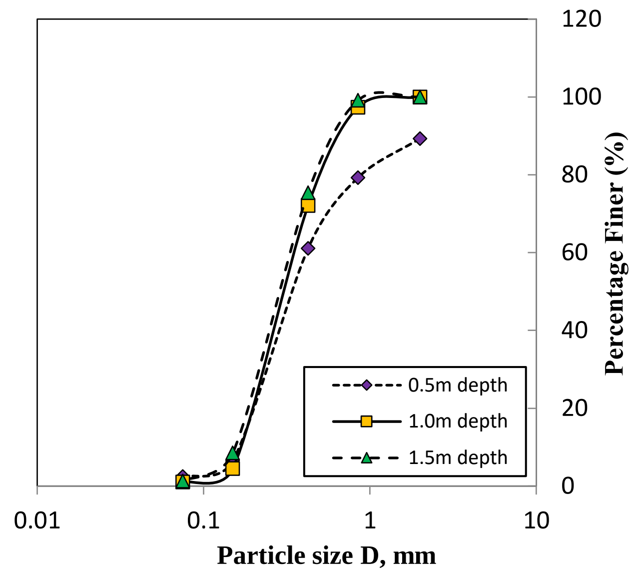


Figure 7.4(d): Particle Size Distributions for dump soil S4

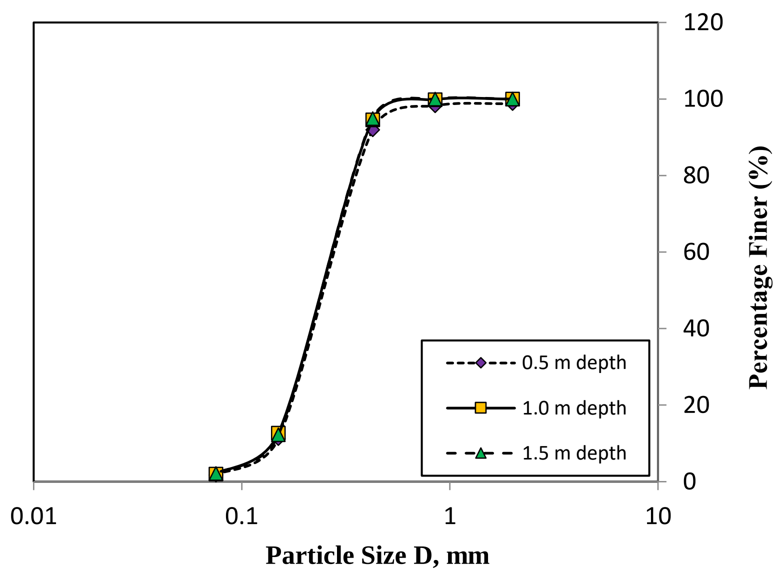


Figure 7.4 (e): Particle Size Distributions for natural soil.

Figure 7.4(a-e) showed that the soil samples were classified as poorly graded sand (SP). The gradation for all the samples at different depths showed similar properties with less content of silt present in them. The parametric values of Coefficient of Curvature (C_c) and Coefficient of Uniformity (C_u) of the soil have been presented in *Table 7.5*.

Table 7.5: Soil Classification

S. N	Sample	Depth	C_u	C_c	Average value over 1.5 m depth (C_u)	Average value over 1.5 m depth (C_c)	Soil Classification
1.	S1	0.5	2.58	0.96	2.31	0.97	SP
		1.0	2.11	0.96			SP
		1.5	2.26	0.99			SP
2.	S2	0.5	2.34	0.92	2.19	0.94	SP
		1.0	2.12	0.95			SP
		1.5	2.10	0.97			SP
3.	S3	0.5	2.55	0.92	2.27	0.94	SP
		1.0	2.09	0.95			SP
		1.5	2.19	0.96			SP
4.	S4	0.5	2.46	0.91	2.23	0.94	SP
		1.0	2.08	0.95			SP
		1.5	2.15	0.97			SP
5.	Natural Soil	0.5	2.06	1.03	2.04	1.03	SP
		1.0	2.05	1.04			SP
		1.5	2.00	1.02			SP

The C_c and C_u values of sample were determined and it was observed that values of C_c and C_u lies in range of 0.92-0.97 and 2.07-2.58. for dump and natural soil respectively. The average values for the dump soil showed that at the shallow depth the dumping of waste results in higher value of C_u due to mixing of waste fraction. The coefficient of curvature value below 4 specify the soil as poorly graded [263].

7.3.2.3 Compaction Characteristics

The compaction characteristics of soil was tested as per IS:2720, (Part-7, 1980) [258]. The maximum dry density (MDD) of soil samples was obtained from the curve corresponding to optimum moisture content (OMC) as shown in *Figure 7.5(a-e)*.

From the *Figure 7.5(a-e)* it was observed that MDD of dump soil was less than natural soil. This may be due to migration of leachate into soil which thus alter the composition and texture of soil samples [29,31,152]. The observed results showed that the dump soil sample at depth 0.5 m has lower MDD value than at 1.5 m depth due to mixing of waste fraction in subsoil. However, the variation below 1.0 m depth is very less because of reduced impact of MSW dumping at deeper depths. The MDD of dump soil reduced from 17.1 kN/m^3 to 16.4 kN/m^3 with OMC of 15.8% to 17.5% respectively. However, the effect of dumping was found to be more on the upper layer of soil.

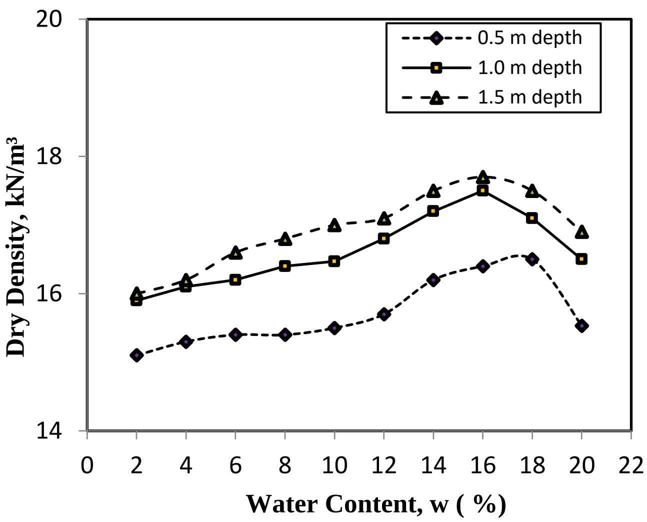


Figure 7.5(a): Compaction curve of soil S1from Standard Proctor Test

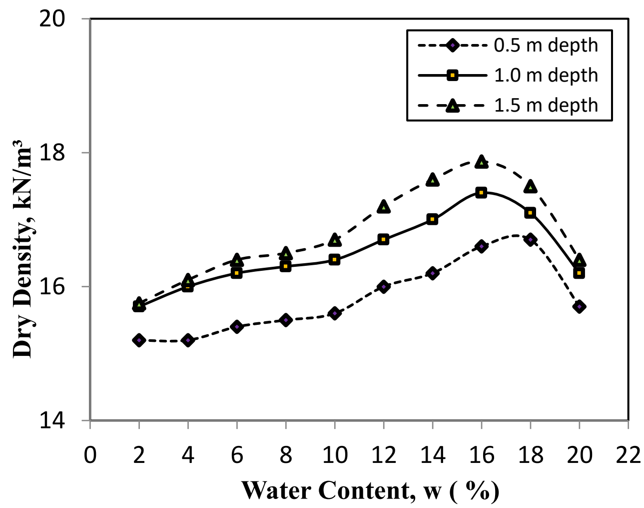


Figure 7.5(b): Compaction curve of soil S2 from Standard Proctor Test

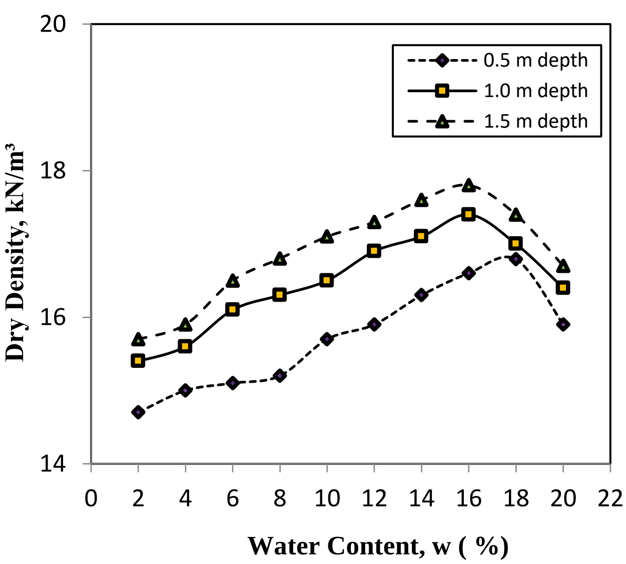


Figure 7.5(c): Compaction curve of soil S3 from Standard Proctor Test

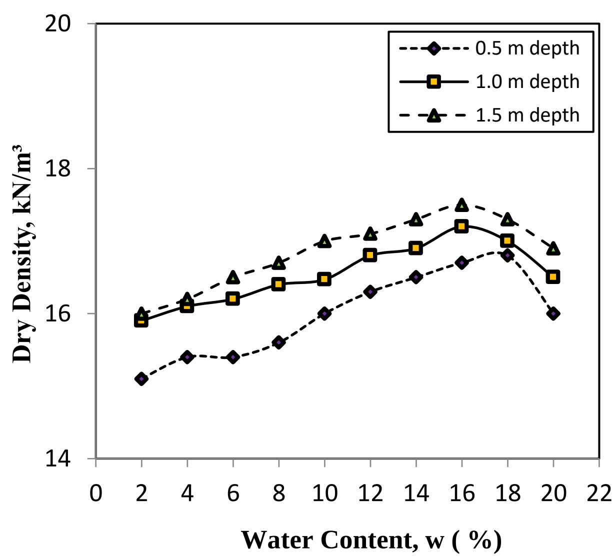


Figure 7.5(d): Compaction curve of soil S4 from Standard Proctor Test

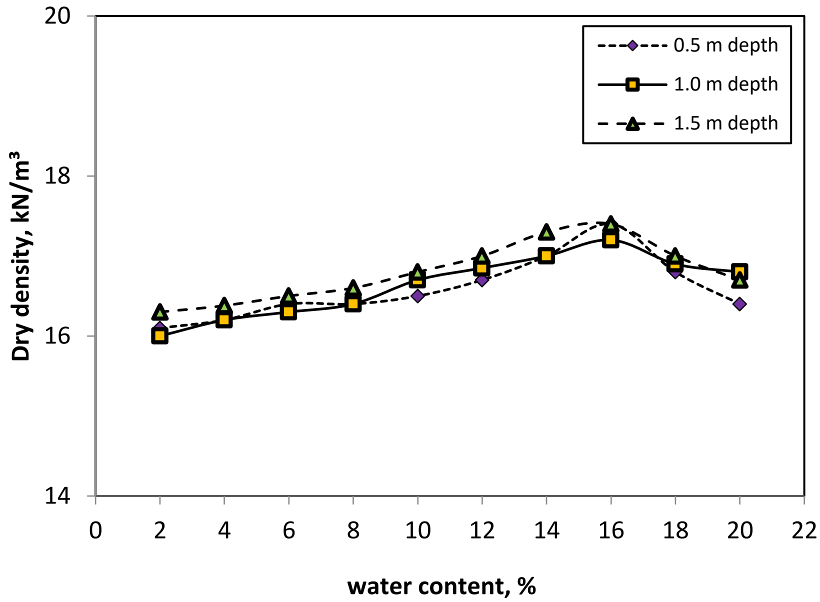


Figure 7.5(e): Compaction curve of natural soil from Standard Proctor Test.

Table 7.6: Compaction characteristics of soil samples.

Soil Samples	Depth	Maximum Dry Density (MDD), kN/m^3	Optimum Moisture Content (OMC), %
S1	0.5	16.1	16.2
	1.0	17.1	15.8
	1.5	17.4	17.8
S2	0.5	16.4	15.9
	1.0	17.1	16.2
	1.5	17.5	17.7
S3	0.5	16.4	18.0
	1.0	17.0	16.1
	1.5	17.4	15.8
S4	0.5	16.3	17.8
	1.0	17.2	15.5
	1.5	17.3	15.4
Natural Soil Sample	0.5	17.2	15.7
	1.0	17.1	15.8
	1.5	17.2	15.6

7.3.2.4 Permeability

The constant head method was used to determine the permeability of cohesionless soil samples as per IS:2720, (Part 17- 1986) [259]. The observed results for permeability of dump and natural samples are presented in *Table 7.7.*

It was observed from the *Figure 7.6 (a, b),* that the permeability of dump sample was less than natural soil. The variation in permeability values may be due to dumping of waste which causes migration of leachate into soil and heavy metals present in waste thus can accumulate in the soil [152,263,264].

