MUNICIPAL SOLID WASTE CHARACTERIZATION AND ANALYSIS IN HIMACHAL PRADESH

Thesis submitted in fulfilment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

By

ANCHAL SHARMA
Enrollment No. 166604

Department of Civil Engineering

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, DISTRICT SOLAN, H.P., INDIA

Month August, Year 2019

MUNICIPAL SOLID WASTE CHARACTERIZATION AND ANALYSIS IN HIMACHAL PRADESH

Thesis submitted in fulfilment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

By

ANCHAL SHARMA
Enrollment No. 166604

Department of Civil Engineering

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, DISTRICT SOLAN, H.P., INDIA

Month August, Year 2019

Dedicated to

My

Beloved Parents

CONTENTS

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY
(Established by H.P. State Legislature Vide Act no. 14 of 2002)
P.O. Waknaghat, Teh. Kandaghat, Distt. Solan – 173234 (H.P.) INDIA
Website: www.juit.ac.in
Phone No. (91)- 01792-25799(30 Lines).
Fax: (91)-01792-245362

DECLARATION BY THE SCHOLAR

I hereby declare that the work contained in the Ph.D. thesis entitled **"Municipal solid waste characterization and analysis in Himachal Pradesh** submitted at **Jaypee University of Information Technology at Waknaghat, India** is an authentic record of my work carried out under the supervision of **Dr. Rajiv Ganguly & Prof. (Dr.) Ashok Kumar Gupta**. I have not submitted this work elsewhere for any other degree or diploma. I am fully responsible for the content of my Ph.D. thesis.

Anchal Sharma
Enrollment No.: 166604
Department of Civil Engineering
Jaypee University of Information Technology,
Waknaghat, Solan, HP-173234

Date:

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY
(Established by H.P. State Legislature Vide Act no. 14 of 2002)
P.O. Waknaghat, Teh. Kandaghat, Distt. Solan – 173234 (H.P.) INDIA
Website: www.juit.ac.in
Phone No. (91)- 01792-25799(30 Lines).
Fax: (91)-01792-245362

SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled **"Municipal solid waste characterization and analysis in Himachal Pradesh",** submitted by **Anchal Sharma** at **Jaypee University of Information Technology at Waknaghat, 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.

(Dr. Rajiv Ganguly)
Associate Professor

Department of Civil Engineering
Jaypee University of Information
Technology, Waknaghat
Himachal Pradesh, India

(Prof. Ashok Kumar Gupta)
Head of Department

Department of Civil Engineering
Jaypee University of Information
Technology, Waknaghat
Himachal Pradesh, India

ACKNOWLEDGEMENT

First of all, I owe and dedicate everything to the **Almighty GOD** for the strength, wisdom and perseverance that he had bestowed upon me during this research project, and indeed, throughout my life. A major research project like this can never achieved by the only person's effort. The contribution of number of people in different aspects have made this happen. I extend my sincere gratitude to everyone who stood by me during the entire course of my Ph.D. work.

I would like to express my special appreciations and sincere thanks to my supervisors **Dr. Rajiv Ganguly & Prof. Ashok Kumar Gupta** for sharing their truthful and illuminating views on a number of issues related to my topic of research, encouraging my research and allowing me to grow as a research scientist. They provided inspiring guidance for successful completion of my research work. I rate this as my privilege to work under their supervision. Your advice on both researches as well as on my career has been priceless. I have been blessed with your continuous moral support, invaluable inputs and suggestions when I needed the most.

I am grateful to all the members of technical and non-technical staff specially **Mr. Jaswinder Singh** for their valuable contributions. I extend my gratitude to Mr. Vivek, Lab technician (NIT Hamirpur) for helping me in experimental work.

I am also thankful to **Prof. S.P. Ghrera, Prof. Ashish Kumar and Dr. Saurabh Rawat** for their guidance and valuable suggestions throughout my research work. I wish to convey my sincere thanks to all the faculty members of Department of Civil Engineering, for their help and guidance at the various stages of this study.

I would also like to extend my thanks to the municipal authorities of respective study regions (Solan, Mandi, Sundernagar and Baddi) for providing valuable data to accomplish the research work.

Life is miserable without parents and beloved ones. I can't forget the pain that my parents and parent in laws have taken throughout my research work. It is only because of their support, love and blessings that I could overcome all frustrations and failures. Last but not least, I would like to thank my **father, mother, grandmother, father in law, mother in law, all family members and relatives** for their unconditional support, both financially and emotionally throughout my Ph.D. They always stood by my decision and provided me all the resources even in difficult times to help me achieve my goals and realize my dreams. I am highly thankful to my beloved sister **Urvashi Sharma** and brothers **Piyush Sharma &**

Priyanshu Sharma *for their moral support.*

At the end, I would like to express great appreciations to my beloved husband ***Akshay Sharma****, for having patience in these working years and for encouraging and inspiring me when things do not work properly. Without his strength and profound support, I would not be here and this work would not be accomplished. His prayers for me were what sustained me so far. Thank you for being a better half of my life. I am also thankful to my brother in law* ***Aayush Sharma*** *for providing me moral support always.*

Besides, I can never ever forget my colleagues and friends ***Pankaj Sharma, Love Sharma, Prachi Vasistha, Sonia Sharma, Charu Bhardwaj*** *who have helped me in numerous ways. I cherish the years spent in the Department of Civil Engineering Department, JUIT, Waknaghat.*

I am indebted to all those people who have made this dissertation possible and because of whom this research experience and wonderful journey shall remain everlasting and cherished forever in my sweet memories.

All may not be mentioned, but no one is forgotten.

Thanks to all of you! Anchal Sharma

ABSTRACT

Open dumping of municipal solid waste (MSW) is one of the most problematic issues for the safety of environment including air, groundwater and soil pollution. In this regard, it is important to have proper consideration for reducing the effect of open dumping on environment as well as on human health. In this context, the current study focuses on evaluating, characterizing of MSW, characterization of compost, geotechnical assessment of contaminated soil, characterization of leachate and groundwater in four selected regions of Solan, Mandi, Sundernagar and Baddi in Himachal Pradesh. The study aims to provide detailed baseline information of the existing MSW management and the possible effects of the waste on soil and groundwater. An LCA approach with different scenarios involving combination of treatment systems was also conducted to determine the best possible treatment options. Finally, an engineered landfill was designed for the waste generated.

The evaluation of the existing waste management practises in the four regions of Himachal Pradesh was evaluated using the "Wasteaware" benchmark indicators and a matrix method was used to quantify the results. The overall results of Matrix method revealed 32% efficiency for Solan and Baddi sites and 36% efficiency for Sundernagar and Mandi sites. The matrix method also reported that overall management of MSW at our study location categorized under low index whereas Chandigarh city lies under the category of Low/Medium index.

The characterization analysis of the study regions revealed that the waste of Himachal Pradesh is rich in organic fraction being followed by the paper waste. The average value of organic waste over the three seasons at the study locations were observed to be 55.35% for Solan, 54.20 % for Mandi, 51.87% for Sundernagar and 50.40% for Baddi respectively. Based on the characterization results a detailed discussion on the possible WTE techniques has been presented.

One of the possible utilizations of MSW generated is composting and the quality of compost was assessed over a period of 60 days with compost samples being analysed on 20th day, 40th day and 60th day of the composting process. The quality of the compost generated is generally classified using FI and CI and using these indexing parameters the classification of the compost at the two sites of Solan and Mandi were Class D and A respectively. A discussion on discontinued and existing practises of compost in HP has also been presented.

The evaluation of geotechnical properties of contaminated soil and its comparative analysis with the natural soil in selected regions of H.P has been assessed. All the dumpsites soil

showed less specific gravity comparative to the natural soil due to the presence of mix waste in the subsoil. Interestingly, the compaction characteristics and CBR value showed less maximum dry density at optimum moisture content and lesser CBR value as compared to the natural soil. Apart from this, the lesser value of cohesion and coefficient of internal friction in the affected soil sample displayed lesser shear strength comparative to the natural soil. Apart from this, the geochemical assessment of dumpsite soil has also been performed with SEM and EDS to comprehend the morphology and elemental analysis of the soil adopted from dumpsite locations

Further, the study also evaluates the characteristics of the leachate and its potential impacts on the ground water reserves of the study locations. The leachate and ground water samples were analyzed for various physico-chemical and heavy metal characterization and analysis. The characterization study of leachate revealed that most of the parameters of leachate samples exceeded their permissible standards for all the four regions in Himachal Pradesh. However, the physico-chemical characterization of the groundwater samples observed that maximum of the parameters was found within the permissible limits except alkalinity, electrical conductivity and total dissolved solids.

Further, the study also evaluates the pollution potential of leachate produced from the study locations. The average LPI over the three seasons were determined to be 17, 17, 14 and 22 for Solan, Mandi, Sundernagar and Baddi respectively. It is observed from the results that the samples exceeded the permissible range of the leachate disposal standards of 7.38 (standard value) thereby needing suitable treatment before its disposal. LPI based on characterization of parameters for a single monitoring campaign in April 2018 showed a reduced LPI value of 15indicated a slight reduction in the pollution potential of the leachate due to reduced MSW loading conditions on the dumpsite.

Similar to above, the groundwater was evaluated using indexing method wherein three methods were used. These included OWQI, BIS 10500 and NSF WQI. The groundwater was classified as *poor quality* in Solan, Mandi and Sundernagar and *very poor quality* in Baddi using OWQI technique.

As per BIS 10500 method of WQI, it was determined that. Solan, Mandi, Sundernagar and Baddi are of fair category within the vicinity of 1Km distance from the dumpsite and after 2.5 Km distance the water quality of Solan, Sundernagar and Mandi shows good quality but Baddi town shows fair quality of water. However, up to the distance of 4 Km from the domain of the dumpsites, Solan, Mandi and Baddi dumpsites exhibit good quality of water

whereas Sundernagar town shows excellent water quality. As per National Sanitation Foundation method the study areas including Solan, Mandi and Sundernagar lies under good category range whereas Baddi region lies under fair category within the domain of 1Km distance from the dumpsite due to the involvement of industrial and pharmaceutical activities in the town.

The present study evaluates the impacts of various waste management alternative scenarios for selected locations using life cycle assessment methodology. The methodology comprised of five different scenarios of waste management along with an existing baseline scenario. In this context, the impact categories analyzed were global warming potential, acidification potential, eutrophication potential and human toxicity potential. The results indicated that among all the proposed scenarios, the scenario with the combination of material recovery facility, composting and sanitary engineered landfill has the minimum impacts on the environment and the baseline scenario showed maximum environmental impacts due to the open dumping of municipal solid waste. The present study proposed the designing of engineered landfill system includes liner system, leachate collection system, gas collection system so that the open dumps can be avoided so that the municipal solid waste management system can be improved.

Keywords: Municipal Solid Waste, “Wasteaware” Benchmark Indicators, Landfill Leachate, Groundwater, Compost, Life cycle assessment, Landfills.

LIST OF ABBREVIATIONS AND ACRONYMS

AAA	Atomic Absorption Spectroscopy
AD	Anaerobic Digestion
AP	Acidification Potential
BAU	Business as usual
BIS	Bureau of Indian Standards
BRICS	Brazil, Russia, India, China and South Africa
C&D Waste	Construction and Demolition waste
COM	Composting
CPCB	Central Pollution Control Board
EP	Eutrophication Potential
EPA	Environmental Protection Agency Federal Register Rule
GC-MS	Gas Chromatography Mass Spectroscopy
GHG	Green House Gas
GOI	Government of India
GWP	Global Warming Potential
HCA	Hierarchical Cluster Analysis
HTP	Human Toxicity Potential
INC	Incineration
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
LPI	Leachate Pollution Index
MSW	Municipal Solid Waste

OD	Open Dumping
OWQI	Oregon Water Quality Index
PCA	Principal Component Analysis
RDF	Refuse Derived Fuel
SLF	Sanitary Landfill
SWM	Solid Waste Management
VFA	Volatile Fatty Acids
WQI	Water Pollution Index
WHO	World Health Organization

LIST OF SYMBOLS

3R's method	Reduce, Reuse and Recycle
Ca^{+2}	Calcium
F-	Fluoride
H	Hydrogen
HNO3	Nitric Acid
Kg	Kilograms
Kcal/kg	Kilo calorie per kilogram
L	Low
M	Medium
L/M	Low/Medium
M/H	Medium/High
LPI	Leachate Pollution Index
Mg2+	Magnesium
m3	Cubic Meter
N	Nitrogen
N	Number of leachate pollutant variables
Ppm	Parts per million
Pi	Sub-index value of the i^{th} Leachate Pollutant Variable
q	Quality Variable
Qc	Characteristic value of q
Wi	Weight for the i^{th} Pollutant Variable

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

The increment in population, economic development speedily intensifying urbanization and altered living standards of public have led to amplified production of municipal solid waste in India [1, 2]. It is observed that the waste volume is estimated to magnify from 64-72 million tons at present to 125 million tons by 2031 [3]. In general, MSW is the compilation of domestic leftover and marketable trash that is produced from the public [4]. In general, municipal solid waste encompasses paper and paper board waste, food waste, textile waste, moderately degradable includes wood and completely non-degradable products including leather, rubber, metal, glass as well as electronic items [5, 6]. The concept of waste has been reported in Figure 1.1.

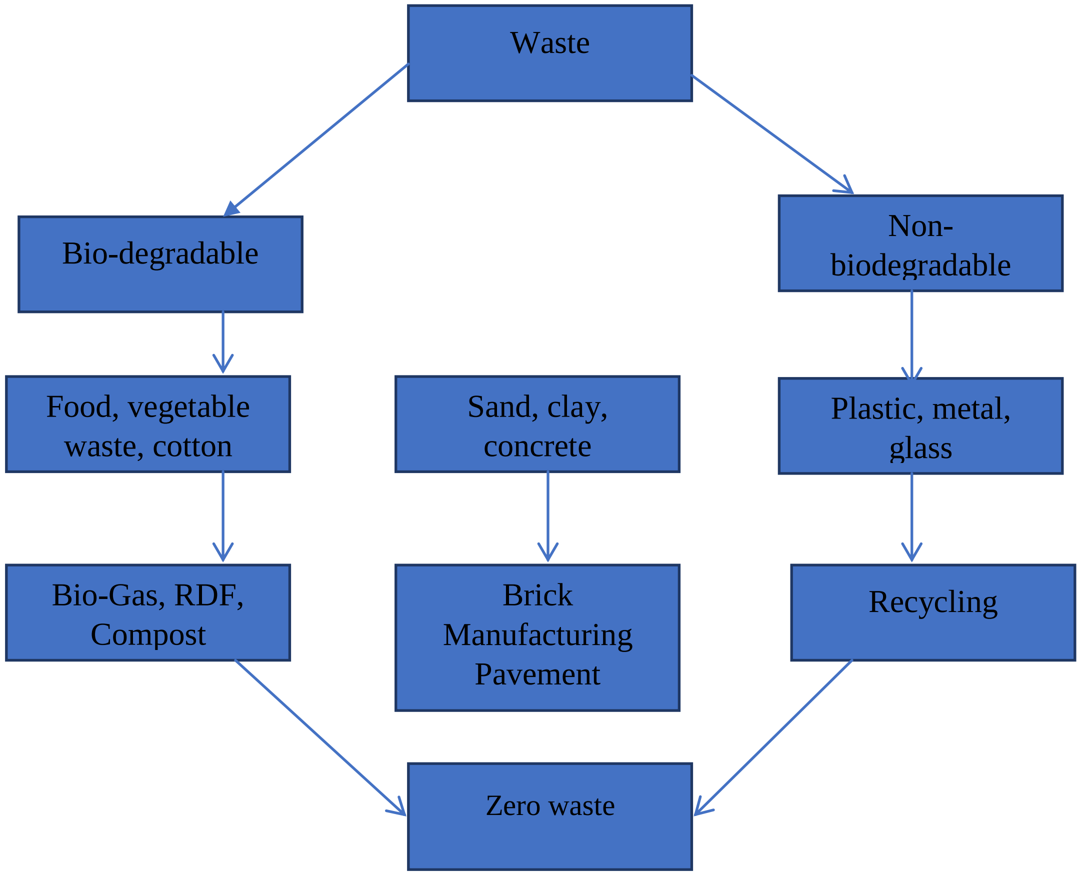


Figure 1.1: Concept of waste.