From the results, it was observed that permeability of sample at 0.5m depth is less than 1.0m and 1.5m. The permeability of dump soil varies with depth from 2.57×10^{-5} to 2.32×10^{-4} cm/sec and 5.8×10^{-4} to 6.7×10^{-4} cm/sec for natural soil.

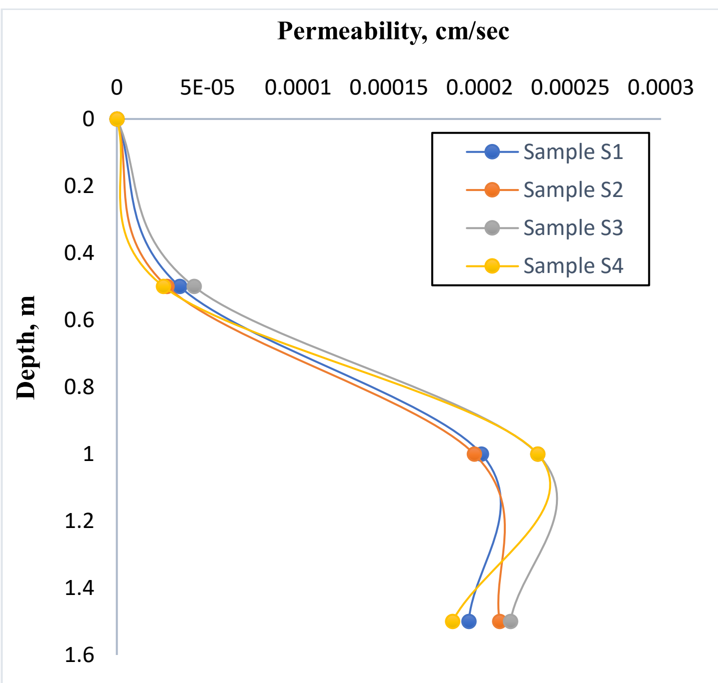


Figure 7.6(a): Variation of permeability of dump soils with depth

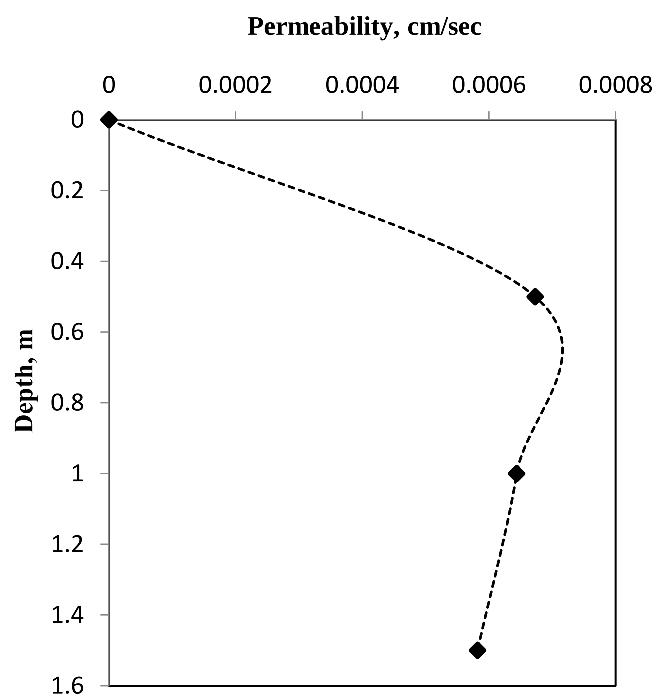


Figure 7.6(b): Variation of permeability for natural soil with depth

Table 7.7: Results of constant head permeability test for dump soil S1, S2, S3, S4 and natural soil.

Sample	Depth (m)	Hydraulic Conductivity, k (cm/sec)	Average
S1	0.5	3.46×10^{-5}	1.43×10^{-4}
	1.0	2.01×10^{-4}	
	1.5	1.94×10^{-4}	
S2	0.5	2.76×10^{-5}	1.45×10^{-4}
	1.0	1.97×10^{-4}	
	1.5	2.11×10^{-4}	
S3	0.5	4.25×10^{-5}	1.64×10^{-4}
	1.0	2.32×10^{-4}	
	1.5	2.17×10^{-4}	
S4	0.5	2.57×10^{-5}	1.47×10^{-4}
	1.0	2.32×10^{-4}	
	1.5	1.85×10^{-4}	
Natural Soil	0.5	6.73×10^{-4}	6.33×10^{-4}
	1.0	6.44×10^{-4}	
	1.5	5.82×10^{-4}	

The average hydraulic conductivity of dump soil was observed to be in range of 10^{-4}. However, the variation in hydraulic conductivity of dump soil with natural soil is much less, depict that at present, the MSW has lesser impact of on soil which may increase with time and continuous dumping. The leachate migration into soil caused accumulation of heavy metals in pores and inducing bond between soil particles and leachate film. The pore size of soil particle thus gets reduced and thus reduced k value of dump soil [263,264]. The waste dumping also results into the migration of finer particles into voids, causing the denser packing of voids thus permeability of soil gets reduced.

7.3.2.5 Shear Strength

Strength characteristics of all the soil samples were analyzed in laboratory by direct shear test as per IS:2720, (Part 13- 1986) [260]. The sample were tested in shear box of size 60×60×25 cm under normal stresses of 58.84 kN/m^2, 39.23kN/m^2, 19.61kN/m^2 at shearing rate of 1.25 mm/min. The shear strength parameters cohesion and angle of internal friction (c, ϕ) were evaluated from the curves as shown in *Figure 7.7(a-e)*.

The slope of failure envelops for dump and natural soil samples has been presented in *Figure 7.7(a-e)*. From the results it was observed that cohesion of contaminated sample (S1, S2, S3, S4) at shallow depth is more than deeper depths. The angle of internal friction of dump soil increases from 18.64° to 20.55° at 0.5 m with increasing value of cohesion and 21.05° to 25.41° for 1.0 to 1.5 m depths with lower values of cohesion. The cohesion was observed in the soil sample due to presence of fine waste particles which gets mixed in soil.

The results depict that cohesion of dump soil is due to waste fraction as compared to natural sample thus affecting shear strength of soil [152]. The leachate produced from MSW contains cations like Ca, Mg, Mn etc. which induced bond between particles [265] thus increasing cohesion of soil.

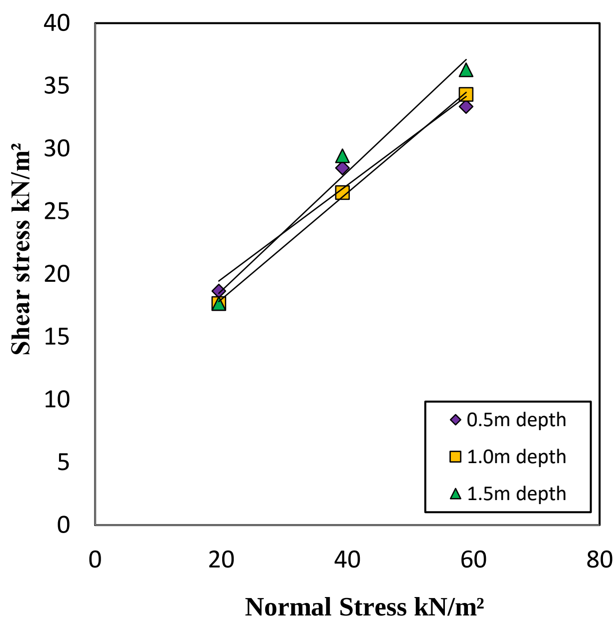


Figure 7.7(a): Shear strength envelops for Soil S1 at different depths

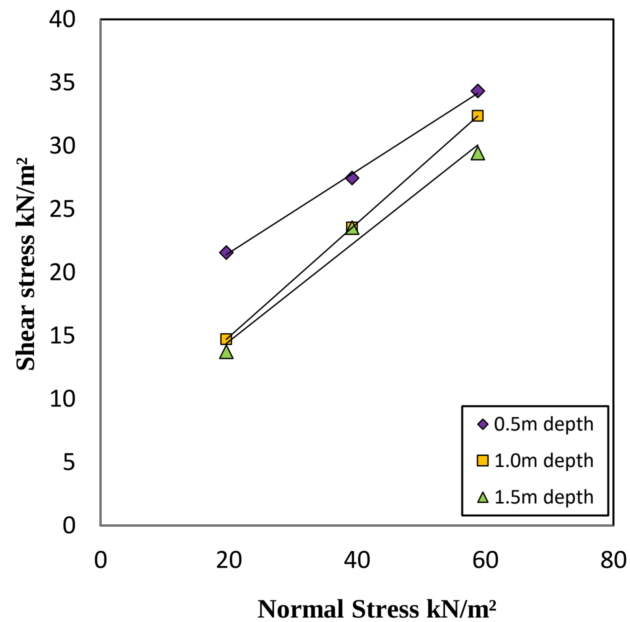


Figure 7.7(b): Shear strength envelops for Soil S2 at different depths.

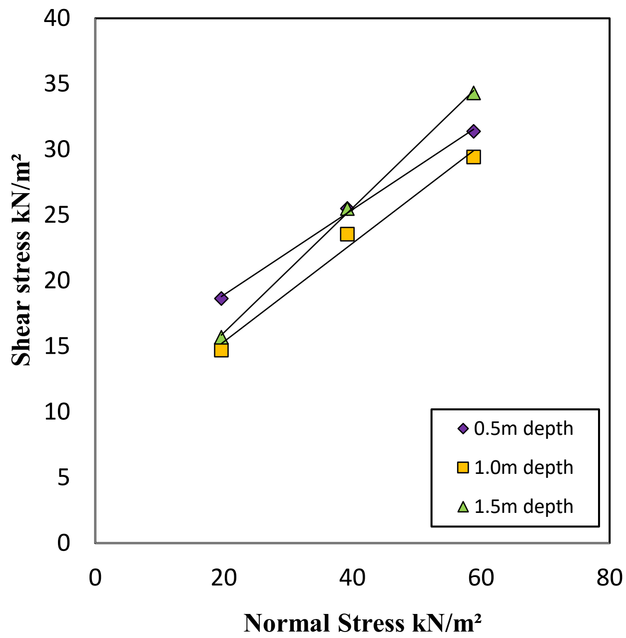


Figure 7.7(c): Shear strength envelops for soils S3 at different depths.

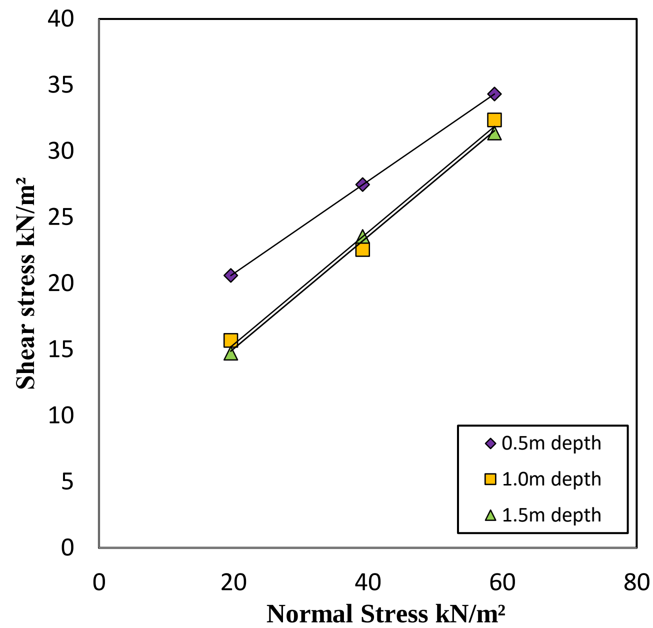


Figure 7.7(d): Shear strength envelops for soils S4 at different depths.

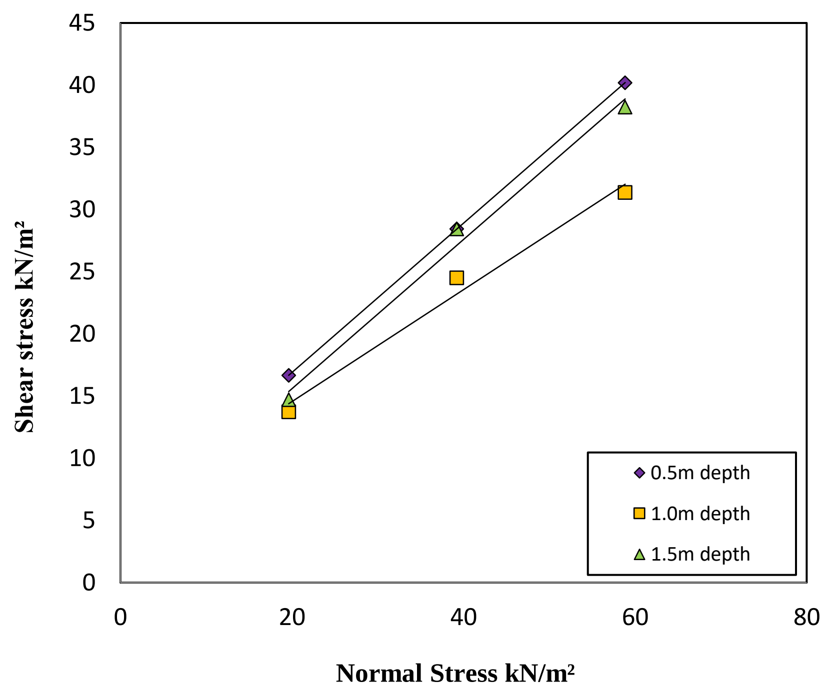


Figure 7.7(e): Shear strength envelops for natural soil at different depths.

Additionally, the soil degradation due to migration of leachate and microorganisms present in results into denser packing of particles thereby increasing ϕ value [152,265]. The degradation of contaminated soil is due to MSW dumping which may increase the disintegration of particles and thereby resulting in higher ϕ value [152,262,266].

7.3.2.6 California Bearing Ratio Test

The CBR testing of soil samples was done for both soaked and un-soaked conditions as per IS:2720, (Part, 17) [261]. The preparation of samples for testing was done at proctor maximum dry density. The samples were tested at standard compaction energy for un-soaked condition and after soaking the sample for four days. The histogram for the contaminated and un-contaminated soil samples were shown in *Figure 7.8(a-h)* and *Figure 7.9(a,b)* respectively.

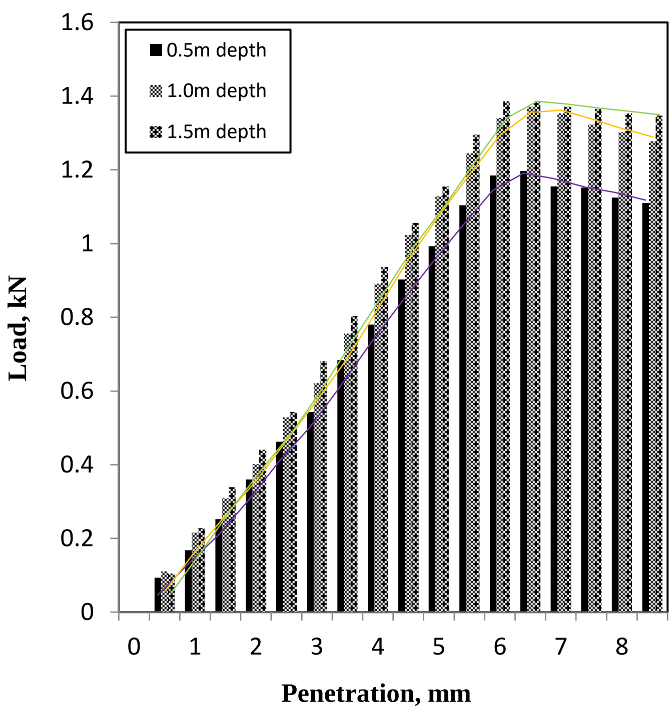


Figure 7.8(a): Histogram of Load and Penetration for dump soil S1 (un-soaked condition).

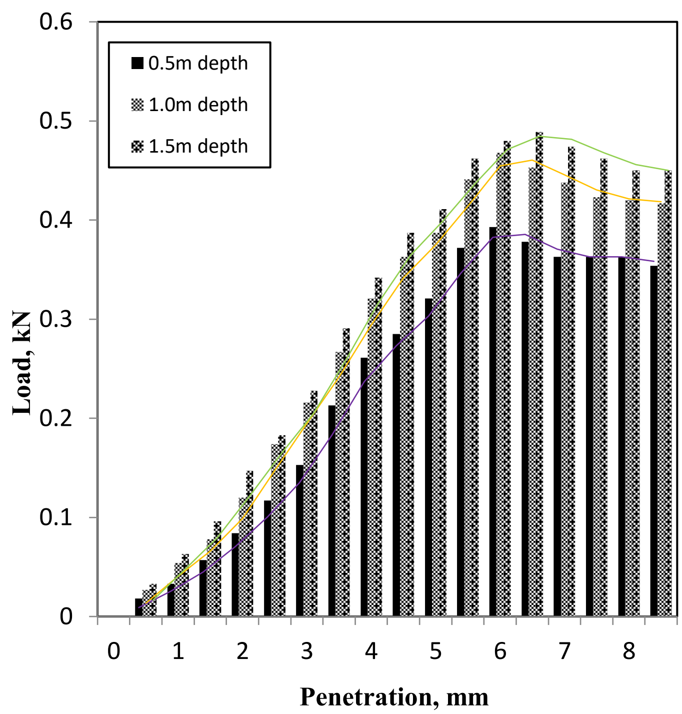


Figure 7.8 (b): Histogram of Load and Penetration for dump soil S1 (soaked condition).

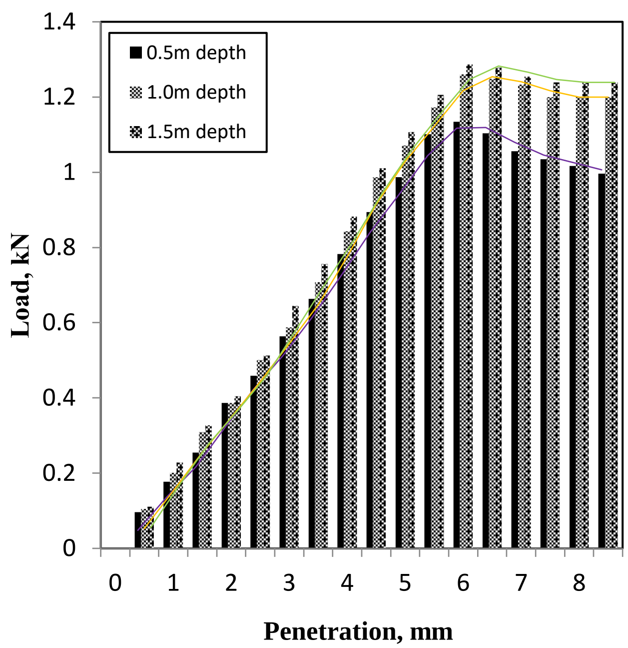


Figure 7.8(c): Histogram of Load and Penetration for dump soil S2 (un-soaked condition).

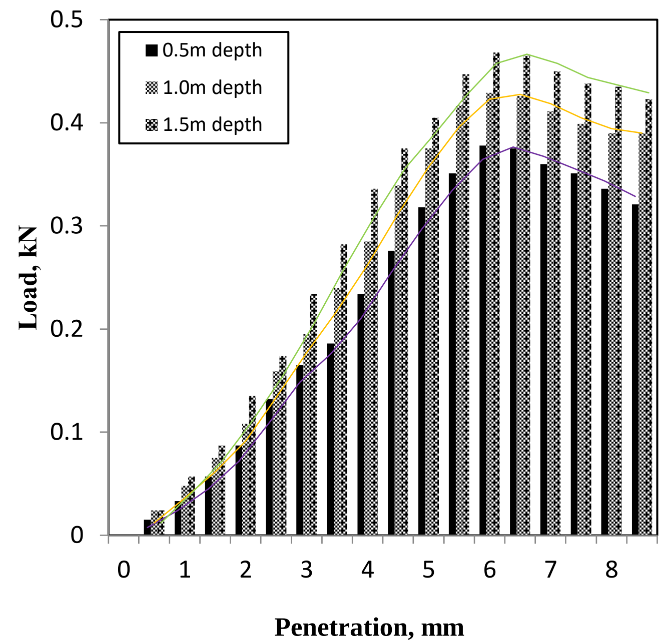


Figure 7.8(d): Histogram of Load and Penetration for dump soil S2 (soaked condition).

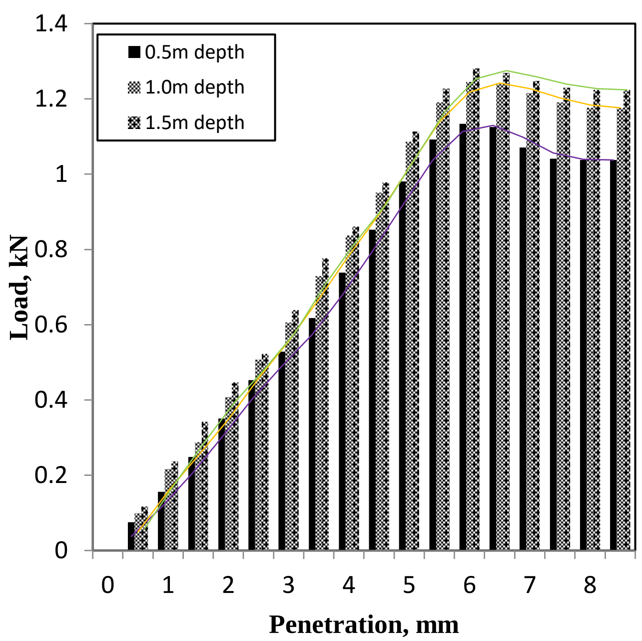


Figure 7.8(e): Histogram of Load and Penetration for dump soil S3 (un-soaked condition).

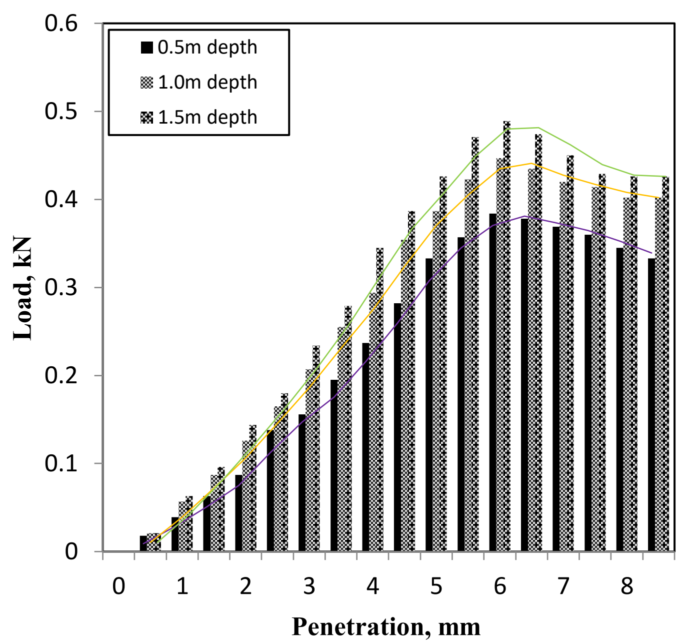


Figure 7.8(f): Histogram of Load and Penetration for dump soil S3 (soaked condition).

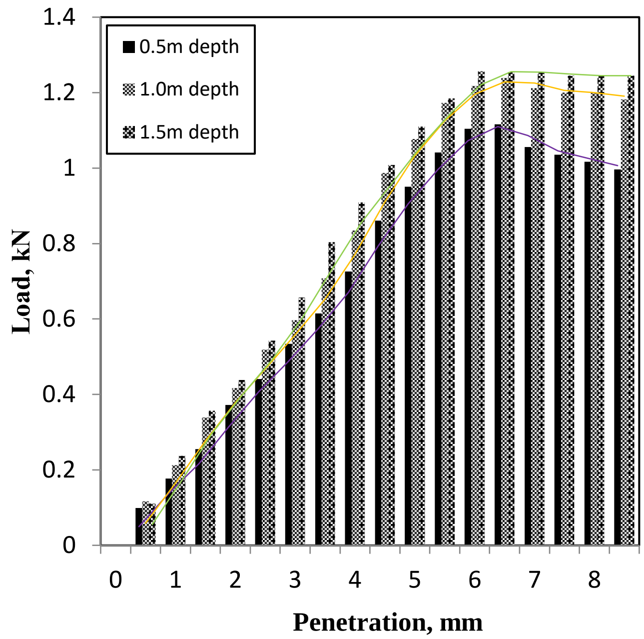


Figure 7.8(g): Histogram of Load and Penetration for dump soil S4 (un-soaked condition)

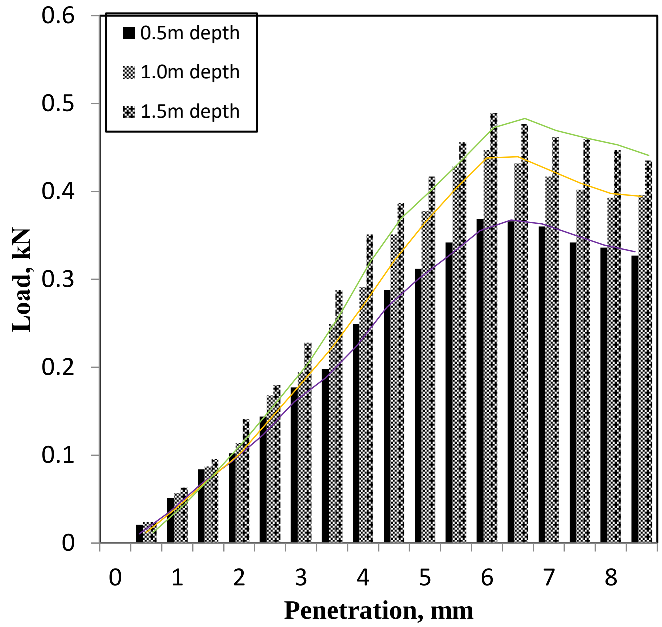


Figure 7.8(h): Histogram of Load and Penetration for dump soil S4 (soaked condition)