The continuous negligent disposal of municipal solid waste practiced on a daily basis leads to underprivileged life style and lack of environmental consciousness [7]. Moreover, the improper waste collection procedures coupled with insufficient waste transportation facilities are primarily accountable for the accretion of MSW everywhere within the city premises [3]. The unscientific controlling and the disposal of MSW is the cause of different complications associated with pollution of environment and the well-being and health issues of the public. For an enhanced and healthier lifestyle as well as sustainable development of the city, it becomes mandatory to comprehend the characterization of waste, proper collection and storage schemes, waste transportation systems and final dumping for proficient and effectual management of the MSW.

1.2 Municipal solid waste: Global scenario

It is observed from the literature survey that the global population was 7.4 billion in 2016 and utmost of the public were settled in developing countries [8]. The municipal solid waste generation rate is approximately 1.3 billion tons per year at global level and is projected to intensify to 4.3 billion by 2025. Particularly, in Asia, the generation of MSW varies in the range of 103-760 tons per day (TPD) in urban regions. It has been proclaimed in study that USA has the utmost generation of waste on the basis of per person per day with a generation rate of 2.6 kg per day [8]. Similarly, the waste generation on the basis of per capita in Germany, France and UK are 2.2 kg per day, 1.9 kg per day and 1.8 kg per day respectively. In the context of developed countries in Asia, China and Japan have more waste generation on per person per day basis at 1.72 kg per day and 1.02 kg per day [9, 10]. Additionally, in context of BRICS country, the per capita generation of municipal solid waste has been observed comparatively lesser than the other developed countries but is still expressively more than developing country like India. Furthermost, per capita waste generation of 0.96 kg per day is observed in Russia whereas Brazil has 1.04 kg per day per capita production rate. The compositions of MSW in different countries have been reported in Figure 1.2.

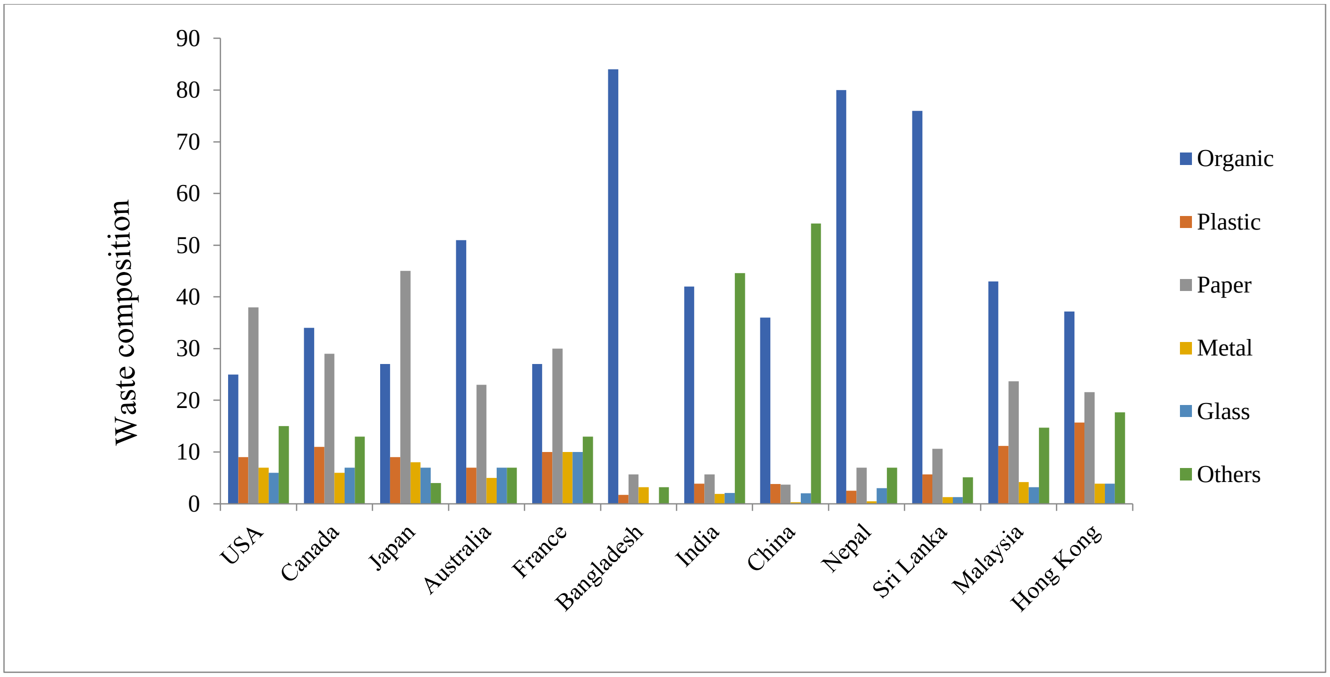


Figure 1.2: Compositions of MSW in different countries

1.3 Municipal Solid waste: Indian Scenario

India is the second most populated nation in the world and consequently the uncontrolled growth of urban areas has led to scarcity in infrastructural services including water supply, waste water treatment facilities, municipal solid waste management etc. The escalating population has resulted in a massive pressure on the existing health-care services, leading to huge amounts of hospital waste and infectious waste generation. The waste production rate in India varied in the range of 0.22 kg/day to 0.63 kg/day [11]. As per the report produced by TERI, out of the total waste generated in India, 89,334 tons per day (TPD) of MSW was gathered and 15,881 tons per day (TPD) was reused [11, 12].

According to the World Bank estimates, a study conducted revealed out that the projected MSW production rate in India is 0.9 kg per person per day by the year 2020 [9] whereas the increment in the production rate of MSW is expected to be around 1.3% on an annual basis in India [13, 14]. However, the collection efficacy of MSW in India is reported as 60% due to the lack of suitable waste transportation vehicles [11, 15].

The issue of MSW management is becoming critical due to the factors including inhabitant's growth, development pursuit, changes in the economic scenarios and apparently improvement in the living standards as discussed earlier [11, 16]. Inadequate assortment of MSW, lack of man power, lack of advancements in treatment technologies, lack of technical persons etc. are the various factors for underprivileged MSW strategy. Apart from this, in most of the times, municipal authorities are having financial crisis and find difficulty to survive with the demands due to continuously and devastating growing population and urbanization. However, the limited revenues assigned by the govt. for the municipal bodies make them harsh equipped to deliver higher cost for the collection, storage, treatment and proper disposal of waste. Hence, the poor organization of MSW leads to open and illegal dumping of municipal solid waste at low lying spaces at the outer edges of the towns. MSW management problem is likely expands to even higher extent and hence it is requisite to resolve this issue [11, 12].

Moreover, it is estimated that approximately 65.2% of the urban population is settled in Class I and metro cities [17]. This high rate of population in urban locations is responsible for highly increased production of municipal solid waste in such areas. The betterment in the living standard of people in urban zones of the country has left the municipalities and government authorities in a difficult position to manage the quantity of MSW generated [18]. In particular, it has been noticed that many of the urban zones in the country suffer from the dearth of different types MSW management problems, despite a huge amount of finances is allocated by the government for proper handling of municipal solid waste.

Furthermost, it is also observed that management of MSW is one of the most provoking issues in metro cities or class 1 towns due to huge production of municipal solid waste particularly in urban locations as discussed above. However, class II and class III cities produce an average of 3991 MT/day of municipal solid waste [19]. The survey conducted by the CPCB through NEERI reported that the estimated waste generation is estimated 39,031 tons per day in 58 cities [20, 21]. This increment in waste generation is due to the endlessly population growth in Indian cities. Characterization analysis of the waste showed rich proportions of biodegradable and organic waste in class-II and class-III towns. The chief problems in MSW management in such categories of cities include adequate collection, transportation and disposal of waste in villages because very less proportion of waste produced on the daily basis [22]. The schematic representation for MSW production and inhabitants from the year 2001 to 2051 has been reported in Figure1.3 and the waste generation on the basis of per capita has been reported in Figure 1.4.

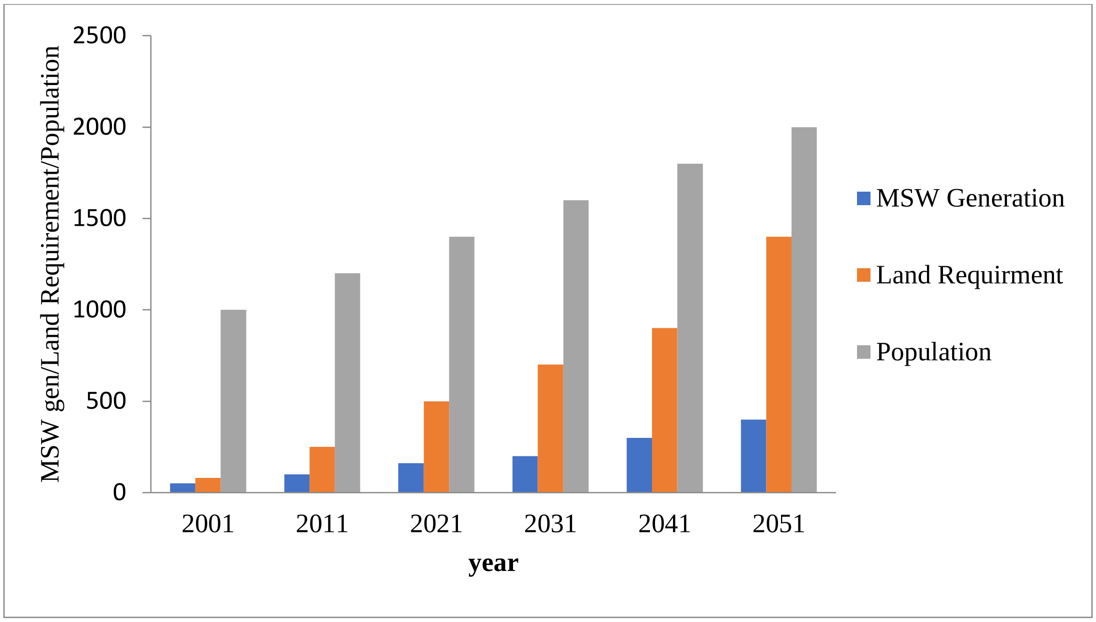


Figure 1.3: Data forecasting scheme for MSW production and inhabitants from 2001 to2051.

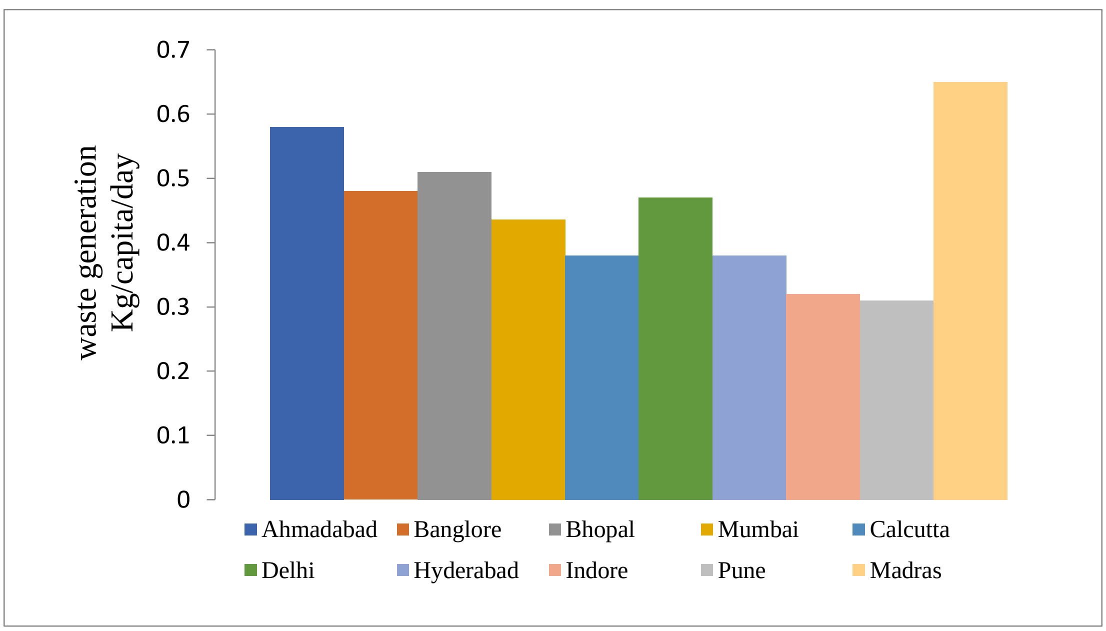


Figure 1.4: Waste generation on the basis of per capita in Indian cities [20].

Increased MSW generation has possible health impacts [11]. Moreover, in the practise of open dumping, MSW can also degrade the quality of groundwater due to leachate percolation in the deep aquifers [23]. Leachate is the dark brown liquid that is generated when the rainfall comes in the contact of the municipal solid waste. To overcome this problem, effectual MSW management must be applied in the Indian cities and towns for controlling leachate formation [17]. Some of the Indian states generating higher proportion of MSW include West Bengal, Tamil Nadu, Uttar Pradesh, Kerala and Delhi [24]. The indicators of waste generation in different Indian states have been reported in Table 1.1 and generation of MSW in Indian cities has been reported in Figure 1.5.

Table 1.1: Statistics of MSW generated in different states in India [22]

States	Municipal solid waste 2000	Municipal solid waste 2009-2011	Collected TPD 2009-2011	Treated TPD 2009-2011	Growth (%)
A. Pradesh	4377	11501	10656	3657	163
Assam	286	1149	809	77.0	305
Delhi	4001	7388	6892	1938	88.0
Gujrat	-	7379	6744	873	-
Karnataka	3279	6502	2103	2114	111
Kerala	1299	8338	1739	4.0	542
M. Pradesh	2685	4501	2701	977	68.0
Meghalaya	35.0	285	238	100	713
Orissa	655	2239	1837	33	242
Punjab	1266	2794	-	-	121
Rajasthan	1966	5037	-	-	156
Tamil Nadu	5403	12504	11626	603	131
Uttar Pradesh	5960	11585	10563	-	94.0
West Bengal	4621	12557	5054	607	172

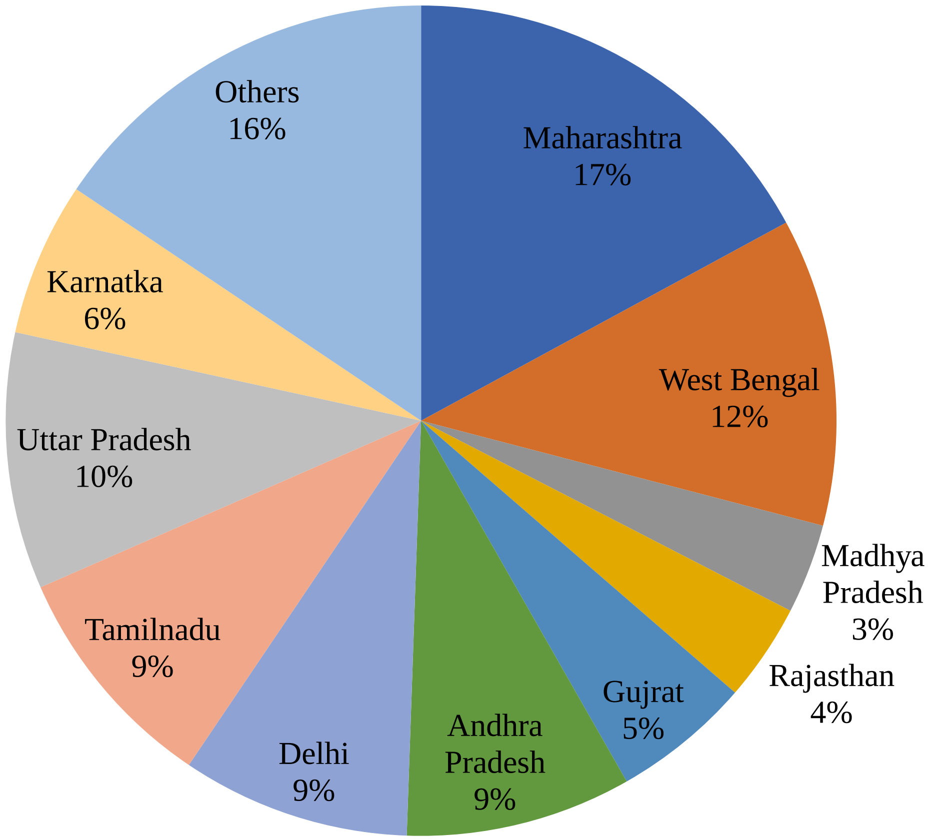


Figure 1.5: Generation of MSW in Indian cities [24]

The lack of awareness of the potential implications of exceeds MSW generation and its non-treatment amongst local population is a significant issue [11]. In the above context, open dumping as well as improper management of waste in both urban and rural areas is of immediate concern. The Urban local bodies (ULB's) do not have suitable action schemes for implementation and depiction of municipal solid waste [24]. The estimated waste generation rate in projected years in India has been summarized in Figure 1.6 and the waste generation on the basis of per capita in projected years in India has been summarized in Figure 1.7 [20].

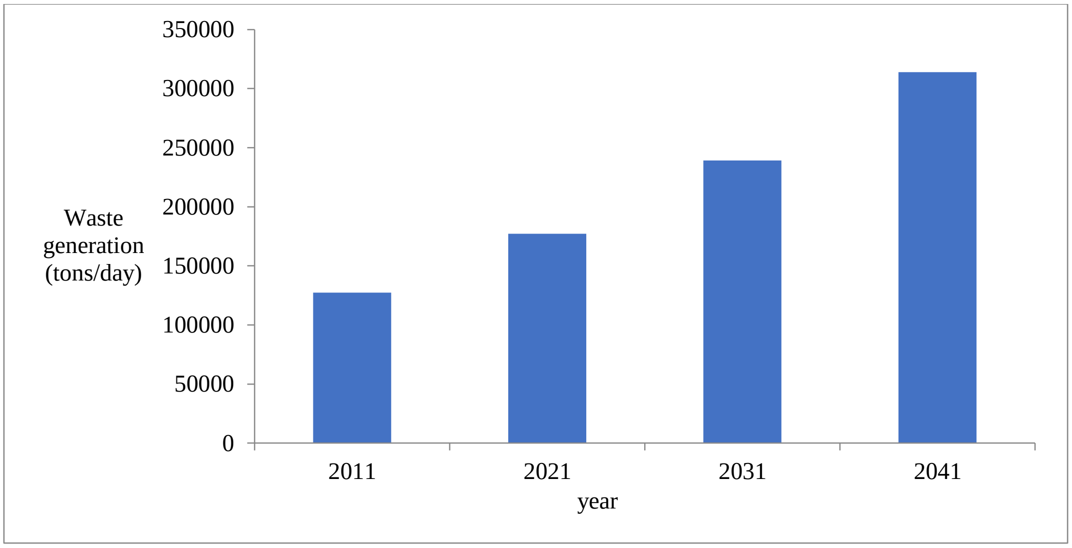


Figure 1.6: Predictable waste production rate in projected years in India [11]

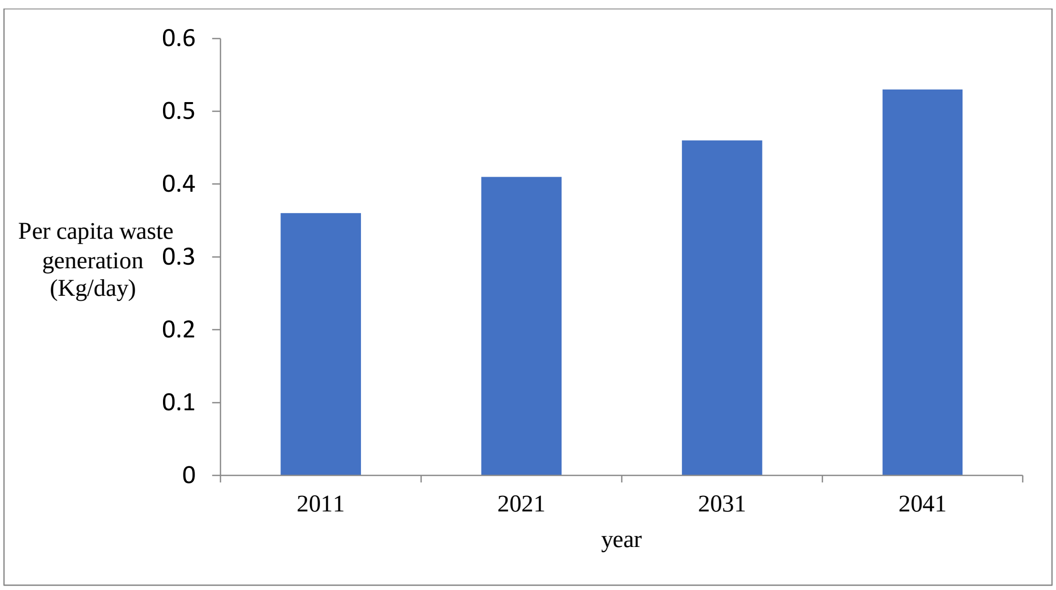


Figure 1.7: Predictable per capita waste production rate in projected years in India [11]

The physical composition of MSW in Indian cities have been presented in Figure 1.8 which indicated that the Indian cities are rich in biodegradable fraction of waste being followed by construction and demolition waste whereas glass and metal have attained minimum fraction of waste out of total waste production.

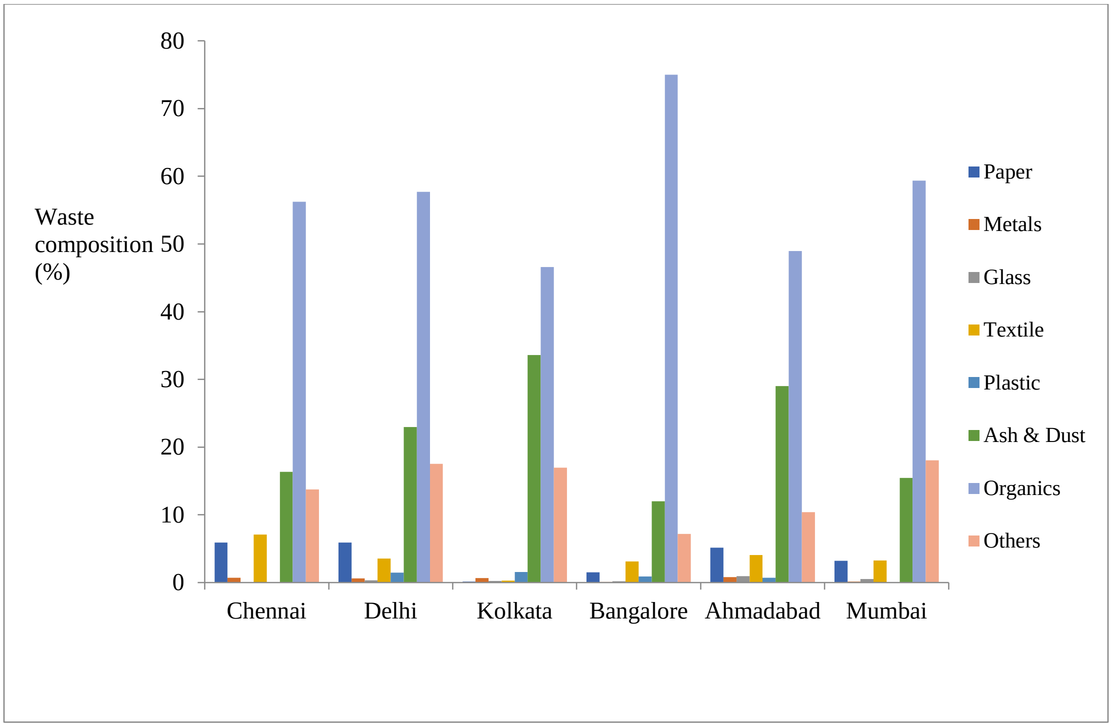


Figure 1.8: Composition of MSW in different Indian cities [11, 24]

Furthermore, in the above context, MSW characterization is the mandatory issue for the eminent MSW management because it may help in choosing suitable and compatible technological alternatives for the processing and usage of waste. The composition of MSW is broadly classified into three categories including organics, inorganics and inert materials. MSW in Indian cities consists most of biodegradable waste (51%), recyclables (17.5%) and inert material (31%) [3]. The chemical characterisation of waste has been summarized in Table 1.2 respectively.

Table 1.2: Typical Chemical characteristics of MSW [3]

Population (in million)	Nitrogen (%)	Phosphorous (%)	Potassium (%)	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

1.4 MSW framework in India

The framework of MSW attempts to deliver an inclusive appraisal of the MSW management system. The management of MSW compiles handling and dealing actions accompanying with collection process, transportation, handling and segregation and ultimate dumping of waste in environment friendly manner.

1.4.1 Collection of MSW: The rules of MSW management recommends the collection of waste at domestic level by using various approaches including doorway collection as well as from municipal containers to exclude scattering and enhance the quality of waste collection strategy. In this context, the main objective of effectual waste management during the collection process is the encouragement of waste segregation at source [3]. Further, separate collection provisions of agriculture and horticulture wastes, construction and demolishing (C&D) waste alongside with the MSW should be encouraged [25]. It is observed that the conflicts associated to the collection of MSW are the inadequacy of alertness and nonexistence of substantial manpower for door way collection facilities [26]. The collection efficiency of municipal solid waste in Indian cities has been reported in Figure 1.9 respectively.

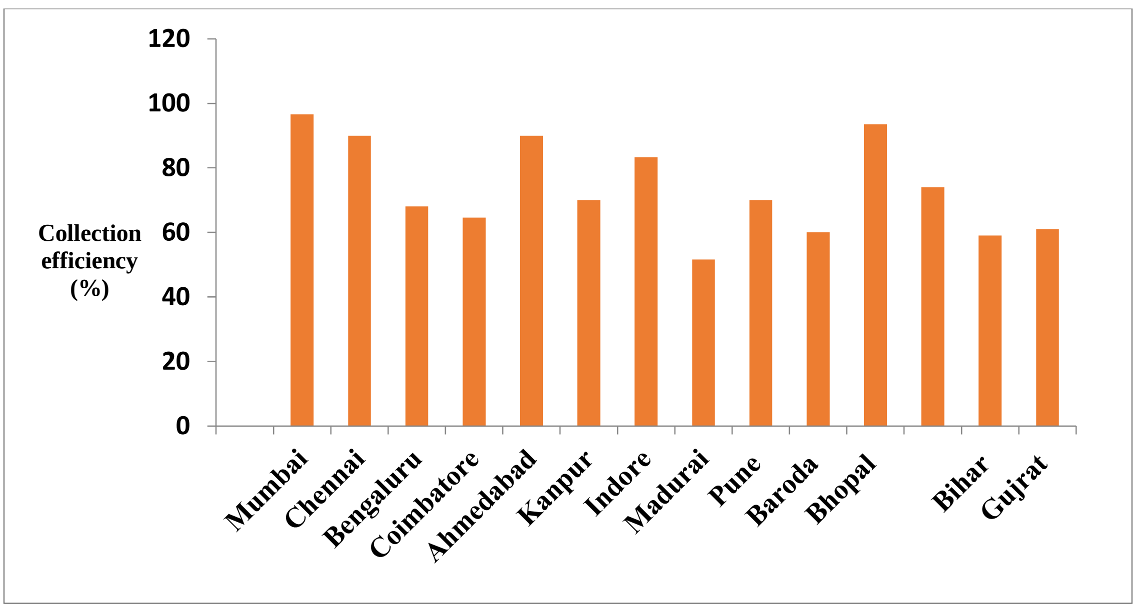


Figure 1.9: Collection efficiencies of Indian states [24]

1.4.2 Waste storage and transportation: According to MSW management rules (MSWM 2000), the municipal corporation should organize secondary storage facilities for the generated municipal solid waste. In this context, it is obligatory to transfer the municipal solid waste from secondary storage points to disposal sites at regular interval of time [27, 28]. Additionally, another substantial aspect that subsidises to the problem of MSW in Indian scenario is the lack of transportation facilities and worn out vehicles or vehicles with less efficiency. Improper planning united with speedy growth of population and urbanization assists to add jamming in streets, and consequently, the waste collection vehicles cannot reach most of the places, hence letting obscenity to build up with the time [22]. Lack of budgetary funds and financial crisis consequences the inadequate or no transportation vehicles for the disposal of waste. Apart from this, municipal solid waste should be enclosed during transportation to avoid the spillage and leaking of waste in the atmosphere.

1.4.3 Waste treatment: According to MSWM rules 2000, biodegradable or organic waste is to be treated by composting, vermi-composting, anaerobic digestion etc. for alleviating and treating of the waste. According to waste composition, incineration process with or without energy recovery may also be advised [29]. It is observed that more prominent prerequisites should be put down to the separation and assortment of waste at door step [30]. Segregation of recyclable material from mixed waste proves beneficial and hence there should be awareness among inhabitants regarding the importance of waste separation at the source only [31]. Apart from this, rather than considering the MSW modestly as waste remainder to be thrown away, it must be renowned as resource recovery materials for the energy, electricity generation and compost reliant upon the techno-economic sustainability [3].