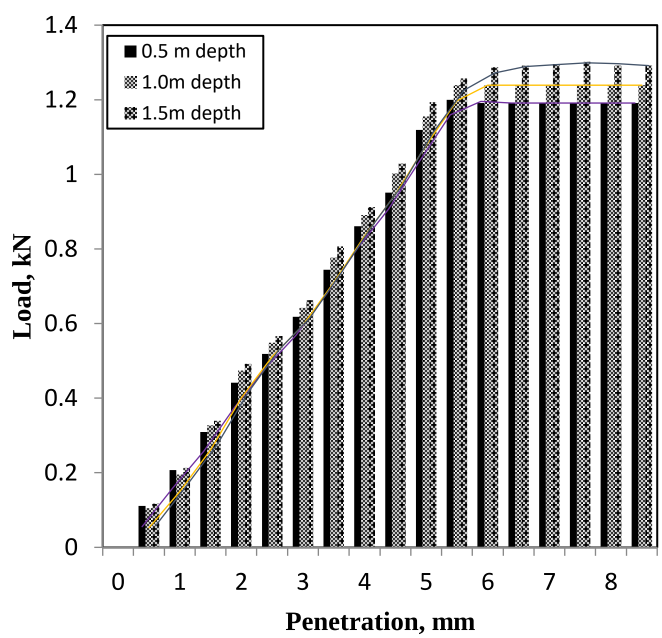


Figure 7.9(a): Histogram of Load and Penetration of natural soil (un-soaked condition).

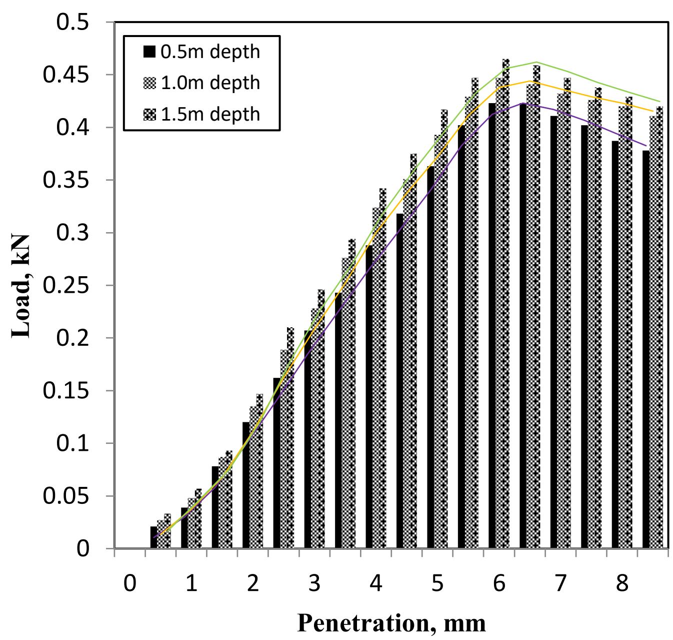


Figure 7.9(b): Histogram of Load and Penetration of natural soil (soaked condition)

The curves for load versus penetration were plotted and CBR value of sample at 2.5 mm and 5 mm penetration were determined. The higher value of obtained CBR test thus can be adopted for designing purpose. The CBR value of dump soil ranged between 4.63% to 5.62% for un-soaked condition and 2.52% to 3.28% for soaked condition. The CBR value of natural soil sample varied in range of 6.45-7.81% for un-soaked and 2.67-4.03% for soaked conditions respectively.

The results obtained from the geotechnical testing of soil samples showed that dumping of municipal solid waste caused degradation of soil particles. The obtained results showed a decreasing trend in specific gravity, MDD, permeability and CBR value of soil [263,264]. The effect of dumping was observed more in upper layer and with increasing depth the effect of MSW and leachate has reduced. The contamination of soil decayed the properties and thus affects the shear strength, dry density and CBR values of soil.

Summary

The continuous dumping of MSW on soil over the years has affected the geotechnical and geochemical characteristics of soil. The SEM and EDX analysis of soil showed presence of silica in soil and presence of oxygen in higher amount showed higher moisture content in contaminated soil samples.

The effect of MSW dumping on geotechnical properties of soil was higher on upper layer and gradually decreases with depth. The dump soil showed lower values of specific gravity, dry density, permeability than natural soil. The insignificant variation in particle size of soil samples was observed and characterized as poorly graded sand. Additionally, the higher value of cohesion and smaller angle of internal friction were observed for dump soil due to presence of finer fraction of degraded waste.

The leachate migrated through the soil caused deposition of cations and inducing bond between soil particles and decreasing void ratio thereby reducing the permeability and increasing the shear strength of contaminated soil than natural soil. The CBR of contaminated sample decreased as compared to natural soil. It was observed from the characterization of MSW that waste in study area was rich in organic content and having lesser fractions of metal, bottles, tins, glass. Therefore, disposal of waste in dumping yard causes generation of leachate which affects the soil properties beneath MSW.

After the completion of waste disposal, the closure of landfill should be done by providing cover on it and it could be used for recreational purposes. Thus, for efficient designing and operation of engineered landfill, settlement of MSW due to biodegradation is discussed in next chapter. In designing the landfill for disposal of MSW, the analysis of settlement of soil and MSW need to be assessed for avoiding any damage to structure.

CHAPTER -8

SETTLEMENT ANALYSIS OF MUNICIPAL SOLID WASTE

8.1 Introduction

Landfills are considered as foremost management option for the disposal of residual waste collected from the households, commercial and institutional sectors. Many countries still consider the landfilling as cheapest and preferred means of disposing the MSW as compared to other methods like incineration, composting, pyrolysis. The continuous disposal of waste leading to long term pollution potential, resulting the settlement in landfill are major concern in landfill management [33,35]. The MSW settles in landfill under its own weight and external loads applied in form of daily soil cover, additional waste layer, final cover thereby affecting the structural stability of landfill. In this context, properties like compressibility, shear strength, hydraulic conductivity were studied for evaluating the stability and structural integrity of landfill. Also, the shear behavior of MSW was studied to determine the slope stability of landfill in previous chapter.

The municipal solid waste landfill requires additional consideration for analyzing the leachate generation, landfill gas emission, settlement and stability, depending upon the characteristics and properties of waste. The degradation of waste changes properties of municipal solid waste and these changes are used for assessing the geotechnical stability, other failures of landfill [105]. The MSW generation in country has been increasing with rapid growth in population, urbanization, industrialization in country, thus should be disposed-off without adversely affecting the environment. The disposal of waste in landfill has been an important parameter in waste management practices. However, land filling is considered as one of the appropriate and cost-effective method for disposal of waste [2].

The settlement of municipal solid waste is associated with large reduction in volume of waste due to degradation of organic content of waste and initial compression. Settlement in landfill continues for a long time and can approach 30-50% of initial landfill height [32,33]. The municipal solid waste landfill requires additional consideration for analyzing the leachate generation, landfill gas emission, settlement and stability, depending upon the characteristics and properties of waste. However, the biodegradation and settlement of MSW is affected by moisture content, temperature because of the presence of micro-organisms in waste [111]. The settlement of MSW that occurs due to fresh and degraded waste is required to be differentiated, to predict long term settlement [35,162,165]. The settlement of the landfill is different for the old landfill and fresh landfill depending upon the fill age [33]. The waste dumped in the fresh landfill site decomposed due to presence of significant amount of organic matters present thus causing considerable amount of settlement whereas in old landfill presence of organic matters is negligible. Prediction of settlement in landfill is a complex process because of heterogeneous nature of waste, complex biodegradation process, variable size and density and different compression characteristics [174,185,188]. The composition of MSW affects the void ratio, water content, unit weight and compressibility of the waste and are important parameter for analyzing landfill performance [37]. However, the composition of waste varies for developing countries and developed countries where moisture content is more because of higher organic content and less where organic content is less respectively [2,77].

The estimation of settlement due to mechanical and biodegradation processes involves various mathematical models and laboratory testing methods. Models based upon the power creep law, rheological model, primary and secondary consolidation models, logarithmic series have been proposed to predict the settlement of landfill over a period of time [32,35,162,165,167,169,174,189].

Numerous model haves been proposed to compute the settlement of landfills considering the constant density over the depth with time [32,167]. However, it was observed by [213] that density varies spatially and temporally in landfill. Further, the effect of moisture content, pH, temperature on the settlement of landfill has not been incorporated in the developed models. Thus, a model developed for settlement evaluation incorporates the temporal and spatial variation in density, pH, moisture content, temperature for estimating the primary and secondary settlement after closure of landfill [174,176].

Settlement is mainly composed of two mechanism: mechanical compression and biodegradation of organic solids. The mechanical compression (initial and primary settlement) occurs due to instant applied load resulting in decreased macro pores, deformation of highly compressible constituents and rearrangement of particles. The biodegradation of MSW after landfilling leads to biogas and leachate production and the settlement occurs during the operation period and after closure of landfill [166]. The degradation process of MSW is time dependent process and thus properties of MSW changed due to degradation. The biodegradation of solid waste causes the long-term secondary settlement in landfill affecting the performance of landfill [170].

The anaerobic degradation of organic matters results in biodegradation settlement of MSW and methanogenesis of waste in landfill [110,170,188]. Biodegradation process of MSW depends upon the waste characteristics, density, pH, moisture content and temperature, microbes present in waste. At the initial stages the secondary settlement is dominated by mechanical interactions and in second stages the settlement rates are higher due to effect of degradation of organic fraction [170] and will continue, leading to the large differential settlements in landfills.

The settlement of waste after post closure causes large settlement in landfill, produces undesirable maintenance problems, developing cracks, failures in cover system. In this context, to estimates the rate and magnitude of settlement over a period of time due to mechanical compression and biodegradation of MSW, a laboratory set up was developed. The effect of both degradation and physical processes were monitored to determine the settlement. The moisture content, pH and compression characteristics of waste were evaluated using consolidation testing of MSW and settlement is predicted using these parameters. The mechanical compression of MSW was determined with variation in density of MSW. The waste composition, start-up condition, leachate generation and biogas composition were monitored during the course of study. Further, the obtained parameters from the laboratory analysis were used to predict the settlement using the model developed [176]. The comparison between the analyzed settlement and modelled settlement of waste for the study area was done.

8.2 Material and Methods

8.2.1 Waste Composition

Fresh sample of waste (approximately two weeks old) was used in the study obtained from the dump site in Una. The characterization of waste was done and it was observed that waste is rich in organic content (56%). The composition of waste sample collected from the dump site was already discussed in chapter 4. The composition of waste was analyzed and various categories of waste were obtained like paper, plastics, wood, combustible etc. The large particles (>40 mm) of waste were shredded and particle size distribution was established (*Figure 8.1*).

As suggested that ratio of cell dimension to the maximum particle size should not be less than 10 [267]. Thus, the size of reactor selected in the present study was (600×600×400) mm.

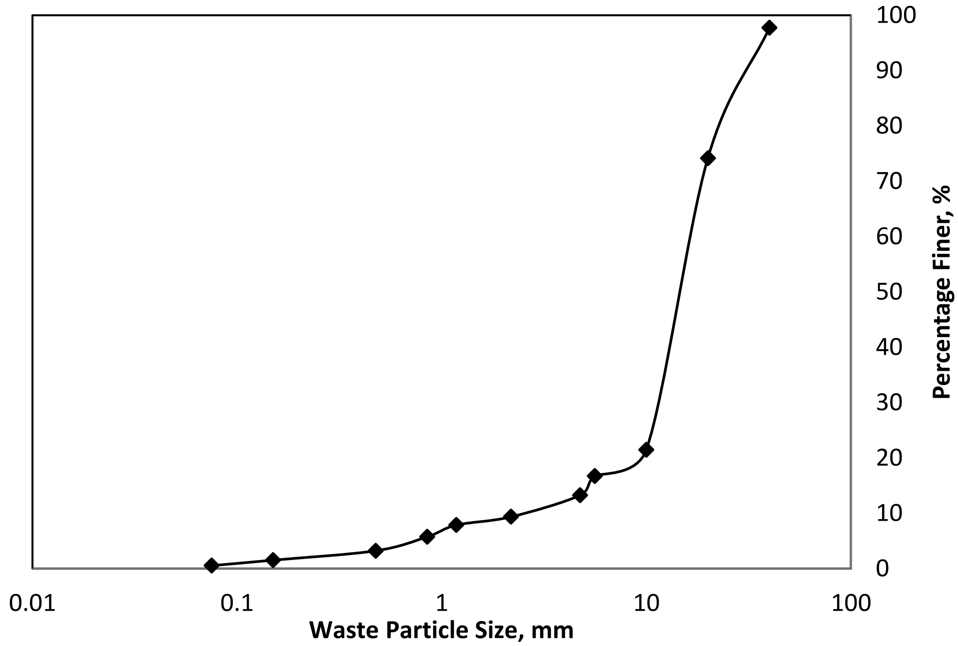


Figure 8.1: Particle size distribution of fresh waste collected from the site.