1.4.4 Disposal of waste: 'Open dumping' or 'Illegal burning' of MSW are one of the main issues in the pathway of ineffective waste management strategy particularly in India [32]. In general, the above said methods of waste disposal are constant sources of detrimental gases, toxic substances like leachate. It is estimated that more than 70 percent of MSW gathered is disposed illegally at unscientific dumping zones by the municipal authorities that leads to health issues and environmental degradation [33]. Apart from this, lack of available land for the disposal of waste particularly in bigger cities and towns is of concern. The treatment of municipal solid waste based on Indian scenario has been summarized in Figure1.10 whereas the disposal efficiency of municipal solid waste based on Indian scenario has been summarized in Figure 1.11respectively.

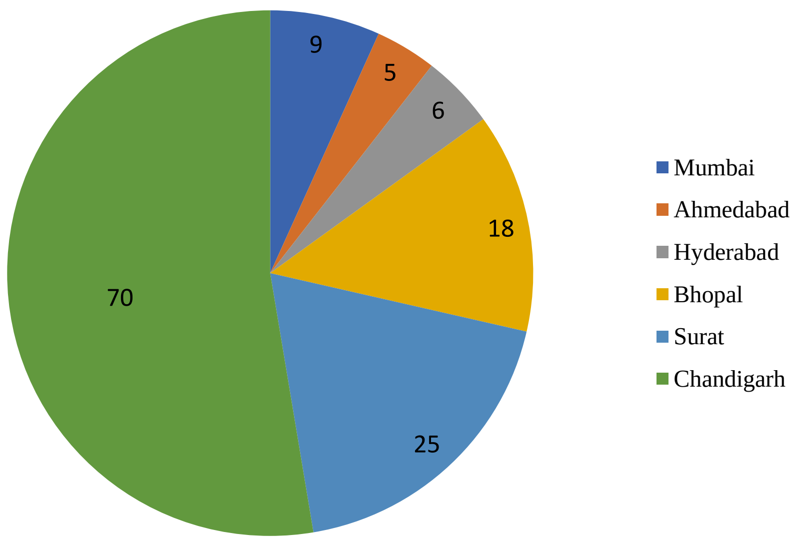


Figure 1.10: Treatment of MSW in different Indian cities

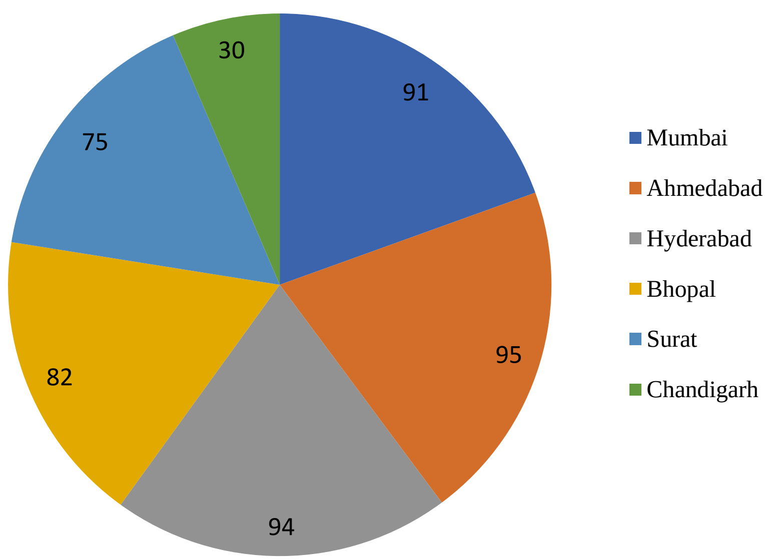


Figure 1.11: Treatment of MSW in different Indian cities

1.5 Impacts of Solid Waste on Environment

The increased rate of waste generation in urban areas is troublesome for disposal of waste as it leads to poor aesthetic appearance and is a potential environmental and human health hazards particularly for developing countries [34, 35, 36].The unscientific disposal methods are most common in India and it is observed from the literature survey that approximately about 90% of the MSW produced in India is directly lying off as open dumps illegally. The disposal of MSW is a severe threat and problematic issue because it can cause to rise in air pollutants if burning and if dumped illegally and non-engineered manner, it can cause environmental pollution includes soil and groundwater contamination in the areas nearby open dumps. This is predominantly because MSW comprises of large quantity of lethal and contaminated chemicals and in contact with moisture leads to leachate production which has the potential to contaminate surrounding environment [33, 34]. Leachate is dark brown liquid release when rainfall comes in contact with the solid waste in landfill and pull out contaminants into the liquid phase [32].

Leachate primarily consists of carbon, nitrogen, manganese and many more chemicals including solvents, organic and inorganic salts [24]. Further, the leachate generated is a mixture of harmful chemicals consisting of both organic (BOD, COD), inorganics (presence of different cations and anions), heavy metals (cadmium, lead, nickel, chromium, zinc etc.) and other refractory chemicals [25]. These constituents vary in proportion depending on the waste characteristics at the dumpsite, site hydrology and volume of rainfall experienced at the dumpsite [37, 38]. Moreover, the characteristics of leachate are affected by the age of the dumping yards as well as the amount of stabilized waste exists on the dumpsite [24]. In practice, for those landfill sites which are in operation for less than five years have pH values of leachate varying from 4 to 6.5 and are acidic in nature due generation of carboxylic acid [34] while older or matured landfills have pH varying between 8 to 8.5 and are more alkaline in nature due to generation of methane. One of the main causes of open dumping of waste is emission of landfill gases that are accountable for climate changes. The problem is further compounded as opening dumping of solid waste is the most common form of disposal due to minimum costs involved.

In the nutshell, lack of effective and economical waste treating practices for final abandoning of municipal solid waste is the matter of severe concern.

1.6 Waste management Policies prevalent in India

The management of MSW in India is governed by organization and supervision of Ministry of Environment and Forests and Climate Change, Ministry of Urban Development, National Environmental Engineering Research Institute, Central pollution control board (CPCB) and State Pollution Control Boards (SPCBs).

The rules relevant to MSWM in India have been reported below [20]:

Hazardous Waste rules (1989, revised in January 2003, August 2010): This includes the compilation of management and treatment of lethal waste.

Biomedical Waste rules (1998): This includes the compilation of management and handling of waste that is produced from hospitals.

Municipal Solid Waste rules (2000): These are the rules pertinent for municipal solid waste and employed by various urban local bodies (ULB's).

The Batteries rules (2001): The guidelines are employed for stake-holders accompanying with the production, handling, exploitation and recycle of various components of MSW.

Plastic Waste rules (2009): The rules compile the final dumping of plastic waste in a scientific manner.

Electronic waste management rules (2011): The guidelines are the rules employed to the stake holders accompanying with the handling, consuming, treating, and reuse of electronic-related waste items.

1.7 Need of the study

MSW management is one of the most neglectful and inattentive aspect in India's environment. There is lack of awareness among public for the effectual management of MSW in India. The scenario of municipal solid waste management has been fluctuating endlessly since last years. Only few or negligible volume of MSW produced is disposed of during proper treatment procedures in Indian context. Inadequate management of MSW in India exists due to various reasons including lack of definite data on generation, improper knowledge of characterization of waste and lack of resource allocations to collection, transportation and disposal of waste as well. The major difficulties in MSW management include lack of waste segregation, lack of transportation vehicles, open and illegal waste dumping, inadequate waste treatment technologies and financial scarcity in municipalities.

Hence, in this aspect, the present study comprehends review of municipal solid waste based on global and Indian scenarios. This helps to intricate the present status of MSW and to ascertain such issues of MSW management. It is clear from the literature survey that MSW treatment and disposal systems as well as their environmental effects are not enumerated. Hence, the study highlights current status of MSW management at four distinct locations in Himachal Pradesh, characterization of MSW, effect of leachate on soil and groundwater, life cycle assessment of MSW and hence recommends the remedial measures to improve the current waste management.

1.8 Objectives of the Research Work

The objectives of the present study compile:

- Assessment of current MSW management in Himachal Pradesh using Wasteaware technique and matrix method.
- Characterization and energy potential of MSW in Himachal Pradesh.
- Spectral Characterization and assessment of municipal solid waste compost by indexing method.
- Evaluation of geotechnical properties of soil being affected by open dumping of MSW.
- Determination of 'Water Quality Index' (WQI) and 'Leachate Pollution Index' (LPI) for evaluating the quality of leachate and groundwater.
- To make a Life cycle assessment of solid waste management in Himachal Pradesh.
- Designing of engineered landfill system for the disposal of municipal solid waste.

1.9 Thesis Outline

The first chapter of the thesis withdraws a brief overview of current waste management system comprised of production, collection, storage and ultimate disposal practices in India. Apart from this, the chapter also highlights the environmental impacts due to open dumps and non-engineered landfill systems for the dumping of MSW. Further, the chapter also highlights the outline of several steps taken by Government of India for the effectual waste management system. The chapter is the preliminary chapter and also outlines the need of the study and the objectives of the research work carried out.

The second chapter present a comprehensive literature review including related studies carried out in Indian as well as global context to observe the significances of MSW dumping yards on the environment. In particular, this chapter presents important facts of the research carried out earlier in the context of proposed research objectives.

The third chapter deal with an overview of the current MSWM practices at the selected study locations (Solan, Mandi, Sundernagar, Baddi) in Himachal Pradesh using 'wasteaware' benchmark indicators for categorizing the efficiency of the current system. Additionally, a matrix method has been employed for the inter-comparison of existing efficiencies of MSW management at the study locations in Himachal Pradesh. Further, some recommendations have been provided for improved waste management practises at these locations.

The fourth chapter focuses on the comprehensive characterization of MSW, energy and methane potential of municipal solid waste generated at four study locations over three different seasons (summer, rainy and winter) to eliminate any biasness due to variations in population or temperature and also suggests some suitable WTE techniques based on the characterization results.

The fifth chapter deal with the evaluation of physical and chemical characterization of compost that is produced from the waste of dumpsites in two study regions including Solan and Mandi in Himachal Pradesh. The spectroscopic characterization of compost has been done to examine the nutrient concentration and change in structural behaviour during the overall process of composting. Scanning Electron Microscopy (SEM) and element detection through (EDS) methods are utilized to examine the physical changes of the compost during different phases of MSW degradation from two study regions including Solan and Mandi. Apart from this, two different techniques of indexing have been applied including '*Fertility Index*' and '*Clean Index*' to evaluate the quality of compost generated from the waste of dumpsites.

The sixth chapter deals with the evaluation of geotechnical properties of soil within the proximity of dumping sites of four study regions and inter-comparison with the natural soil outside the periphery of dumping sites to check of pollution potential of non-engineered disposal of waste on soil. However, the geochemical assessment of dumpsite as well as virgin soil has been performed with two techniques including scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) to comprehend the morphology and element configuration of soil around the dump site.

The seventh chapter presents the impact of the leachate that is produced from the dumping sites on the groundwater in four study regions. The aim of the current study was to assess the quality of leachate in three different seasons. The leachate samples were examined for different physical, chemical as well as for heavy metals analysis. The chapter also compiles leachate pollution index (LPI) and heavy metal analysis (HPI) of leachate that is utilized to determine the pollution potential from the dump sites of study regions in Himachal Pradesh.

The chapter eight compiles the evaluation of overall effect of leachate on the ground water quality that is within the proximity of dumpsites. In this context, the ground water samples were collected from the nearby areas of dumpsite and hence examined for different physical, chemical and heavy metal analysis based on the seasonal variation. Further, the chapter also deals with presenting water quality indexing by various techniques including Oregon water quality index method (OWQI), Bureau of Indian standard (BIS 10500) and National sanitation foundation water quality index (NSFWQI)from all the four study regions of Himachal Pradesh. It helps to generate a score that comforts to examine the quality of ground water. Further, Multivariate analysis including Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) has been also done to comprehend the inter-relationships of the attained results.

The chapter ninth presents the Life Cycle Assessment (LCA) of MSW management in four study regions of Himachal Pradesh. In this context, four different scenarios of waste management are examined and performed including with baseline scenario. The scenarios include waste management preferences; including landfilling, incineration, composting, material recovery facility, reduced derived fuel etc. whereas the impact categories analyzed are named as global warming, eutrophication, acidification and human toxicity. Furthermost, sensitivity analysis was also performed that assists to categorize sensitive parameters and evaluates whether a slight alteration in an input parameter would persuade enormous variation in the respective impact category.

The chapter tenth presents the designing of landfill system in hilly terrain i.e. Himachal Pradesh. The designing of landfill includes liner system, leachate assemblage facility, gas collection facility and the introduction of cover system. In this context, it is observed that one of the major issues that are facing the municipal authorities is the effectual and enduring dumping of solid waste. Rather, there are deficits in the current waste management strategy i.e. segregation of waste is taking place to a lesser extent only whereas the abandoned dumping of waste from the valley side is being conceded in continuous manner. However, it is apparent that respective municipality's requisite to go for effectual and resourceful waste dumping practices which will become a streamline for the conservation of resources and environment safety as well. The appropriate scientifically dumping of MSW is not only undeniably obligatory in the point of view of public health but it has an enormous prospective for rescue of resources. In the current scenario, there is dearth of the provision of engineered landfill system in the study zones. In the nutshell, it is mandatory to overwhelm this problematic issue and hence design of sanitary landfill in Himachal Pradesh is required.

The chapter eleventh confers the comprehensive summary of the results and conclusions that are the resultant from the overall study. However, some recommendations for the upgrading of current waste management practices in Himachal Pradesh with the remarks of the future scope of the research work.

CHAPTER 2

LITERATURE REVIEW

The chapter compiles the brief review of literature of the entire study that will provide the facts and information for inventive and effectual designing of waste management system. It helps in providing the knowledge base and vision into the theoretical and conceptual background of the study.

India is one of the developing countries of the world having 16 % of the world population [39]. The survey revealed that class I cities having the waste production (population >I lakh) of 32,460 tons per day [40].

As many of the population starts shifting from rural to urban areas consequently the quantity of MSW increase and become one of the most important incidental products in today's lifestyle. In this regard, waste management is very requisite for effectual management. The waste generation varies considerably in different countries according to income level, awareness towards sanitation among public etc. However, the major reason of the waste generation varied according to the economic growth.

Expeditious growth in industrialization, urbanization and population outbreak in Indian cities precedence to the shifting of rural people to cities and towns which cause enhanced production of MSW. The increment in the continuous production of municipal solid waste shows a positive correlation with the economic growth of people due to the improved living standard of people [7, 41].

The management of municipal solid waste is the fundamental assistance that is imparted by Indian Govt. The municipal solid waste generation and characterization phenomena may different for every state, district, towns and even various regions of identical towns [6, 42]. In India, it is estimated that the increment rate of solid waste generation is 1 to 1.5 % on an annual basis. The population expansion in India between 1911 and 2011 has been reported in Table 2.1 on the basis of CPCB report, 2012.

Table 2.1: Population growth in India [20]

Sr. No.	Census year	Population (Crores)	Decadal growth (%)	Average annual exponential rate (%)	Progression rate (%)
1.	1911	252.0	13.7	0.56	5.76
2.	1921	251.3	-0.8	-0.03	5.42
3.	1931	278.9	27.6	1.04	17.02
4.	1941	318.6	39.7	1.33	33.67
5.	1951	361.6	42.4	1.25	51.47
6.	1961	439.2	78.1	1.96	84.25
7.	1971	548.1	108.9	2.20	129.94
8.	1981	683.3	135.1	2.22	186.64
9.	1991	846.4	163.1	2.16	255.05
10.	2001	1028.7	182.3	1.97	331.52
11.	2011	1210.2	181.4	1.64	407.62

Presently, 1, 27,577 tons of MSW is produced because of the different household, commercial & institutional activities [20]. The waste generation on per capita basis in India has been reported in Table 2.2.

Table 2.2: Per capita waste generation rate in India [43]

Sr. No.	Population size	Waste generation (Kg/capita/day)
1.	>2000000	0.43
2.	1000000-2000000	0.39
3.	50000-1000000	0.38
4.	100000-500000	0.39
5.	<100000	0.36

The drastically increment in the amount of municipal solid waste proves exceedingly threatening to the life of human beings [43, 44]. Moreover, it can also degrade the quality of groundwater when the leachate percolates in the deep aquifers [24]. Leachate is the dark brown liquid that is generates when the rainfall comes in the contact of the municipal solid waste. To defeat this problematic issue, effectual SWM must be appliances in the Indian cities and towns for the efficient MSW management [45].

Still there is very less awareness among public regarding waste management and its grading system in India [4]. The matter of MSW management is being delicate because of diverse factors such as development pursuit, changes in the economic scenarios and obviously improvement in the standards of living as discussed earlier [4]. Inadequate collection of municipal solid waste, lack of transportation vehicles, lack of man power, lack of advancements in treatment technologies, lack of technical persons, financial deficit etc. are the various factors for underprivileged MSW management strategy. The management of solid waste management is a condemnatory element towards the sustainable blooming, source segregation, collection, storage and dumping facility of municipal solid waste to curtail the inauspicious effects on environment [44]. The adequate and efficient waste management system is the leading matter of concern particularly for developing countries like India [4]. Further, municipal solid waste in Indian cities consists most of biodegradable waste (51%), recyclables (17.5%) and inert material (31%) [46]. Characterization of solid waste varies [47] however collection efficiency of MSW is estimated as 72% around most of the Indian cities [48]. The composition of municipal solid waste in India based on regional variation has been reported in Table 2.3.

Table 2.3: Composition of MSW in India based on Regional variation [46]

Cities	MSW (tons/day)	Compostable (%)	Recyclable (%)	Inert (%)	Moisture (%)	Calorific value (Kcal/kg)
Metro cities	51,403	50.87	16.77	32.83	49	1523
Others	2,725	51.96	19.78	28.09	49	2084
North India	382	50.43	21.45	28.13	47	2341
East India	6836	52.39	16.79	30.89	49	1623
South India	2349	53.42	17.05	27.52	52	1827
West India	385	50.42	21.48	28.18	47	2341
Overall urbanization	130000	51.39	17.50	31.24	46	1751

In this context, municipal solid waste characterization is the obligatory issue to best management of MSW because it may help in choosing suitable and compatible technological alternatives for the treating of waste. The composition of municipal solid waste is broadly classified into three categories including organics, inorganics and inert materials [47, 48].

Further, prevailing studies showed that approximately 80% of the waste generated in India is disposed directly in an open land [1]. Even after ten years of execution of the MSW (Management and Handling) Rules, open dumping of waste is still in practice in India. In this context, Solid waste Studies [49, 7] is considered as the third highest pollution however, the air pollution still leads followed by water pollution. The waste management has become a substantial environmental issue due to the drastic increment in waste generation annually and in the present scenario of waste management, it become impossible to find solutions and appropriate actions to the foremost problem that is being faced by the system [50-52].

The inclusive approach is mandatory for the improvement of different policies, rules and regulations to accomplish an ecological waste management system. In this regard, an approach has been utilized i.e. "Wasteaware benchmark indicators" to analyse the prevailing waste management system and for recognizing the downsides in existing waste management system.

The "Wasteaware" benchmark indicator is an effective technique that analyses the existing MSW management practices as well as recycling activities in a town, city and municipality in a reliable manner. The basic aim of 'Wasteaware' benchmark indicators is to permits a town evaluate its performance of waste management facilities and to provide information for the enhancement in the services.

The "Wasteaware" benchmark indicators compiles three components in which first component depicts the background information of the city, second component depicts the Public health collection services, quality of collection, treatment and controlled disposal methods, 3R's facility whereas the third component measures the governance factors.

Apart from this, the literature survey revealed that open dumps are there in practice in Indian cities for the dumping of MSW that may causes serious health issues as well as degraded the quality of environment [53]. Open dumps are the main contributors to breeds and provide natural habitat for the disease-causing vectors. However, the major disadvantage observed by the practice of open dumping is contamination to aquifers because of the percolation of leachate deep into the groundwater [54]. In this regard, it is mandatory to have understanding about the nature of waste and physico-chemical characterization of waste that is disposed in the dumping sites. However, the impact of environmental contamination is not only the problem exists in India but it does affect the whole world. The capacity to develop an efficient and sustainable MSW management programs in developing countries like India has been restricted by lack of data regarding volume, generation and waste characterization [27, 55, 56].

Solid waste generation rates as well as characterization of waste may differ from country to country and depend on the economic condition, industrial activities as well as waste management guidelines and regulation. The characterization and quantification are major aspects of ecological solid waste management system [57].

Sharholy et al. analysed the study based on physical and chemical characterization of MSW in different cities of India. The results analysis reported that the composition of MSW mainly comprised of large biodegradable content (40–60%), inert waste (30–40%), paper waste (3–6%) and plastic, glass and metals (< 1%). However, the C/N ratio varied in the range of20-30 and the calorific value varied in the range of 800 and 1000 kcal/kg [7, 58].

The analysis results reported by Sethi et al. reported that the municipal solid waste is rich in biodegradable and inert content. The physical composition for paper was reported as 3.2$\pm$1.85, 6.5$\pm$1.98 for plastic, 0.2$\pm$0.19 for glass, 0.5$\pm$1.20 for rubber, 28$\pm$8.9 for inert and 0.1$\pm$0.64. Moisture content analysis of waste was 30.3 ($\pm$5.6), 20.4 ($\pm$4.45) for volatile matter, 42.0 ($\pm$7.05), 7.5 ($\pm$4.34) for fixed carbon, 28.2 % by dry weight for carbon was 28.2 ($\pm$3.28), 3.77 ($\pm$2.25) for Hydrogen and 0.63 ($\pm$0.65) for sulphur [42].

Further, studies carried out by [43, 44] in 59 Indian cities reported that the average waste composition varied in the range of 30–45% for biodegradable content, 6–10% for recyclables while the rest of waste is inert material in nature [45-58].

The study conducted by Katiyar et al. in regard of characterization of MSW produced in Bhopal, India. The poorly designed municipal bins, unsuitable and inappropriate locations of the dust bins, torn out collection vehicles, inappropriate man power for the collection of waste as well as inadequate waste treatment, processing and disposal facilities were chief problems has been observed in the city, Bhopal. Further, the waste of Bhopal has higher MC and lesser calorific value that helps to promote aerobic composting [59]. However, the large quantity of plastic material in the municipal solid waste promotes the waste recovery goals [60].

Municipal solid waste may be processed in many ways i.e. composted, incinerated, vermi-compost, landfilled etc. In this context, open dumping of the waste is quite popular all over the world [61]. Apart from recycling of waste, methods such as composting are also being followed up for accomplishing the sustainable waste management. One of the main criteria for making compost is that the waste utilized should be well segregated to making compost. However, the compost prepared from the mixed waste results into the polluted compost with organic, inorganic and heavy metal contaminations [46]. However, most of the energy recovery methods including reduced derived fuel have also been intended and designed that may proves better alternative to the illegal disposal of waste in open land [61].

It was perceived from the literature that the nature of municipal solid waste is heterogeneous in characterization, climate and seasonal variations and based on the economic status of the community concerned [62]. It was perceived from the literature that the MSW in most of the Indian cities, waste is rich in organic content. In this context, some of the researches have been carried out to assess the characteristics of the compost. The variation in nutrient concentration and structural changes in the entire composting process has been assessed by the analysis of various physico-chemical parameters and spectroscopic characterization [63]. The study revealed the structural changes at 20, 40 and 60 days of composting samples. However, the results indicated that pH of the samples was tends to neutral from alkaline behaviour towards the last day i.e. 60th day of degradation phenomena [64].

Another study conducted on MSW compost in Jabalpur, India. The study was carried out to evaluate the practicability of compost of source segregated materials of produced MSW in low, middle- and high-income regions of Jabalpur city. However, the results of MSW investigation revealed the occurrence of large percentage of biodegradable content, moisture content and suitable C/N ratio in the waste of Jabalpur region and found appropriate for the composting phenomena [65].

The study conducted on the evaluation of heavy metal in MSW dumpsite in Mysore, India. The research was an attempt to analyses the trace metal contents present in fine fraction of municipal solid waste collected from different piles of Mysore city. Heavy metals concentration of these samples was compared with the standards prescribed limits of Central Pollution Control Board for compost [66].

Another study conducted on the evaluation of MSW compost quality by means of index method generated in various cities of India [67]. The results revealed that almost all the samples showed normal range of pH as well as electrical conductivity. However, as well as macro nutrients such as nitrogen and phosphorus in municipal solid waste composts are observed in lesser amount in comparison to the composts produced from the rural wastes.

The study carried out on the characterization of municipal solid waste in Indian Cities - A Case Study [68]. The results clearly indicated that the biodegradable fraction of waste in MSW of Indian cities has been found approximately 50% that could be converted into compost. However, the aerobic composting by windrow method is proved as the best and economical way of waste processing. The study carried out by Rawat et al. reported that the samples have also been assessed for heavy metals analysis. The samples have been found with larger content of heavy metals as compared to the permissible limits for its application as compost.

The study carried out by Mutairi et al. revealed that MSW collected from city in Arabian is appropriate for the compositing phenomena because of the occurrence of higher organic matter, suitable macronutrients including N, P and K content as well as appropriate C/N ratio in the waste [69]. However, processing of organic content of municipal solid waste for degradation process stabilizes the putrescible biodegradable matter rapidly produces a soil improvement thereby improving the fertility of the soil, texture of soil as well as water holding capacity, hence reduce the volume of municipal solid waste in Riyadh city. Further, the produced MSW compost that has been utilized to modify the soil characteristics also serve as an environmentally safe and economically sound method of waste disposal.

Another study carried out on the municipal solid waste (MSW) characterization and the compost produced from the solid waste in Zanzibar region [70]. The analysis reported that the compost generated form the municipal solid waste proves the effectual as well as cost effective way of waste processing. The macronutrients such as nitrogen, phosphorus and potassium have been evaluated to assess its usage in the agricultural purposes. The samples were composted aerobically and anaerobically. However, the results analysis revealed that aerobic composting condensed the volume of waste approximately by 60-65%. In this context, this reduction in the waste volume by means of composting phenomena, it may cause increment in the space for landfilling. Further, the author observed that the compost produced under anaerobic conditions having relatively high concentration of the dissolved ions and species compared to the compost produced under aerobic conditions. It was also observed that the compost produced from the waste having such content of plastics and paper thereby had low nutrition capacity and was supplemented with the trace of heavy metals due to the dumping of mix waste in the dumpsite.

The study carried out on the organic compost characterization for its usage in agricultural [71]. The study revealed that the application of biodegradable matter for agricultural soil enhances the soil nutrition, enhances the soil fertility and structure, betterment of water holding capacity as well as increase the soil microbial populations. Further the study revealed that the composted organic sheep manure revealed the highest concentration of biodegradable content, total nitrogen as well as higher humic acids. However, composted cow manure revealed the highest concentrations of microbial activity and micro-biomass and bacteria. Henceforth, the study concluded that the composted cow manure revealed very lesser amount of the pollution pollutants thereby good quality of compost specified by the Amendment quality index (AQI) hence it was concluded the most suitable and appropriate amendment for its usage in agricultural purposes.

Another study has been carried out on the characterization and open windrow composting of municipal solid waste in Rajasthan, India [72]. The study revealed that the chief advantage of the composting process is the stabilization and processing of the waste; considerably reduction in the carbon/nitrogen ratio as well as effectively diminishes the odour and pathogens. Composting phenomena is done by number of ways but among all, windrow type composting proves simple and cost-effective technique for the production of compost. Further, this type of composting is accomplished under the aerobic conditions under the temperatures of 55°c or even more than that temperature range. Further, the time duration of open windrow composting method of municipal solid waste has been assessed for eight weeks in the particular study. Apart from this, the author revealed that the material utilized in the windrow composting was the municipal solid waste without any kind of segregation. The moisture content has been reduced in the complete degradation phenomena from 59% to 48% thereby windrow accomplished a thermophilic temperature for about two and half weeks. Further, the author reported that the pH, Carbon/Nitrogen ratio (C/N) and temperature variations were compared the outmoded windrow composting. The maximum temperature observed was 69°c whereas the temperature range above 60°c persisted for more than two weeks. Finally, the analysis results concluded that the composting could diminished the mass of municipal solid waste by 30%.

Apart from this, as it is already discussed that the trend of open dumping of municipal solid waste is very common trend in India. Consequently, the leachate produced from the illegal disposal of MSW has worst impact on the environment such as air, water as well as on soil. Many researches have been observed the impact of open dumps of MSW on the soil quality. The studies conducted by Goswami and Sarma to assess the effect of open dumping of waste on the quality of soil in Guwahati city [73]. It was observed that the physicochemical parameters increased for the dumpsite soils or the soil mixed with the solid waste in comparison to the natural soil.

The study conducted by Raman and Narayanan on Pallavaran solid waste dumpsite Chennai [74]. The soil and groundwater samples were collected to observe the possible impact of open dumping on soil and groundwater quality. The results revealed that many of the groundwater parameters have been exceeded their permissible standards as prescribed by IS10500. Further, it has been concluded that the pollution is because of the open dumping of solid waste materials.

Pillai et al. carried out the study regarding open dumping of MSW on the soil in Kerala, India [75]. The leachate as well as soil samples were collected from the dumpsite and the areas near to its vicinity to evaluate the impact of leachate percolation on the quality of soil. The study revealed that the synthetic leachate can alter the soil properties and significantly modify the quality of soil. Further, the impact of leachate on physicochemical properties of soil was assessed by treating it with the synthetic leachate.

Roseta et al. conducted a study in Owerri capital of Imo State to assess the heavy metal concentration of waste for more than 15years old dumping site. Soil samples were gathered from 10 meters distance away from the two different dumpsites at different depths [76]. The results revealed variability in soil properties with varying in depth. The soil samples of the non-engineered disposal site at varying depth are classified as slightly acidic in nature having aggregate stability (76%). It has also been observed that heavy metal content was generally higher at deeper depths. The waste dumped at the hill sides has higher values in comparison to the gulley dump site only at shallow depth.

Salami et al. conducted a research on Okeafa dumpsite to find out the effect on surface and groundwater quality in the vicinity of the dumpsite. Soil samples were gathered from different places and from different depths from the dumpsites. The results revealed that closed dumpsite has no severe effect on the ground and surface water quality. The results of the groundwater samples varied in the range of the guidelines for drinking water prescribed by WHO however there was a scarcity of guideline for soil of closed dumpsites for the purpose of comparison [77].