8.2.2 Laboratory Set Up and Operational Procedure

An anaerobic reactor was composed of perspex sheet of size (600×600×400) mm was designed and constructed to allow overburden to be applied on sample (*Figure 8.2 & 8.3*). A load delivery system is attached to the reactor to apply a constant surcharge load on the waste. The load was applied on the waste samples placed in the reactor through a system comprised of hydraulic jack 65 mm diameter connected to a perforated load platen of size (595×395) mm to maintain or distribute equally the load on waste sample. The perforations were made in the platen to allow the leachate to pass through the waste. The bulk unit of landfill is approximately 7.15 kN/m^3, load corresponding to 10m of the overburden of waste can be simulated in reactor [170,268].

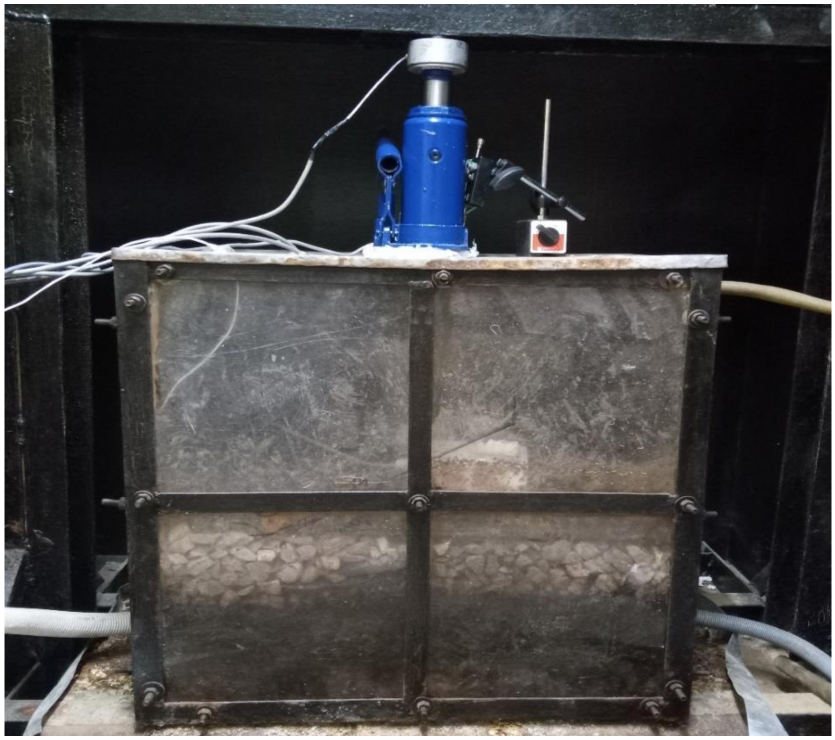


Figure 8.2: Laboratory set up of reactor.

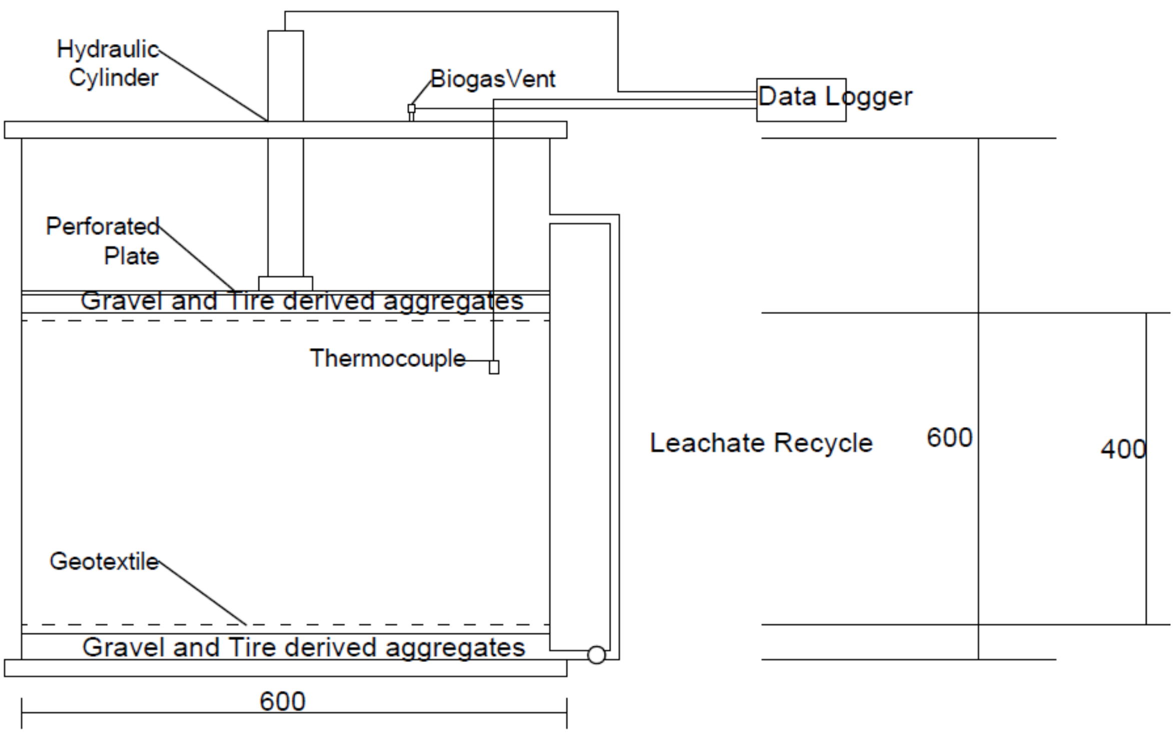


Figure 8.3: Schematic view of laboratory anaerobic reactor.

A 15-cm thick gravel and tire derived aggregate (TDA) drainage layer was placed on the bottom of the reactor [269]. The maximum particle size for gravel 20mm and TDA (longest dimension 20-25mm) was selected and washed with the distilled water, dried before placing in the reactor (*Figure 8.4*). The drainage layer was overlain by polypropylene geotextile filter layer of size 2×2 mm square mesh to prevent the migration of solid particles into the drainage layer (*Figure 8.5*).

Figure 8.4: Drainage layer material: Gravel (avg. dia 20mm) and Tire derived aggregates (Avg. dimension 20-25mm).

Figure 8.5: Placement of drainage and filter layers in reactor.

The waste sample collected from the landfill site was dried at 60°C to obtain constant weight and then placed in the reactor at height of 400mm. The sample was placed in 5-7 successive layers, properly compacted with the wooden tamper to give a uniform density throughout. Drainage layer (5 cm thickness) was placed on top of waste separated with geotextile to allow the even distribution of leachate into waste sample.

The reactor is equipped with thermocouple for monitoring the temperature, linear variable displacement transducer (LVDT) for displacement monitoring, gas sensors for measuring the biogas generation in reactor (mainly Methane and CO_2) and leachate recirculation system. The reactor is completely sealed and sparged with nitrogen gas to remove the oxygen from waste and gravels and headspace of reactor. Synthetic leachate was prepared and filled in reactor to enhance the microbial activities.

The reactor was operated at constant mesophilic temperature of (27±3)°C during the operation period of experiment. The reactor was operated and settlement and biogas generation were monitored continuously monitored for a period of 202 days. The vertical load was maintained at 50 kPa during the operation period of experiment.

8.3 Settlement Analysis

The settlement of MSW landfill is complex and caused problems after closure of landfill leading to undesirable maintainance problems, damaging the structure, liner system, leachate collection system and failure of cover system. Thus the post closure settlement of landfill needs to be considered for analysing the rate of settlement.

8.3.1 Biodegradation Settlement

Various models were proposed for analysing the biodegratadtion settlement of waste [35,165,175,176,184]. Different mathematical models have been presented in scientific literature to calculate biodegradation settlement of MSW [33,162,163,167] but the empirical model proposed helps in determining the settlement due to biodegradation of the MSW [176]. The details of this model have been discussed below:

The rate of change of mass depending upon moisture content (θ), temperature T , pH is predicted to follow equation

$$\frac{d(M_{sj})}{dt} = -k_j \xi(T, pH, \theta) M_{sj}, \ (j = 1,2,3,4) \quad (8.1)$$

where ξ is the function of pH ,moisture content θ) and Temperature (T) in fraction portrayed by researchers [168, 270] as shown by equation.

$$\xi(T, pH, \theta) = \frac{T\theta \exp\left[-(pH-7)^2 \ln\frac{4}{3}\right]}{\left[1+\exp\left(\frac{T}{4}-18\right)\right]} \quad (8.2)$$

whereas, M_{sj} are the masses of different components of waste such as non- biodegradable (M_{s1}), slowly biodegradable (M_{s2}), moderately biodegradable (M_{s3}), and rapidly biodegradable (M_{s4}), with their respective rate constants k_1, k_2, k_3, k_4 .The decay rate of biodegradable waste (k) for slowly biodegradable, non-biodegradable, rapidly biodegradable and moderately biodegradable waste are categorized as 0.00001 day^{-1}, 0.00 day^{-1}, 0.001 day^{-1} and 0.0001 day^{-1}.

The total masses of N layer of soil become,

$$M_{s,N}(t) = \Sigma_{i=1}^{N} \Sigma_{j=1}^{j=4} (\% fi) M_{si,j}.\exp[-k_j \xi(T, pH, \theta).t] \quad (8.3)$$

The volume of layers (V_s) at time (t) is evaluated by equation (8.4)

$$V_{s,N}(t) = \Sigma_{i=1}^{N} \frac{1}{\rho i} \Sigma_{j=1}^{j=4} (\% fi) M_{si,j}.\exp[-k_j \xi(T, pH, \theta).t] \quad (8.4)$$

where, ρ = Density of waste

% f = Percentage of waste under diverse classes

M_{si} = Masses of different components of waste

Now the strain (ε_b) due to biodegradation is estimated by using equation

$$\varepsilon_{b,i}(t) = \Sigma_{i=1}^{i=N} \frac{V_{i,N} - V_{S,N}(t)}{V_{i,N}} \quad (8.5)$$

$V_{i,N}$ denotes the initial volume of every layer.

Finally, the settlement at any time (t) due to biodegradation is then computed by equation (8.6), in which (H_i) is the initial thickness of each layer.

$$S_b(t) = \sum_{i=1}^{i=N} H_i \varepsilon_{b,i}(t) \quad (8.6)$$

Modelling Parameters

The waste comprised of layers of finite thickness and landfill of 10m having 10 layers of 1m thickness each was assumed. The density of waste was evaluated and increased with depth. The MSW fractions having different phases of slowly degradable, moderately degradable, rapidly degradable and highly degradable content. The degradation constant (k) values 0.00001 day^{-1},0.00 day^{-1}, 0.001 day^{-1}, 0.0001 day^{-1} were taken for slowly degradable, non-degradable, rapidly degradable and moderately degradable waste respectively [251]. In the literature temperature of 32°C to 42°C was considered as optimum temperature for biodegradation of MSW [165,172,176]. Therefore, for biodegradation the favorable conditions at temperature of 32°C to 42°C and pH values for acidic and basic condition (2 to 14) are considered [165,174,176]. Also, the evaluated parameters of the laboratory testing of MSW were used for evaluation of settlement using the model developed.

The spatial variation in moisture content was observed with depth.

Density of soil:

$$\rho_z = \rho_m + (\rho_m - \rho_0) . \frac{z}{z + 12.4} \quad (8.7)$$

where, ρ_0 = initial value of density, kg/m^3

ρ_m = maximum value of density, kg/m^3

Moisture Content: Volumetric moisture content for depth (z) is evaluated as

$$\theta(z,0) = 0.20 + 0.01z \quad (8.8)$$

8.3.2 Settlement attributed to mechanical compression

The mechanical compression in landfill occurs due to overburden load and addition of new waste layer causing additional weight on the underlaying layer. Thus, strain in each layer of fill can be estimated by equation given by [174]

$$\varepsilon_{mi}(t) = C_m.\log\left[\frac{\gamma_i H_i + \sum_{j=j+1}^{N} \Delta\gamma_j H_j}{\gamma_i H_i}\right] \tag{8.9}$$

where, $\varepsilon_{mi}(\mathrm{t})$ = strain attributable to mechanical compression.

C_m = coefficient of compressibility for mechanical compression.

H_i = initial height of compacted lift

$\Delta\gamma_j$ = increment of unit weight imposed by lift j on lift i.

The mechanical compression in obtained by

$$S_m(t) = \Delta H \, \varepsilon_{mi}(t) \tag{8.10}$$

ΔH = initial height after closure.

8.4 Results and Discussion

The settlement of waste in the reactor was measured for 202 days under 50 kPa load for the raw waste. Initially, under no load condition, addition of synthetic leachate resulted in approximately 1.87% of settlement and about 3% of settlement was reported on liquid addition [170]. The settlement of waste in reactor was plotted against log time. The settlement of waste in reactor was determined in three stages: i) Immediate settlement, ii) Primary Settlement and iii) Secondary settlement.

8.4.1 Immediate Settlement

The settlement in the waste occurred instantaneously during the time of application of load. It was observed from the obtained results that approximately 29.9% of settlement occurred immediately after application of load. The results indicate that higher settlement at initial stage of loading is due to lack of compaction, higher fraction of organic matter present in fresh waste and initial trapped gases. However, this value is less than field values as given by [271] indicating lack of compaction and almost similar to [170].

8.4.2 Primary Settlement

The settlement obtained by many researchers after completion of immediate settlement of MSW is arbitrary [165,170,182]. Therefore, primary settlement was evaluated using Terzaghi's theory of one-dimensional consolidation. The time factor for completion of primary consolidation was evaluated using equation,

$$T = \frac{c_v t}{d^2} \sim 1 \tag{8.11}$$

where T = time factor, c_v = consolidation coefficient, t = elapsed time after loading, d = max. drainage path length, d= h/2.

The coefficient of consolidation c_v was evaluated graphically using time square root time method (*Table 8.1*). c_v can be determined by using eq. given [272], depending upon the standard interpretation based on best fit straight line drawn through initial data points and horizontal asymptote representing ultimate settlement intersecting at time $\sqrt{t_x}$, where

$$c_v = \frac{3d^2}{4t_x} \tag{8.12}$$

Table 8.1: Result of consolidation analysis using time square root method.

Parameters	**Values**
d (m)	0.2
$\sqrt{t_x}$	5.8
t_x (seconds)	121104
$c_v = \frac{3d^2}{4t_x}$ (m^2/s)	2.47×10^{-7}
T (after 48 hours)	0.773

The primary settlement in the reactor resulted in additional 10.14% of settlement after immediate settlement in the waste sample. The observed total settlement after 48 hours (end of primary settlement) in the waste for the study was reported to be 40.04% which may be attributed to the heterogeneity of sample and difference in compaction of waste. As reported, the total settlement of 33 to 48% was observed for raw MSW by end of 24 hours of settlement [170].

8.4.3 Secondary Settlement

The settlement attributed to long-term biodegradation and creep induced settlement of waste was plotted against log-time in *Figure 8.6*. The secondary settlement in the reactor was recorded for the 202 days after completion of primary settlement which was recorded to be completed after 48 hours after application of load on the sample. From the test results obtained, total secondary settlement after 202 days was recorded to be 5.85% for raw waste. In comparison to study conducted by [170], the total secondary settlement of 25% was obtained after 919 days of experiment.

The long-term secondary settlement at 50 kPa load in reactor was obtained from the test result was plotted in *Figure 8.7* and compared with literature. The rate of biodegradation k of 0.477 day^{-1} was estimated using non-linear regression analysis from the obtained results and biogas generated from the waste over the duration of experiment. The estimation of creep induced settlement needs to be done through anaerobic digestion in control reactor.

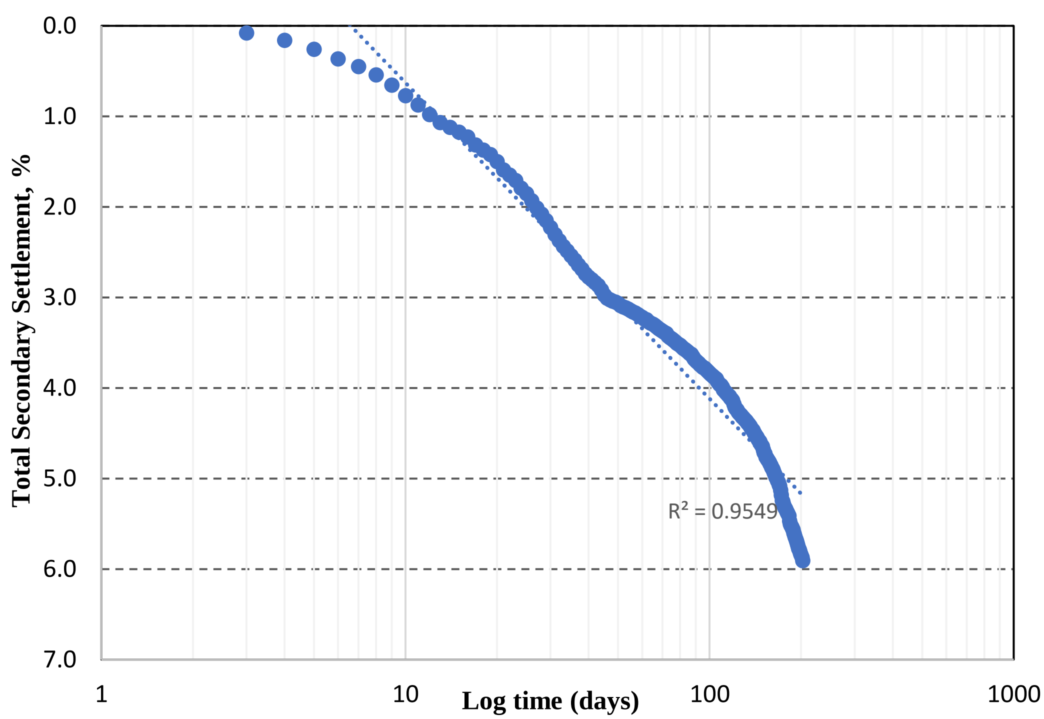


Figure 8.6: Secondary settlement at 50 kPa load for raw waste in reactor.

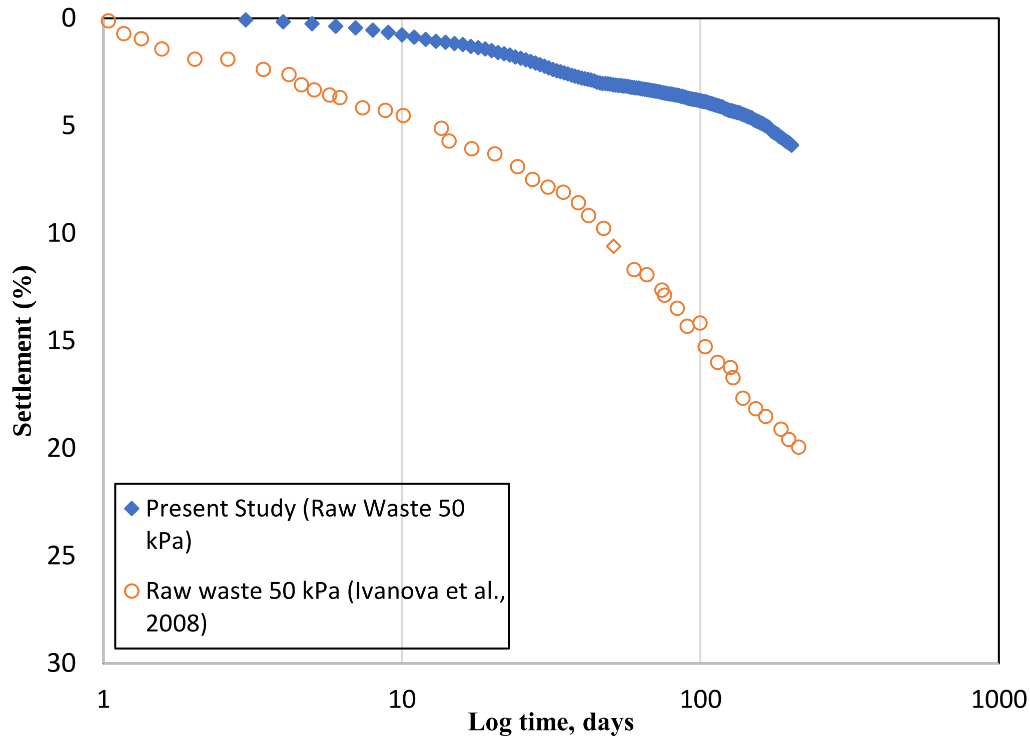


Figure 8.7: Comparison of secondary settlement at 50 kPa load.

The results depict that the rate of secondary settlement of waste was slow in comparison to [170] which may be due to composition of MSW and bulk density of waste and the test conditions for the experiments. The rate of degradation obtained for the present study was higher than reported literature which may show the presence of easily digestible food waste, organic/biodegradable content having high rate of degradation. In contrast to the previous studies, despite of higher k value the settlement is slower may be attributed due to the operation condition of experiment [33,170]. As the test was conducted at room temperature, the variation in temperature was due to anaerobic condition developed inside the reactor. The temperature initially raised from 23℃ to 28±2℃ and remained almost constant for 202 days indicating the biodegradation of waste. The monitored biogas generation and temperature variation has been shown in *Figure 8.8* and *Figure 8.9*.

The total settlement (immediate, primary and secondary) in reactors was estimated to be 45.9% after the application of load in reactor at end of 202 days of experiment (*Figure 8.10)*. The experimental analysis revealed that the settlement of waste during the initial stage was higher may be due to nature and heterogeneity of waste, lack of compaction. However, the study carried out by [170] showed the primary settlement of 33.4% and long-term secondary settlement of 25% for raw waste. The obtained results of consolidation from the laboratory experiment has been presented in *Table 8.2*.

Table 8.2: Results of the consolidation analysis.

Parameter	Height of Sample (mm)	Settlement (mm)	Remarks
Initial Height of sample	400	0	-
Height after leachate addition	392.5	7.5	-
Height immediately after application of load (50 kPa)	274.91	117.59	Immediate Settlement
After 48 hours of load application	235.11	39.8	Primary Settlement (U=90%)
Height after 202 days	212.12	22.99	Long term Secondary Settlement

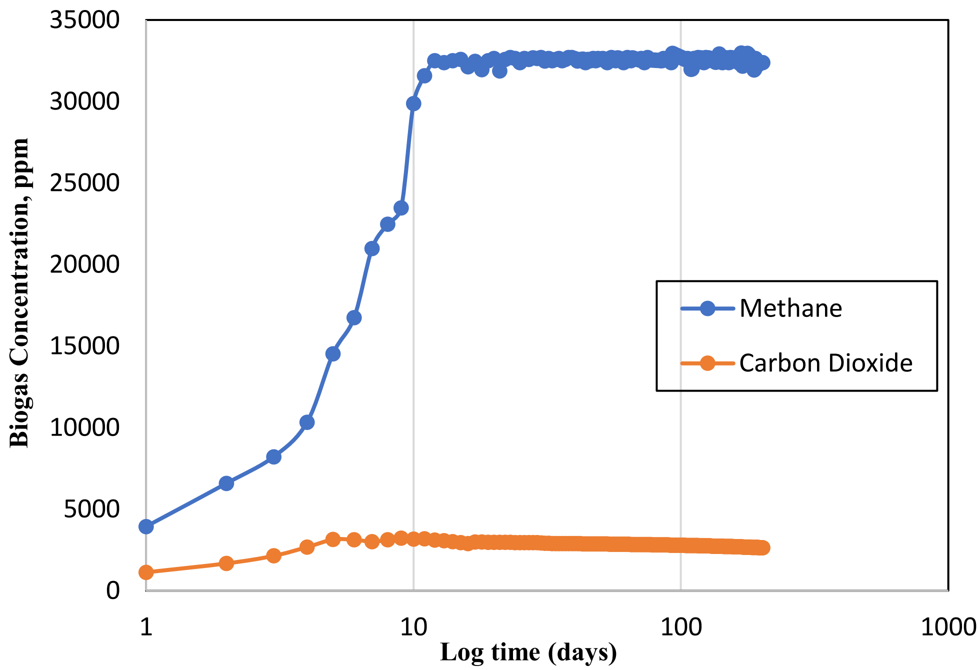


Figure 8.8: Biogas generation in reactor.