The study conducted to check the pollution potential of municipal solid waste dump sites on soils as well as on plants [78]. The analysis study revealed the open dumping effect on soil and vegetation in Nigeria. The result revealed that the effects of the heavy metals were significantly higher in the dump sites.

Another study conducted on effect of MSW dumping site on the soil properties and ground quality in, India [79]. The results revealed that the open disposal of MSW alter the geotechnical properties of soil and also the quality of ground water. Further the results revealed that the open dumping has severely increased the cohesion and compressibility properties of the soil thereby making it more plastic.

The study conducted on the effect of degraded solid waste on the shear strength of soil [80]. The study revealed the effect of leachate from degraded solid waste of an open dumpsite on the shear strength of soil and to check the suitability of these dumping sites for the various construction purposes. The soil samples were collected from three parts of an old solid waste dumpsite. The analysis revealed some variations in the properties of soil by means of open dumping and infiltration of leachate into the soil.

The study conducted by [81] on physico-chemical characteristics and heavy metals contents in the soils mixed with municipal waste dumpsites in Allahabad, India. The study evaluated the quality of contaminated soils in three MSW dumpsites in Allahabad. The pH of the dumpsite soils ranged from 7.24±0.62 to 7.76±0.24 which is tending towards alkaline behaviour. However, physico-chemical parameters and heavy metal contents at each disposal sites have been correlation with each.

Another study carried out on effect of MSW disposal on geotechnical assessment of soil [82]. The study analysis revealed that considerable release of leachate forms the dumping locations happened since past years thereby the soil mixed with MSW at the dumping site experienced excessive contamination. The results revealed that the soil with higher OMC and reduction in maximum dry density. However, the variation in pH makes the soil slightly alkaline.

The study conducted on the evaluation of heavy metal pollution potential because of percolation of leachate from disposal sites [83]. The results analysis revealed the higher amount of heavy metals has been observed in the soil samples. The higher concentration of manganese content followed by lead, copper and cadmium has been observed in the soil samples. However, the occurrence of heavy metals in the soil specified the substantial pollution of the soil by the infiltration of leachate from non-engineered landfill system.

Further, the processing and dumping of MSW by means of landfilling is the most viable and environment friendly option [84, 85]. But in Indian context, the practice of illegal disposal of MSW is still in practice and absence of proper sanitary engineered landfilling system [34] Waste placed in dumpsites is subjected to percolate by means of precipitation and as water flows, it picks up organic and inorganic compounds within it resulting into contaminated water are 'leachate' [86] Many researches stated that leachate generated from MSW poses substantial threat to water sources [87].

The study conducted on assessment of physic-chemical and bacteriological evaluation of the leachate to check its impact on aquifers [88]. The results suggested the altered physic-chemical parameters in comparison to the permissible limits [86].

The study conceded out [24] for the assessment of the leachate effect on the aquifers from the open dumps of waste. It was perceived that the concentrations of physico-chemical parameters and heavy metals has been found in higher proportion thereby revealed the contamination of the quality of aquifers significantly hence make it inappropriate for the domestic water usage as well as for additional uses.

Another study was conducted to assess the characterization of leachate from MSW dump site in Nigeria [25]. The variation in physico-chemical parameters has been analysed based on seasonal variations. The study revealed that leachate thus produced from unlined landfill sites caused severe problems to the ground water reserves.

The drastic increment in urban as well as industrial activities urged by growing population as well as life style of public resulted into the production in huge amount of MSW. However, as it is already discussed that the disposal of waste in an open land results into degradation of environment as well as human health. In this context, the most frequently described risk to the health of public from open dumping is the usage of groundwater contaminated by means of leachate percolation into the aquifers [89]. The investigation of physico-chemical characteristics and heavy metal in groundwater system around the open dumpsite in Tamil Nadu was done by Kanmani S. et al. [83]. The results revealed that the leachate is having dominating effect on the quality of groundwater.

Although composition of leachate may vary within the successive aerobic, acetogenic, methanogenic, stabilization stages of the waste [90]. The nature of leachate is highly in constant as well as heterogeneous liquid found in nature. The literature survey concluded that the concentration of organics (COD) has been reported more than 15,000 mg/l in the leachate produced in young landfill while the concentration of COD is below 5000 mg/l in the landfill older than ten years [91]. The leachate mainly contains organic substances including aromatic compounds, chlorinated aliphatic compounds.

The study carried out by Kumar et al. regarding the assessment of pollution potential of leachate from the dumping site using leachate pollution index (LPI) [92]. LPI is a vital tool that is utilized for the computing the contamination potential of dumping sites. The author revealed the application of LPI by relating the leachate contamination potential of active as well as closed dumpsites in Hong Kong. The results analysis reported that the leachate produced from the closed dumpsites have more pollution potential as compared to the active dumpsites henceforth the suitable remedies as well as monitoring should be guaranteed at the closed dumpsites.

Apart from this, for assessing the comparison of leachate pollution index of different dumpsites, a system has been produced. To formulate LPI, 80 panellists were surveyed and the survey was accompanied by utilizing various questionnaires to express LPI depend on Delphi Technique. The survey analysis and complete evaluation of this method resulted into a single index that specified the pollution potential of leachate [92, 93].

The study carried out on characterization of leachate and identification of pollutants by utilizing LPI for open dumping site [94]. This study was conducted to determine the leachate quality, identification of contaminants and to assess LPI of an active and closed dump site in Kolkata, India. Out of various contaminants, heavy metals are of substantial concern to the environment [95]. However, the physico-chemical as well as biological assessment of leachate specified that dumpsite was in methanogenic phase. Further, ammonia is one of the odorous pollutants released from the dumping sites [96]. Heavy metals are persistent and toxic in nature [97] and are capable to contaminate the groundwater reserves [98].

The non-engineered open dumping of municipal solid wastes poses severe threat to environmental menaces including air, soil and the groundwater reserves thereby affect the health of public [99, 100, 101, 104]. Leachate was highly concentrated effluents which contains both inorganic compounds and heavy metals.

Numerous dumpsites exist in India discharging many hazardous pollutants to the groundwater reserves [102]. The pollution of groundwater has been described by Parameswari et al. [103]. Higher pH in leachate within the stipulated standards (pH = 8) showed that the involvement of biochemical activities in the dumpsite and also revealed that the organic load was biologically stabilized.

Further, the analysis conducted [105] on the assessment of ground water pollution. The study revealed that biodegradable content present in the municipal solid waste leads to the depletion of oxygen in the groundwater reserves. Further, the author reported the presence of various heavy metals in ground water reserves due to leachate.

The previous research addressed that there is a dire need for regular monitoring of groundwater [106]. Further, for the valuation of aquifer quality in a single index, many studies have been conducted by using aggregation indexing method [101]. The reason being that as the municipal solid waste decomposed, the waste ingredients percolated into the deep aquifers with the rain water and hence contaminating the ground water reserves. The pollution of groundwater is a main concern in landfill operations because of leachate and its severe health hazards [107]. Water quality improves as the distance increase from the landfill [101].

The assessment of water quality in a single index is particularly known as water quality index or leachate aggregate index because the technique consists the aggregation of sub-indices into a single index called aggregate index. The Study [108] conducted for the evaluation of water quality in Kuwait. The analysis results reported that almost of the water quality parameters has been found well within the permissible limits.

However, the assessment and evaluation of the municipal solid waste performance is the complex task because MSW is the heterogeneous material. In this perspective, “life cycle assessment” (LCA) is a systematic and logical tool that assists in evaluating the impact of municipal solid waste on the environment. The study conducted by Zhao et al. regarding the LCA tool to analyses the management strategy of municipal solid waste in China [108]. The result analysis revealed that methane gas breakout from the dumping sites was the chief contaminant that causes global warming. However, the studies also recommended that the material recovery facilities such as recycling & recovery of waste lead to reduction in the environmental impacts [108].

To achieving the goal for increasing the efficiency of solid waste management strategy, a novel method has been induced based on life cycle assessment that assists in assessing the various threats to the environment. Further, many of LCA models have been developed and assessed for the evaluation of the product system.

The study conducted on implementation of LCA to check the potential of MSW management system in Mumbai, India. The study reported that the methodology has been utilized to assess the effect of MSW management strategy under various scenarios. The scenarios comprised of different options such as combination of landfill and collection of biogases, combination of incineration and material recovery facilities, combination of composting, anaerobic digestion and incineration etc. The combination of composting and incineration significantly diminish the global warming effect due to the avoided emissions whereas human toxicity would increase these effects [109, 110].

Another study carried out by Khoshnevisan et al. on life cycle assessment approach in waste management strategy. In this context, life cycle assessment is an environmental management tool intended at supporting policies rather than being a decision-making tool [111]. In the assessment of life cycle assessment, the “cradle to grave” option is employed to describe the production stages. Further, it delivers the perceptions and vision about the principles and methodology for the assessment of life cycle assessment.

The study carried out on life cycle assessment (LCA) of MSW management by Mali & Patil [112]. The study comprised of the characterization of municipal solid waste and leachate in the dumpsite of Kolhapur, India. Further, SimaPro software has been utilized for assessing the environmental impacts by virtue of various categories. The scenarios of MSW comprised of the combination of open dumping, composting, anaerobic digestion (AD), material recovery facility etc. and their inter comparison. The analysis study revealed that the illegal disposal has displayed highest environmental effects. However, composting and material recovery facilitates most environmentally favourable conditions for the management options of municipal solid waste [113, 114].

Further, the study conducted on life cycle assessment of municipal solid waste management in Minna, Niger state, Nigeria [115]. Life cycle assessment (LCA) was utilized to assess the MSW management strategy in Nigeria. In the study, three alternative scenarios have been made in combination with current waste management system. SimaPro 7.2 educational software is run to perform life cycle assessment (LCA) study in this project. Further, the environmental impact parameters comprised of eco-toxicity, acidification, eutrophication and global warming and human toxicity.

Another study was carried out on the review of life cycle analysis of municipal solid waste management options by [116]. LCA is analytical software utilized for the evaluation of the environmental impacts of MSW management. Further, LCA helps in assistant of the identification of opportunities for the prevention of pollution.

Another case study has been carried out on the life cycle analysis for MSW management in Ahvaz, Iran [117]. In the particular study, the various scenarios have been modelled for the proper management and processing of municipal solid waste and hence the impact categories have been evaluated including global warming, acidification potential, photochemical oxidation, eutrophication and human toxicity etc. The analytical study revealed that more than 50% of gas and energy recovery from the dumpsites diminished the effect of global warming potential by 15% in comparison to the compared to the non-recovery methodologies.

The study conducted on the life cycle analysis for the betterment of municipal solid waste management strategy by [118]. LCA is an inclusive technique that used to assess the environmental burdens thereby the environmental effects throughout the life cycle of product system. LCA is the decision-making tool used for making the environmental and ecological municipal solid waste management since 1995. Further, life cycle analysis can help in the reduction of waste management costs by adopting the best fit scenario for the management of municipal solid waste.

In the present scenario, non-engineered landfills are in trend for the disposal of waste in worldwide [119]. However, the sanitary engineered landfills are meant for reducing the exposure of humans and environment from toxic waste [119]

Some landfill tragedies had been reported in the different parts of the world due to inadequate designing, improper handling and disposal of municipal solid waste in the constructed landfills by which contaminants migrated into the underground water and soil reserves.

Few of the case studies related with ground water and soil contamination are as follows:

Love Canal is the most dangerous tragedy of environment in American history. The land of love canal sold at a public auction to the city of Niagara Falls in 1920 and they began to utilize the land as landfill for disposal of the chemical waste. As a result of these dumping of canal was soon turned into a municipal and industrial chemical dumpsite. After the closure of landfill, schools and residential buildings were built on the landfill site. After few months many sever health hazards and strange odours were reported from the site. Thereafter Environmental Protection Agency (EPA) was asking to propose a system for the clean-up of the contaminated site. Environmental Protection Agency submitted the proposal in which it was recommended that the contaminants dispersed in the nearby surrounding area must be cleaned by the polluter agency. In addition, EPA formulated many guidelines for the proper disposal and better use of landfill sites. Another tragedy reported is from the village Mavallipura situated very near to Bengaluru (Bangalore) boundary limits. Mavallipura turned into a garbage dumping ground for the city of Bengaluru within one decade. The site was rapidly converted into virtually uninhabitable as it had become a breeding ground for diseases. During monsoons, leachate from the garbage dumps flowed directly into the village's water sources, which showed visible signs of severe contamination. The farmers in the village started to find alternative sources of their survival like brick making etc. due to the contamination of soil and water resulted into the crops failure [120].

By studying the selected experiences/tragedies of leachate contaminant migration into the groundwater reserves, it is well understood that there is a need to design proper sanitary engineered landfill system and completely avoid the open dumps [121, 122].

Hettiaratchi et al. concluded various results in **"**Evaluation of alternative method of leachate collection system design" and to provide an approach for variations in the production of leachate [123]. Author concluded that the wet landfill in tropical regions required the PLF of 4 and dry landfill could be designed with the peak leachate factor of 2. PLF (peak leachate factor) could be an important design parameter for leachate collection and removal system in landfill cells especially those operated with "leachate recirculation".

Stark and Newman concluded results in the "Design of landfill final cover systems" [124]. Author studied and concluded many slope stability analysis and slope failure at MSW containment facility. Author recommended that the final cover angle should not be greater than the lowest geo-synthetic interface strength [125, 126].

Xu et al. concluded various results in **"**Impact of pressurized liquids addition on landfill slope stability" and the effect of pressurized liquid addition on landfill that pressurized liquids could be added to a horizontal trench, under a sloped landfill without inducing slope failure [127]. It was also observed from the studies that when moisture movement become obstructed, factor of safety reduced [128-133].

Summary

It is evaluated from the literature review that municipal solid waste management is one of the chief responsibilities of municipal authorities. The main and foremost goal of MSW management authority is to diminish the contamination potential to the environment. The literature studies revealed that municipal solid waste was dumped in inappropriate manner and the absence of sanitary engineered landfill system has been noticed everywhere in Indian cities without any liner system and leachate collection system thereby causes health hazard issues to human as well as degraded the quality of environment. The drastic population growth increases the production of MSW hence lessen the capacity of municipal authorities. Further, the waste management strategy has been observed very inadequate due to the lack of efficient resources, lack of recycling and recovery of produced waste, lack of manpower, lack of knowledge about sanitation in public, lack of waste-to-energy techniques and finally the trend of open dumping of municipal solid waste. It is observed that source separation is totally absent in the communities that is one of the bad examples of municipal solid waste management. However, source separation as well as sorting techniques has been the core of materials recovery facilities in developed and developing countries. It has become a common practice in Indian cities that solid wastes are not knowingly processed but dumped at selected sites in the municipalities. The environmental unfriendly methods such as open-burning, open-dumping and the absence of sanitary landfill are still in practice.

From the above literature survey, it is concluded that because of inadequacy in management of waste disposal and infiltration of leachate into aquifers, all the water reserves and soil being affected. All the physico-chemical characteristics of groundwater showed higher values than the permissible values of these parameters and the standards of World Health Organization (WHO). Hence, this showed the improper management of MSW.