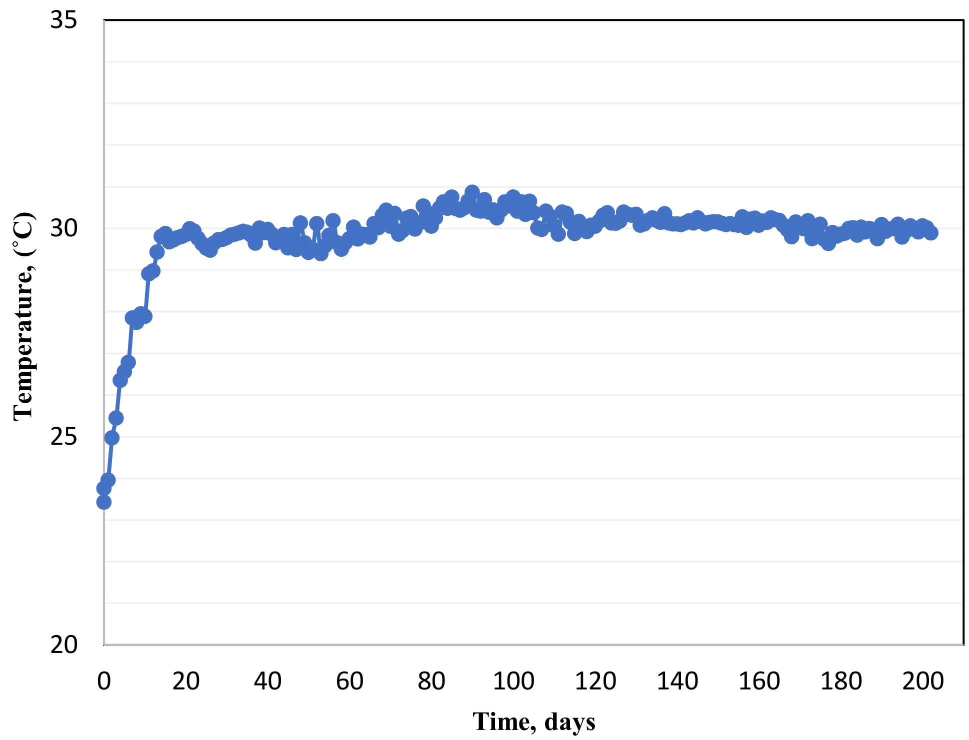


Figure 8.9: Monitored temperature over the duration of experiment.

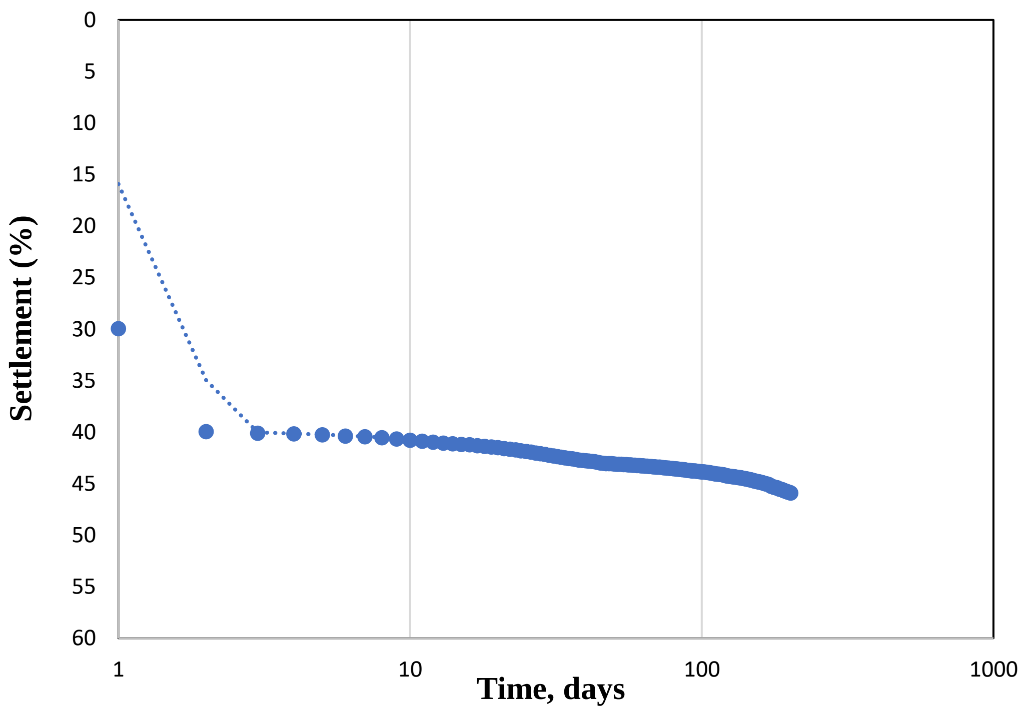


Figure 8.10: Total settlement in reactor at end of 202 days.

8.4.4 Mathematical Modelling for Prediction of Settlement

The obtained results from the experiments were used for approximation of settlement due to biodegradation and mechanical creep depending upon the model developed by [176]. The mathematical model developed thus incorporates the pH, temperature and moisture condition to simulate the field conditions and biodegradation settlement [176]. As reported in the literature [35,165,176,185,189], the favorable conditions for the biodegradation of MSW gives optimum range of pH (5.6 to 8), temperature (34-42℃) and moisture content (4-44%). The spatial and temporal variation in moisture content of waste was observed. Thus, the obtained results from the laboratory experiment were compared with the optimum range selected for the biodegradation.

8.4.4.1 Biodegradation settlement

The biodegradation settlement of MSW landfill of 10 m height was estimated depending upon the variation in moisture content, pH and temperature. The variation in different parameters were observed and settlement attributed to biodegradation was estimated depending upon the actual and predicted conditions of pH of waste, moisture condition and temperature. *Figure 8.11, Figure 8.12* and *Figure 8.13* showed the variation in settlement of waste for actual condition as simulated in laboratory and predicted values of pH, temperature and moisture content.

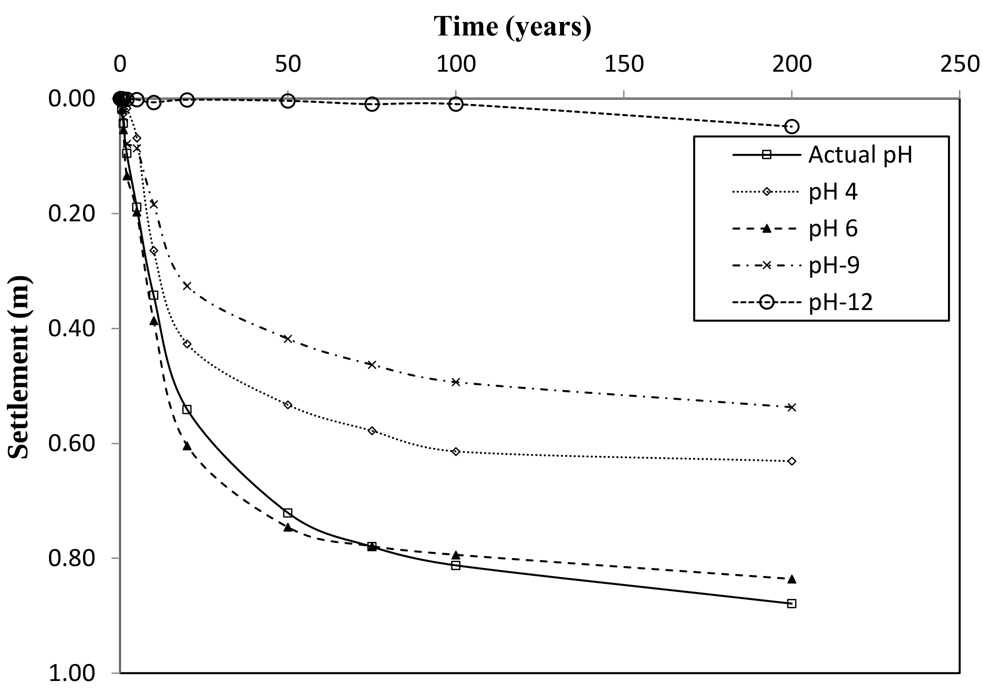


Figure 8.11: Variation in settlement with varying pH.

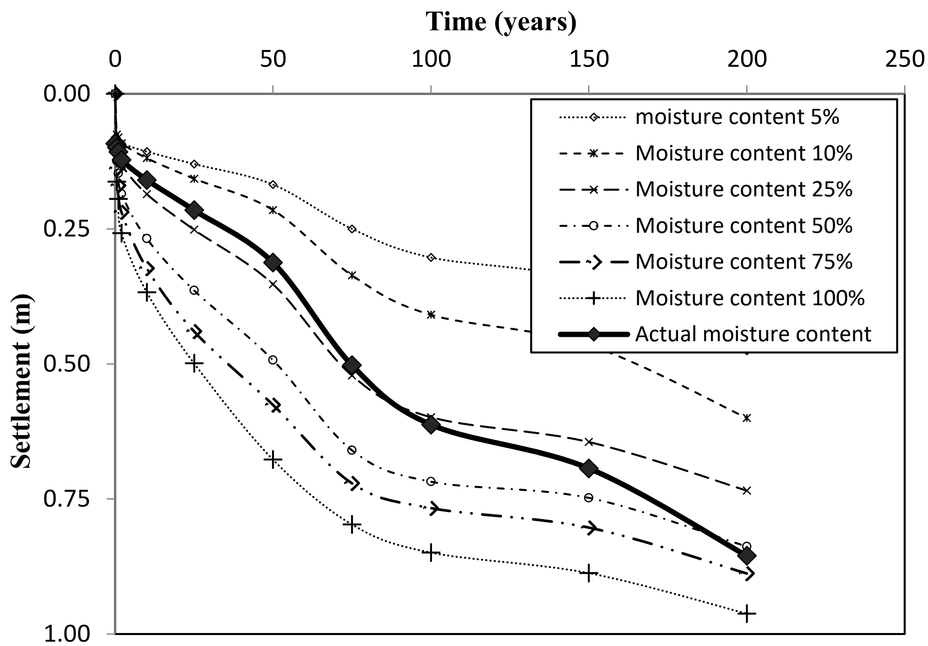


Figure 8.12: Variation in settlement with varying Moisture Content.

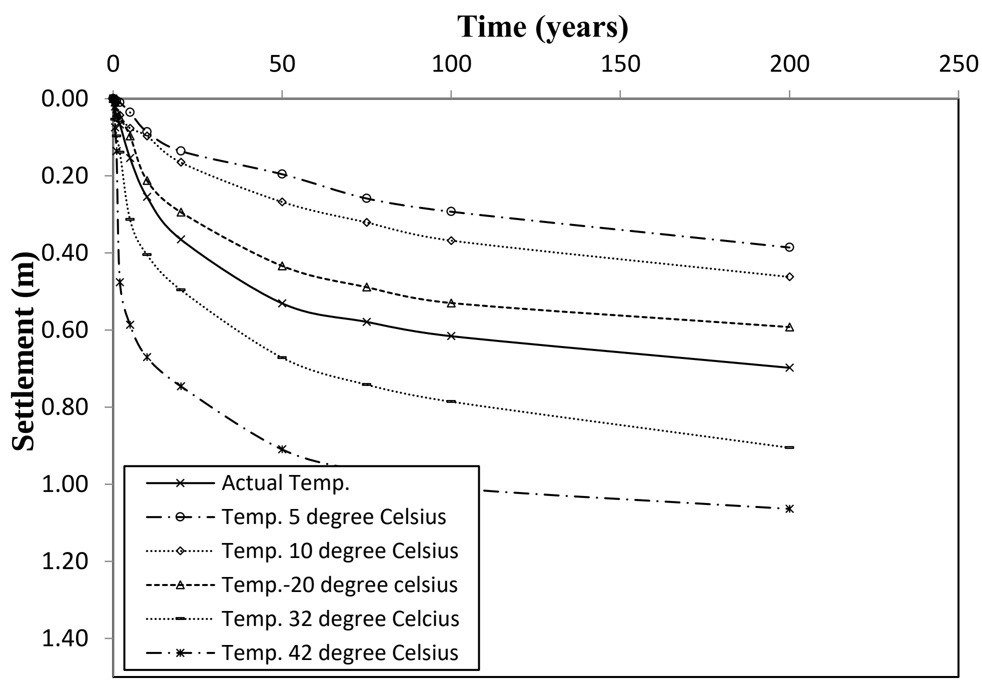


Figure 8.13: Variation in settlement with varying temperature.

The actual temperature in the study area was also considered for predicting the settlement. It was observed that with increase in the temperature the settlement increases. However, the variation in pH of waste showed higher settlement at pH-6 and actual pH of waste sample. It was observed that increase in acidic and alkaline nature of waste reduces the biodegradation and thus reducing the settlement. The moisture plays an important role in biodegradation of waste. The spatial and temporal variation in moisture content in landfill was considered with increasing depth.

The long-term biodegradation settlement in landfill of height 10 m was estimated to be 0.85 m at end of 100 years for obtained biodegradation parameter. However, the predicted range of temperature and moisture content depict that with increase in the temperature and moisture content the settlement in landfill increases about 15-25%. The biodegradation settlement varies from 0.85m to 1.06m at end of 100 years with variation in temperature and moisture content.

8.4.4.2 Mechanical Compression

The coefficient of compressibility lies in range of 0.02 and 0.03 as reported by many researcher [33,108,169,184,189]. The observed mechanical compression for 10 m landfill height was 1.15 m for C= 0.02 and 1.72m for C =0.03 at end of 100 years. It was observed from the results that increase of 0.01 in value results in increase of 0.57m in the settlement. Thus, it was clear that mechanical compression is important for analyzing the settlement of landfill as a very small change in C value results in large settlement variation.