Due to the varying nature of MSW especially in the composition and characterization; the study observed that government has to take immediate steps for the improvement of the efficiency of MSW management. Although substantial efforts have been made by the municipalities and govt. for grab and tackle the various problems relatable to the waste, still there are major gaps. The most vigorous gaps including scarcity of finance, lack of waste processing techniques as well as the lack of awareness among people towards the sanitation.

The conclusion drawn from literature survey revealed that the disposal of municipal solid waste without any treatment may prove deteriorates for the human life as well as for the environmental safety point of view. Henceforth, there is a dire need of improvement in the present waste management scenario. Waste should be separated prior to dumping in the landfill and moreover only inert waste should be dispose of in the landfill to reduce the weight of landfill thereby increase the life span of the landfill.

Hence, in the nutshell, it is deducted from the background study that characterization of MSW, leachate and groundwater is very needful for the appropriate management of MSW. The pollution index of leachate as well as groundwater proves beneficial to analyse so that the particular remedy could be applied to reduce the pollution of ground water reserves and to make the environment clean and green.

Therefore, in this work an attempt has been made for waste characterization and analysis, compost characterization, soil characterization affected by the dumpsites, leachate characterization and groundwater characterization in four selected location of Himachal Pradesh including Solan, Mandi, Sundernagar and Baddi to comprehend the current scenario of waste management strategy in Himachal Pradesh. As there is no such baseline data available for the analysis of waste in H.P. so the analysis may prove helpful for the enhancement and betterment of current MSW management system in Himachal Pradesh for all study locations.

CHAPTER 3

ANALYSIS OF MSW MANAGEMENT USING 'BENCHMARK' INDICATORS IN HIMACHAL PRADESH

3.1 Introduction

The management of MSW has become a crucial challenge in today's world because of the inadequate waste management processes which affect the healthiness and the overall comfort and the aesthetics of the cities [4]. The volume and characterization of MSW may differ by place to place [1]. The management of MSW is a compelling issue for the ULB's, but unfortunately often has the last preference. Further, the different associated functions in management of MSW are often not accomplished in adequate manner; subsequently leading to environmental, cleanliness and health issues within the city limits [134]. Apart from this, the population of India is reported as 1.34 billion with a majority of inhabitants migrating to urban region from rural areas. The recent statistics indicates that approximately 60% of inhabitants will tend to be shifting in urban regions by the year 2030. In this aspect, speedy development and expansion of urban regions has led the current municipalities ineffectual in proper management of MSW generated [4]. Further, the issue in management of MSW has been escalated due to increased budget cuts being faced by municipal authorities for in the waste management system [135]. Additionally, it is necessary to make the appropriate dumping of municipal solid waste for the maintenance of aesthetic appearance of the cities.

Furthermore, numerous studies have been organized in the perspective of Indian cities dealing with different aspects of waste generation and its management, modeling studies for increased waste generation, characterization of waste generated, leachate generation and its effects on natural surrounding conditions, LCA for management of MSW and design of sanitary landfills

The state of Himachal Pradesh is mountainous and of undulating topography and is the minimal urbanized state in India. The generation of MSW in HP was reported as 360 tonnes per day (TPD) in 2015 [136]. Out of total waste generated, 5% waste is incinerable, 10% is recyclable and the remaining is disposed of in non-sanitary landfills [137]. The average waste production on the basis of per capita is about 0.413 kg/capita/day in Himachal Pradesh. The probable waste production rate in Himachal Pradesh in the projected years has been précised in Table 3.1.

Table 3.1: Projected production of waste in HP [4]

Year	Generation of waste (per person per day) (Kg/day)	Waste production (tons per day)
2011	0.42	310
2021	0.48	421
2031	0.55	560
2041	0.62	710

However, mountainous regions face many challenges in solid waste management due to extremely insubstantial environment and challenging topography [68]. Hence, in the above context, non-engineered dumping sites for the disposal of waste have become the prime sources of pollution in Himachal Pradesh. So, there is an awful need to develop waste treating facilities for the effectual management of enormously produced municipal solid waste

Additionally, the current study emphasizes the actual waste management processes in four regions in Himachal Pradesh including Solan, Mandi, Sundernagar and Baddi. Further, the present study employs the '*wasteaware*' practices for categorizing the efficiency of the prevailing practices of waste management. Further, a '*matrix' method* has been employed for the comparison of various study regions and the outcomes attained have been compared with Chandigarh city atop tier-II city located closest to the study locations. Furthermore, the study also recommends appropriate corrective measures to improve the current waste management practices prevalent in the study regions.

3.2 Methodology

3.2.1 Site locations

Solan

Solan is the largest municipal council of Himachal Pradesh and it is located 46 km in south direction of the capital, Shimla. The population of entire district is reported as 5,80,320 and the population density is 300 persons/km^2.Solan city is divided into 13 wards and lies within the coordinates of 30.9046°N and 77.0968°E. The overall population of Solan city is 39,257 of which 54% are males whereas 46% are females as per the Census India 2011 report. There are total 6 tehsils and 2 sub-tehsils. The average literacy rate in Solan notified is 85.02. The geographical area is reported as 1936 m^2. The rural population is reported as 82.4% whereas the urban population is 17.6%. Further, the production rate of MSW reported as 22 tons per day out of which 13 tons per day is directly disposed in open dumps [4].

Mandi

The population of Mandi city has been reported as 26,423 according to the report of Indian census, 2011. The coordinates of the town are within 31.5893°N and 76.9183°E. The waste generation in the city is reported to be 21 tons per day out of which 12.6 tons per day is dumped in open places in ill-mannered way. The population of males comprises 53%of the overall population. The average literacy rate is reported to be 83.5% and is higher than the national average of 65.38%. The economy of the region is mostly agricultural with about75% of population reliant on farming for earning.

Sundernagar

Sundernagar is a small city in Mandi district of Himachal Pradesh, India. Sundernagar is situated on National Highway (NH) 25km from Mandi. The coordinates of Sundernagar 31° 32' 0" North, 76° 53' 0" East. The town has an average elevation of 866 meters (2,841 ft). The population of the town is reported as 24,344 according to census report 2011 and the males constitute 53% of the population. The waste production is reported as 18-20 tons per day with a collection efficacy of60%. Sundernagar has an average literacy rate of 82%.

Baddi

Baddi is known as industrial town situated in southwestern Solan district in Himachal Pradesh. This lies in the border of two states named as Himachal Pradesh and Haryana. The coordinates of the town are 30.928°N 76.796°E and the average elevation of the town is reported as 426 meters (1397 ft).Baddi town had a population of 29,911 according to the census report 2011 with65% males and 35% females. The literacy rate was 86.33%, higher than the state average of 82.80%. The waste production rate of the particular town is 18 tons per day out of which 12tons per day is directly disposed as an open dump.

The study locations of four distinct study regions have been shown in Figure 3.1.

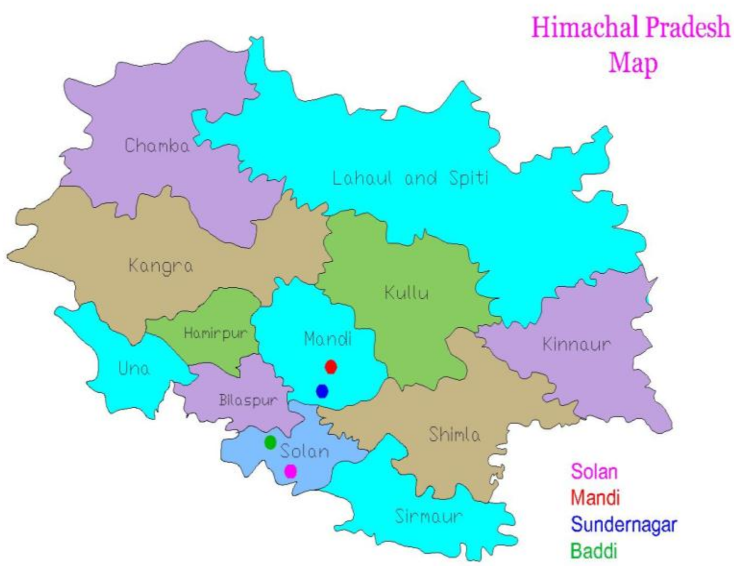


Figure 3.1 Location of study regions

3.2.2 Geomorphology and climatic conditions

Solan

The climate of Solan is reported as warm and moderate and the average temperature is 17.5 °C on an annual basis whereas the annual rainfall is reported as 1414 mm. The variation in annual temperature is around 16.1°C. The mean maximum and minimum temperature vary between 32.2°C and 0.6°C. Solan district presents a sophisticated montage of hilly terrain as well as valleys and the altitude lie within 300 to 3000 meter above mean sea level. The topography is moderate to highly dissever with steep slopes. Additionally, the soil type is sandy loam in general mostly in valley region whereas skeletal in hilly side. Soils are rich in nutrients and thus are fertile.

Mandi

The climate is notified as hot and temperate sometimes whereas the temperature on an annual basis is reported as 21.8 °C. The annual precipitation reported as 1679 mm and the average monthly precipitation is reported as approximately 18 mm. However, the highest temperature is reported in June whereas the lower most temperature is reported in January month of 4°c. However, the average temperature varied by 18.3 °C in a year.

Sundernagar

The climate of Sundernagar is warm and temperate with the temperature is reported as 20.9 °Con an annual basis. However, the average annual precipitation falls 1432 mm in Sundernagar town. The mostly dry month is November and the average monthly precipitation is reported as 17mm. The warmest month of the year is June with the temperature reported as 29.0 °C.

Baddi

The climatic condition of Baddi town is warm and mild. The average annual temperature in Baddi town is reported as 23.4 °C. The annual average precipitation is reported as 1186 mm. Most of the precipitation falls in July and the average precipitation recorded as 355 mm. The average temperature is reported as 32.4 °C. The warmest month is June and the average temperature is reported as 13.1 °C. The difference in precipitation is 344 mm in between the driest and wettest months. The average temperatures vary during the year by 19.3 °C.

3.3 Current Scenario of MSW Management in Himachal Pradesh

The management of MSW compiles the assortment of waste from the houses, waste storage, waste transportation and ultimate dumping of waste. The management of MSW depends on the municipal authorities of respective regions as well as other establishments like Himachal Pradesh State Pollution Control Committee (HPSPCC). Figure 3.2 exhibits the current waste management practices in study regions of Himachal Pradesh.

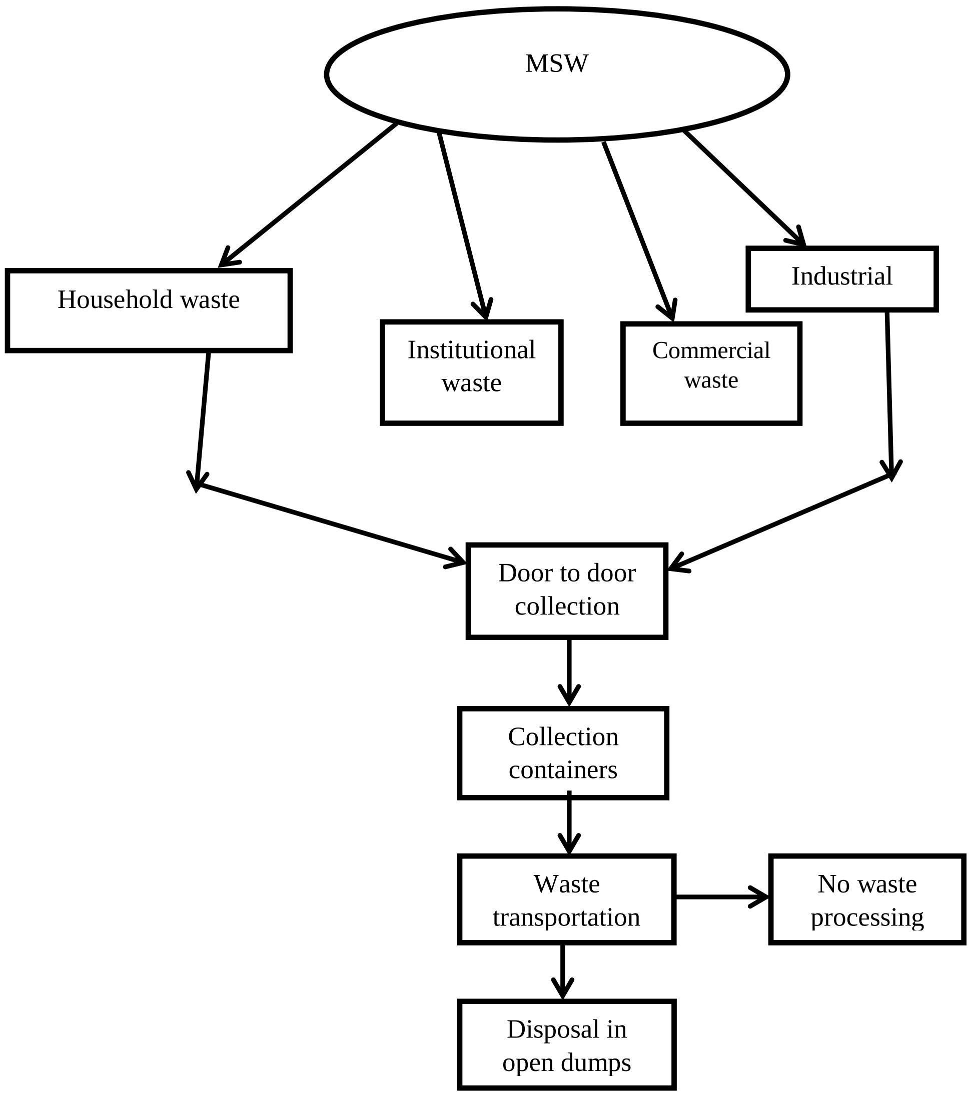


Figure 3.2: Current waste management practices in study regions of Himachal Pradesh

3.4 'Wasteaware' Benchmark indicators for sustainable management of waste in HP

The accomplishment of MSW management is an important function of municipality because it is substantial service on which the health of people and the aesthetic appearances of environment are reliant. In this context, benchmark indicators for sustainable waste management were utilized for the evaluation of MSW management performance as well as recovering and reprocessing of waste systems in the city. The chief objective of this index is offer statistics for decision-making on efficiencies for waste management services. 'Wasteaware' benchmark indicators compile both physical (quantitative indicators) and governance factors (qualitative indicators). The physical components include waste collection facilities, processing and final disposal of waste, 3R's facility includes reduce, reprocessing and recycling facility whereas qualitative indicators compiles the governance factors.

The description of 'wasteaware' benchmark indicators for the performance of physical constituents has been illustrated in Table 3.2.

Table 3.2: Description of qualitative indicators of MSW management

Sr. No.	Physical constituents	Name of indicators and description	Color coding				
			Low (L)	Low/medium (L/M)	Medium (M)	Medium/high (M/H)	High (H)
1.1	Waste collection	Collection of waste Coverage	0-49%	50-69%	70-89%	90-98%	99-100%
1.2		Waste seized by the MSW management and recycling	0-49%	50-69%	70-89%	90-98%	99-100%
2	Disposal of waste	Organized processing of waste With proper dumping	0-49%	50-74%	75-84%	85-94%	95-100%
3	3R's - Reduce, reuse, recycle	Recycling rate	0-9%	10-24%	25-44%	45-64%	5% and over

Additionally, there are certain Criteria that are utilized to evaluate indicators including 1C: Waste assortment and lane cleaning amenities, 2E: Degree of ecological protection in the treatment of waste and final disposal, 3R: 3R's- reduce, reuse and recycle-provision, 4U and 4P: Degree of user and provider inclusivity, 5F: Degree of financial sustainability, 6N-National framework, 6L-Local institutions.