The obtained results from the laboratory analysis showed 5.85% secondary settlement at end of 202 days. The modelled parameters also showed about 6.4% of biodegradation settlement for landfill height of 10m for initial 202 days. The model and laboratory results can be accurately predicted after evaluating the creep induced settlement for the raw waste. The mechanical compression due to overburden of waste was predicted to be 10-18%. Further, the investigation can be done on predicting the settlement depending upon the creep and biodegradation induced settlement by analyzing the settlement behavior of MSW.

Summary

The analysis was done to investigate the effect of long-term biodegradation and settlement of raw waste under anaerobic conditions. The generation of biogas and settlement under the effect of loading was observed over a period of time. The biogas generation in the reactor showed the methanogenesis process in waste having higher concentration of methane. The settlement analysis of waste showed that majority of settlement occurred as immediate compression accounting for 29.9% of initial height of waste in response of loading. The time taken for the completion of primary settlement of waste in reactor was observed to be 48 hours and at end of this period primary settlement of 10.14% was observed in the reactor. The long-term secondary settlement of waste was determined about 5.85%. It was observed from the test results that at end of 202 days the total settlement occurred about 45.9% and still continues due to presence of organic fraction in waste. The field conditions and obtained parameters from the experiment were used to model the settlement. The obtained results showed that the secondary settlement due to biodegradation and creep results about 6.4% settlement for landfill of height about 10m. In comparison with the test result, the measured secondary settlement in laboratory was approximately 5.85%. Temperature, pH and moisture content showed significant variation in settlement. The temperature variation results in increased settlement rate providing favourable condition for growth of micro-organisms. The observed results showed that the settlement increased up to 10-15% with every 10° rise in temperature.

However, the obtained results give an approximation about the secondary settlement based upon model. The settlement attributed to biodegradation and mechanical creep was predicted using model and showed 0.8m and 1.15m settlement respectively after 100 years for 10m height of landfill. The laboratory analysis requires investigation of creep induced settlement in control reactor which is not considered in present study thus need further analysis. Thus, the long-term settlement curve for raw waste can be reproduced with model based upon logarithmic law for creep and kinetic model for biodegradation induced settlement. Therefore, the analysis for settlement in landfill helps in estimating the post closure settlement for designing of landfill final cover system, and also helps in preparing post-closure maintenance and operation plans.

CHAPTER -9

CONCLUSION

9.1 General

The chapter comprises the conclusions derived from the investigated field observations and laboratory analysis.

9.2 Conclusion

- The Municipal Corporations are responsible for the overall management of the MSW which includes the collection of the waste from the households, storage and transportation to final disposal sites. The waste generation in Una district is about 20.4 tons per day with per capita waste generation rate of 0.42 kg. The Una town generates about 6 TPD waste out of which 5.5 TPD is disposed in open dump site. The collection efficiency of waste in the study area is about 80-90% which is quite better than the other cities of the state. However, the storage and transportation facility of the waste is not good because of insufficient number of collection bins and collection vehicles.

- The untrained man power, unavailability of sufficient number of collection bins in the study area leads to littering, unhygienic conditions and odour problem in the city. Lack of resources and funds available for municipalities leads to ineffective waste management system in the area. Also, lower efficiencies of waste management practices are due to inadequate treatment facility, machinery and available transportation. The dumping of waste is being done on open land and no control measures exist to prevent the harmful impact of leachate on soil and groundwater.

- It can be concluded from "Wasteaware" benchmark analysis that the existing waste management practices had *Low/Medium* efficiency. The analysis revealed that collection efficiency in Una indexed as (M/H) as compared to other cities of H.P. where collection efficiency is low. However, the environmental control measures and 3R's lies in Low/Medium index. The score for city from disposal methods and by efficiency of *3R* *method* is classified as 'Low' since no recycling facilities are available for the city and other regions of the state.

- The matrix method for evaluation showed the quantitative parameters 36% was significantly less than the qualitative parameters (40%). The overall classification of the city was in the low categories. However, the weightage of quantitative and qualitative parameter for other states of Himachal Pradesh were 30% and 35% respectively, which also lies in low categories. Therefore, recommendations are suggested for improving existing waste management practices in the study region. The segregation of waste, recycling and recovery of material, installation of waste to energy units and engineered landfill construction for the final disposal of waste may prove helpful in waste management in study area.

- The characterization was done for mixed waste collected from the town for analyzing the nature and composition of waste. The physical characterization of waste was done for three seasons which revealed that waste in the study area is rich in organic content (56%). The study revealed that during summer seasons biodegradable waste fraction is higher and lower during winter season. This is due to high consumption of fruits, vegetables during summer season. The fraction of paper and plastics were found to be 12.2% and 10.3% respectively. Though use of plastic has been banned by the Government of Himachal Pradesh, but Una being a border region to Punjab, no such legislation is present and transit tourists has increased the plastic fraction in town.

- The proximate analysis of waste observed high moisture content in waste (49.9%) for three seasons which is due to higher organic fraction present in waste. The ash content in waste was 24.87% and volatile matter in waste was 22.2%. The ash content in waste was higher due to inert fraction in waste and may be due to burning of waste during summer seasons. The average calorific value for waste was 2263 kcal/kg showed higher value in summer season. Based upon the higher organic fraction in waste, it was suggested that integrated waste treatment practices need to be adopted in collaboration with other cities which would thus provide a better solid waste management system.

- The elemental analysis of waste revealed that presence of carbon content in waste was 32.46% attributed to higher organic fraction in waste. The average concentration of Sulphur and Nitrogen in waste was determined to be 0.11% and 1.44% respectively. The average C/N ratio was determined to be 22.72 which is indicative that the MSW generated is suitable for treatment of organics including composting and energy generation.

- The heavy metal analysis of waste showed that the presence of heavy metals in waste was within permissible limits at the study location which make it suitable for composting. However, Una is emerging as an industrial area of state, thus require future consideration for direct disposal of waste containing harmful chemicals leading to increased concentration of heavy metals.

- The energy content of 2263 kcal/kg of MSW compared with empirical models were found in agreement with the predicted values. The energy content determined using the models showed a correlation of physical composition and ultimate analysis with measured values. The average calorific value of waste is high due to presence of food waste, paper, plastic which makes it suitable for installation of energy recovery and waste to energy units. In this context, recommendations were made for utilizing the energy content of waste by adopting suitable biological or thermal treatment process.

- The effect of degradation on geotechnical properties of waste was observed to increase with age of waste sample. The study showed that the presence of organic fraction is more in fresh waste. However, it decreases with increasing age and degradation of MSW. In fresh waste degree of degradation was absent and it varied between 78.1% to 90% for degraded waste. The study revealed that the degradation of waste increased the inert fraction of waste. The presence of moisture content in waste sample increased with age of waste but did not follow any pattern. With further increase in the age of waste, complete degradation of organic fraction results in decreased moisture content.

- The geotechnical analysis of MSW showed that specific gravity of waste increased with age owing to disintegration of particles into soil like material. The unit weight of fresh waste is less as compared to degraded waste. The degradation results in denser or closer packing of particles which increases the fines in waste and reduces voids, thus increasing the unit weight, shear strength and reducing the hydraulic conductivity of waste. The compressibility of fresh waste was higher than degraded waste and it further decreased with the increasing age and degradation of waste.

- The weak correlation between decomposition and properties of waste was observed due to heterogeneity and complex nature of waste. The degradation of waste results in settlement, affecting the structural stability of landfill. Therefore, the geotechnical analysis is important for assessing the changes due to degradation of waste in order to minimize the catastrophic failure in landfill.

- Degradation of waste over the time changes the mechanical properties thereby causing stability and serviceability concern. Thus, the stability of slopes of landfill was analyzed by determining the shear behavior of municipal solid waste. The effect of composition, density and degradation has influence on shear strength of waste which changes with time, degradation and compression. The observed anisotropic nature of waste may have been due to the presence of fiber content and complex orientation of fiber in waste. The variation in shear strength of sample was observed with increasing horizontal displacement.

- The cohesion (c) of waste sample for fresh to degraded sample varied between 30.8 kPa to 35.5 kPa and angle of internal friction (φ) ranges between 16° to 24°. The results depicted that increase in friction angle is due to presence of inert fraction which results due to disintegration, physico-chemical biodegradation of particle with age and depth. However, the variation in shear parameters for waste samples of different age is not significant and mobilized shear strength showed that cohesion and friction angle vary from 31.9 kPa – 33.2 kPa and 19°-21° respectively, for different depths. For the observed results, the best fit failure envelops for degraded sample and gives a cohesion value of 32.6 kPa and angle of friction of 21°.

- The assessment of geochemical properties of dump soil was done using SEM and EDX analysis to study the morphology and elemental composition of soil sample collected from dump site and for natural soil. The analysis showed that the main fraction is silica in both dump soil and natural soil as the soil sample is mainly sand. The elemental analysis of soil sample showed presence of sodium, magnesium, calcium in dump soil compared to natural soil. The higher fraction of oxygen and silica was found in dump soil. The geotechnical analysis of soil showed lower value of specific gravity than natural soil owing to the presence of waste fraction in soil. The gradation of soil sample depicts that soil was mainly poorly graded sand.

- The MDD, permeability and CBR of dump soil showed lesser values than natural soil. The higher value of cohesion and lower friction angle was observed in dump soil than natural soil which may be due to the presence of finer fraction of degraded waste. The leachate produced from waste migrates into soil thereby inducing bond between particle and decreasing the void ratio. Thus, permeability of soil sample gets reduced in comparison to natural soil.

- The geotechnical analysis revealed that soil in dump site has minor effect of waste dumping. However, with time and increasing waste generation, properties of soil will get affected due to un-engineered and unmanaged dumping of waste. The migration of leachate generated from waste into the soil will not only deteriorate the soil properties but also pollute the groundwater and adjoining water resources. Thus, construction of engineered landfill is recommended to prevent the migration of leachate and soil contamination.

- The long-term settlement is mainly associated with volume reduction due to biodegradation of organic fraction of waste and physical creep compression. It was observed from the study that biodegradation of waste gets affected by moisture, temperature, composition, pH and microbes present in the waste. At initial stage immediate settlement of 29.9% occurred during application of load on the waste sample. The high rate of settlement observed can be accounted to poor compaction, higher organic/biodegradable fraction present in the waste. The effect of loading observed after 48 hours was considered as time for completion of primary settlement. The consolidation results obtained from the experiment were determined and primary settlement of 10.14% was observed in the reactor. The test was carried out at normal temperature conditions and settlement of 40.04% was recorded at end of primary settlement. This settlement rate was higher attribute to heterogeneity of waste sample and compaction variation.

- The long-term secondary settlement in waste sample occurs due to biodegradation and creep induced settlement. The total secondary settlement of 5.85% was observed for 202 days after completion of primary settlement of waste sample and continues for a longer period of time. The concentration of biogas generation in the reactor was approximately 32000 ppm of CH_4 and 2900 ppm of CO_2. The degradation constant for the waste was recorded to be 0.477 day^{-1}. The total settlement in the reactor was estimated to be 45.9% at end of 202 days of testing period.

- The settlement of waste sample was predicted using a model depending upon the obtained parameters from the laboratory analysis. However, the effect of waste degradation and compression on sample depict settlement of 6.4% and 10-18% respectively in landfill over a period of 202 days. The obtained results revealed that settlement of waste in landfill is highly dependent on the organic fraction of waste, temperature, moisture, pH and rate of degradation of waste. The mechanical compression of waste sample depicts that the overburden pressure and increasing unit weight of waste are important parameters for evaluating the settlement.

- The observed parameters from the study predicted the long-term settlement of the waste and analyzed the post closure settlement in landfill. The waste degradation due to combine effect of biodegradation and mechanical compression poses the structural and operational problems in landfill. In this context, settlement analysis helps in determining waste degradation rate and rate of settlement of landfill. The estimation of settlement will be useful for designing different landfill components and also maintaining the structural integrity of the landfill.

9.3 Limitation of Work

The study was conducted to determine the stability of MSW landfill depending upon the characteristics of waste. The stability of landfill gets affected due to heterogenous properties of waste and degradation. Thus, the present study analyzed the mechanical and biodegradation settlement of MSW under anaerobic condition at end of 202 days. However, the present work could not specify the creep settlement of waste under non bioactive condition.

9.4 Future Scope of Work

Depending upon the current work, following suggestions for future work can be made:

1. Assessment of environmental impact of open dumping in Himachal Pradesh.
2. The sensitivity analysis of degradation constant and gas generation needs to be conducted for estimating the settlement.
3. Further investigation needs to be done for analysing the characteristic of leachate produced, identifying the presence of potentially harmful organic substances which may affect the degradability of MSW.
4. Development of numerical model for understanding the landfill processes of waste degradation, leachate quality and gas production for predicting the long-term settlement.

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