The flow charts for above said different criteria's have been illustrated in Figure 3.3-3.10

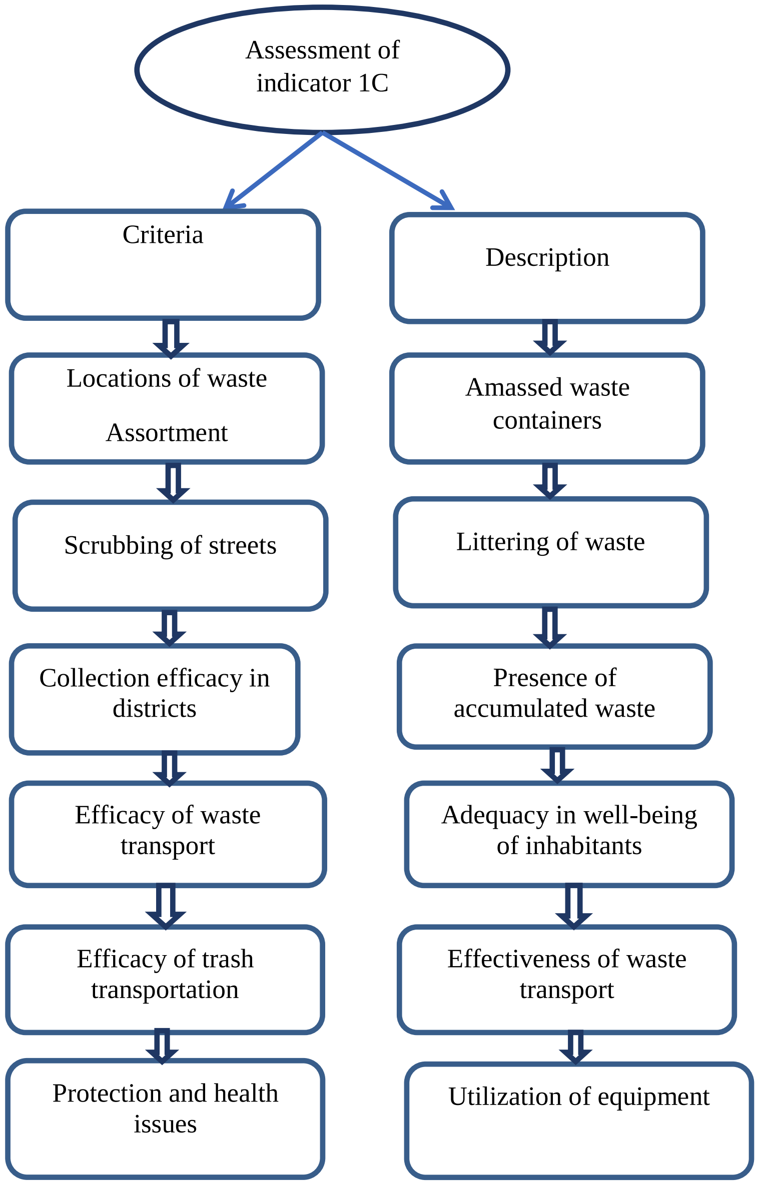


Figure 3.3: Criteria utilized to evaluate Indicator 1C: Quality of the waste collection and street cleaning facilities [52]

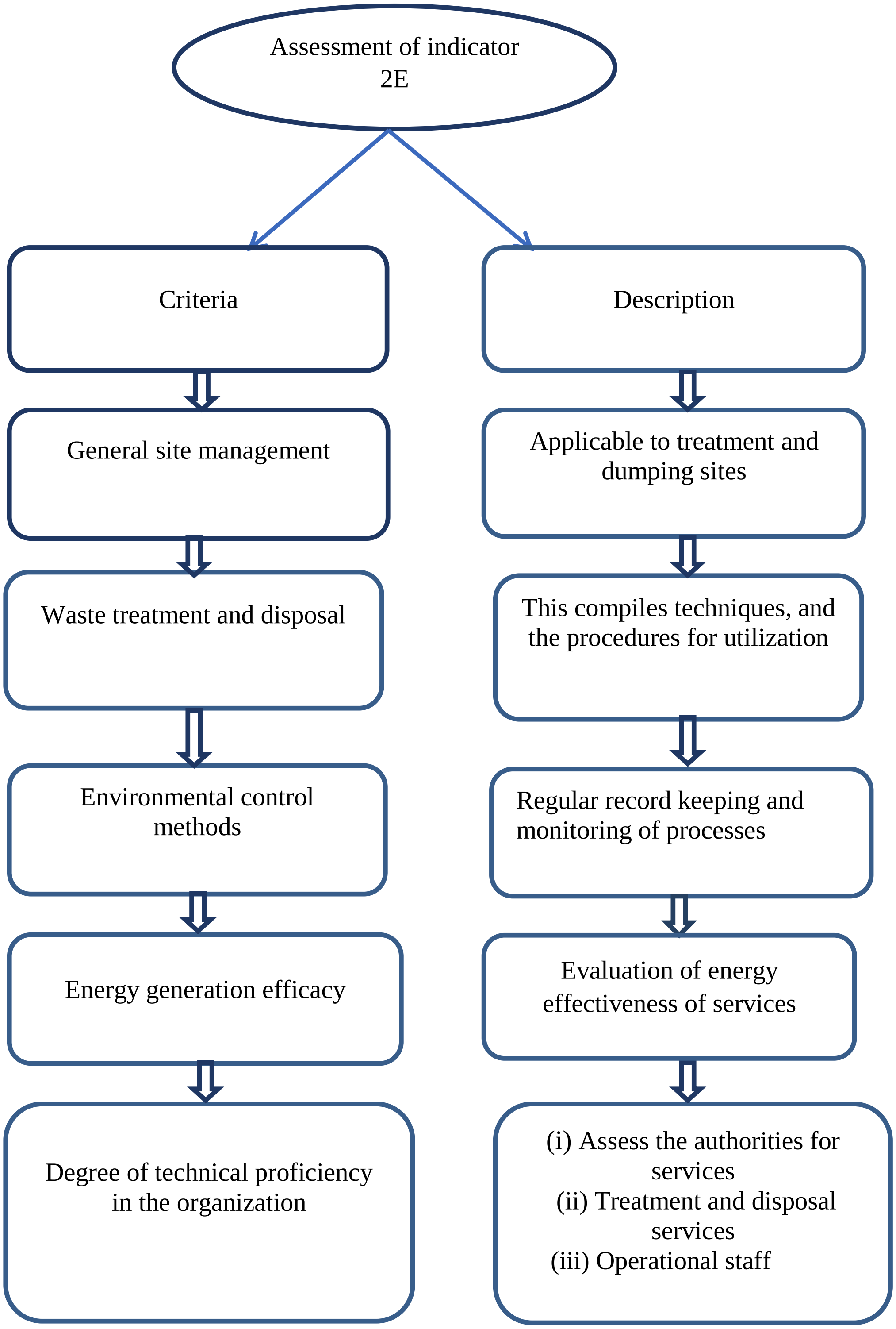


Figure 3.4: 2E: Environmental protection for processing and final dumping of waste [52].

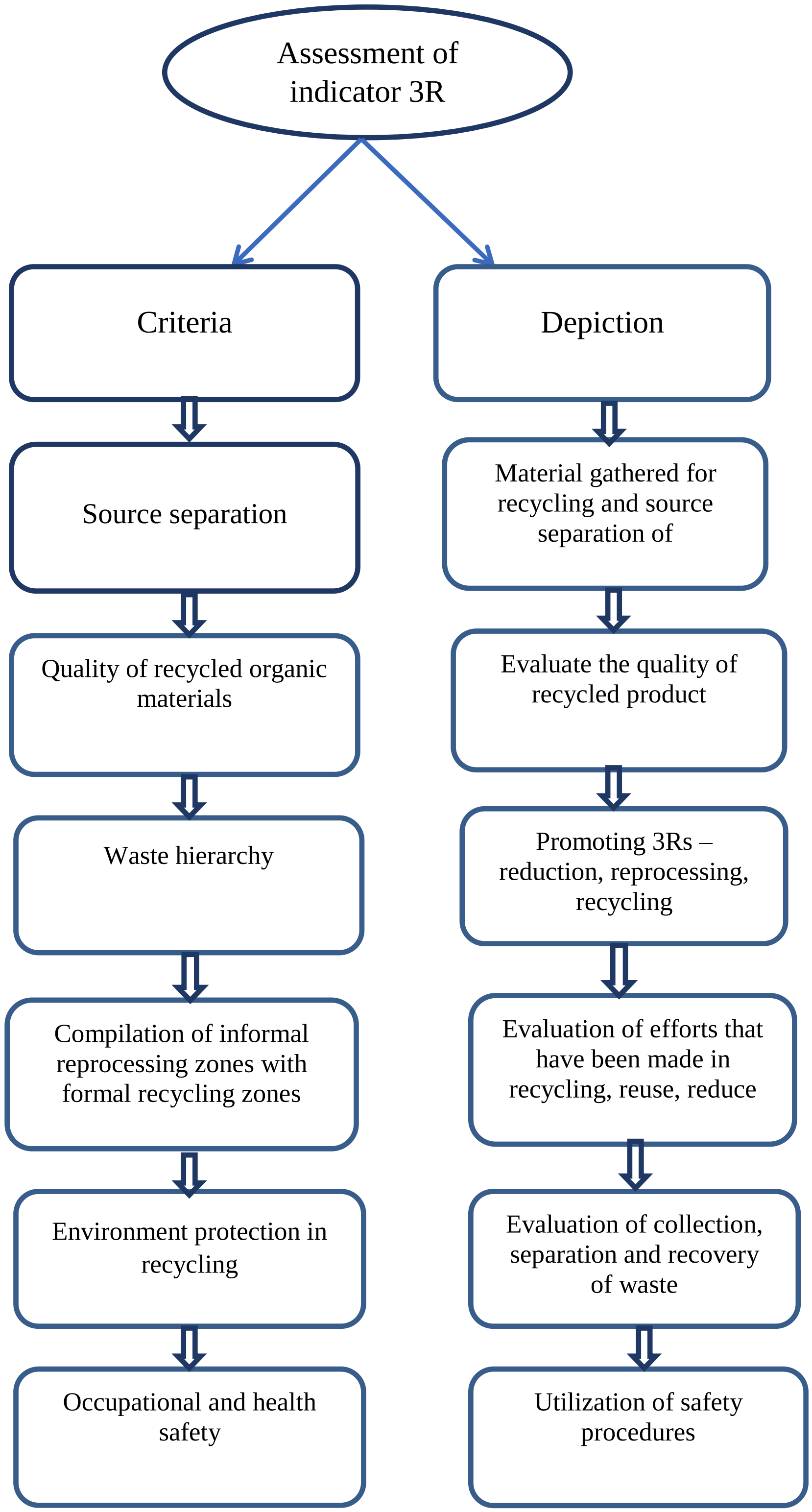


Figure 3.5: 3R: 3R's- reduce, reprocessing and recycling phenomena [52]

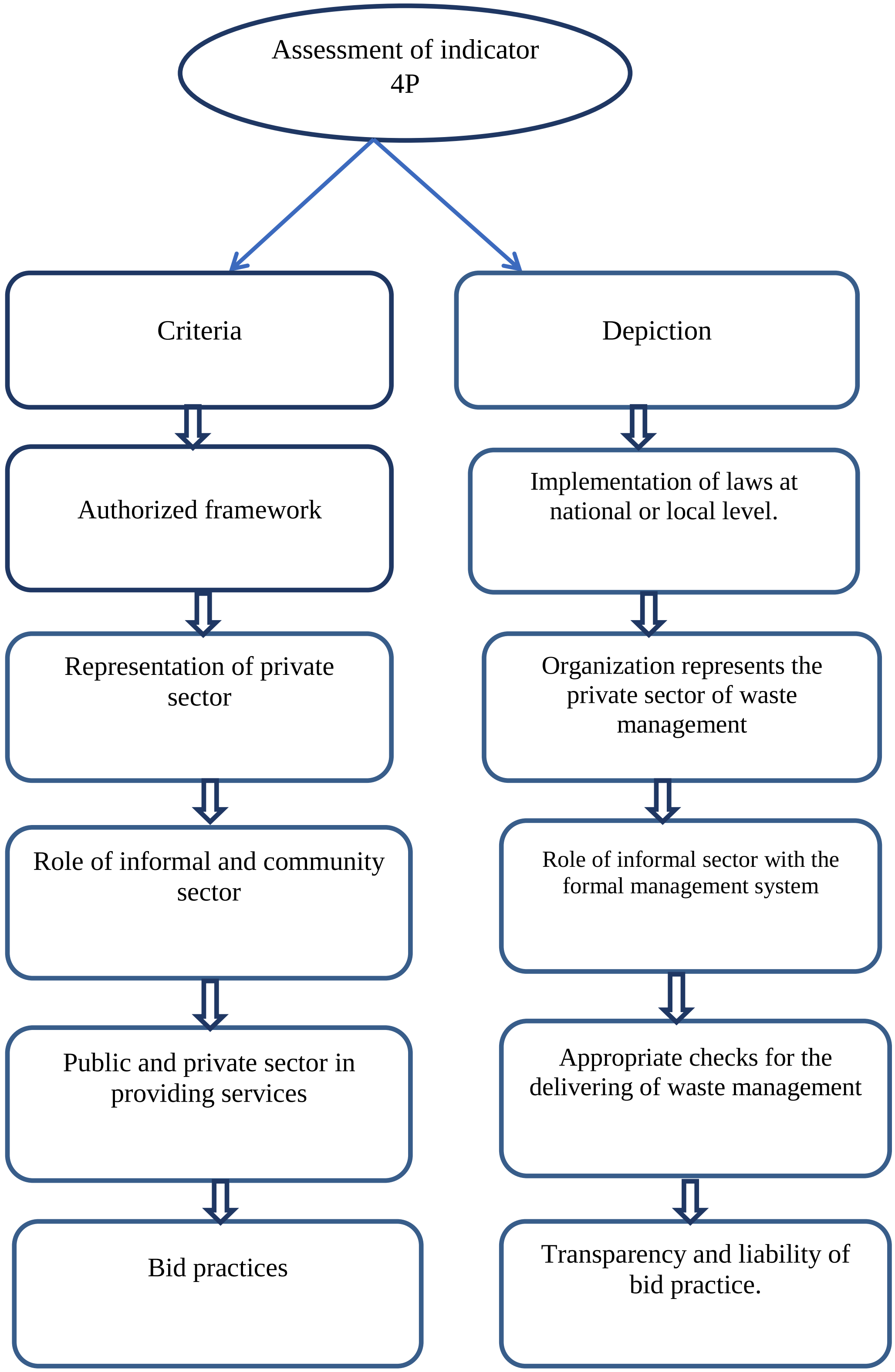


Figure 3.6: 4P: Degree of provider inclusivity [52]

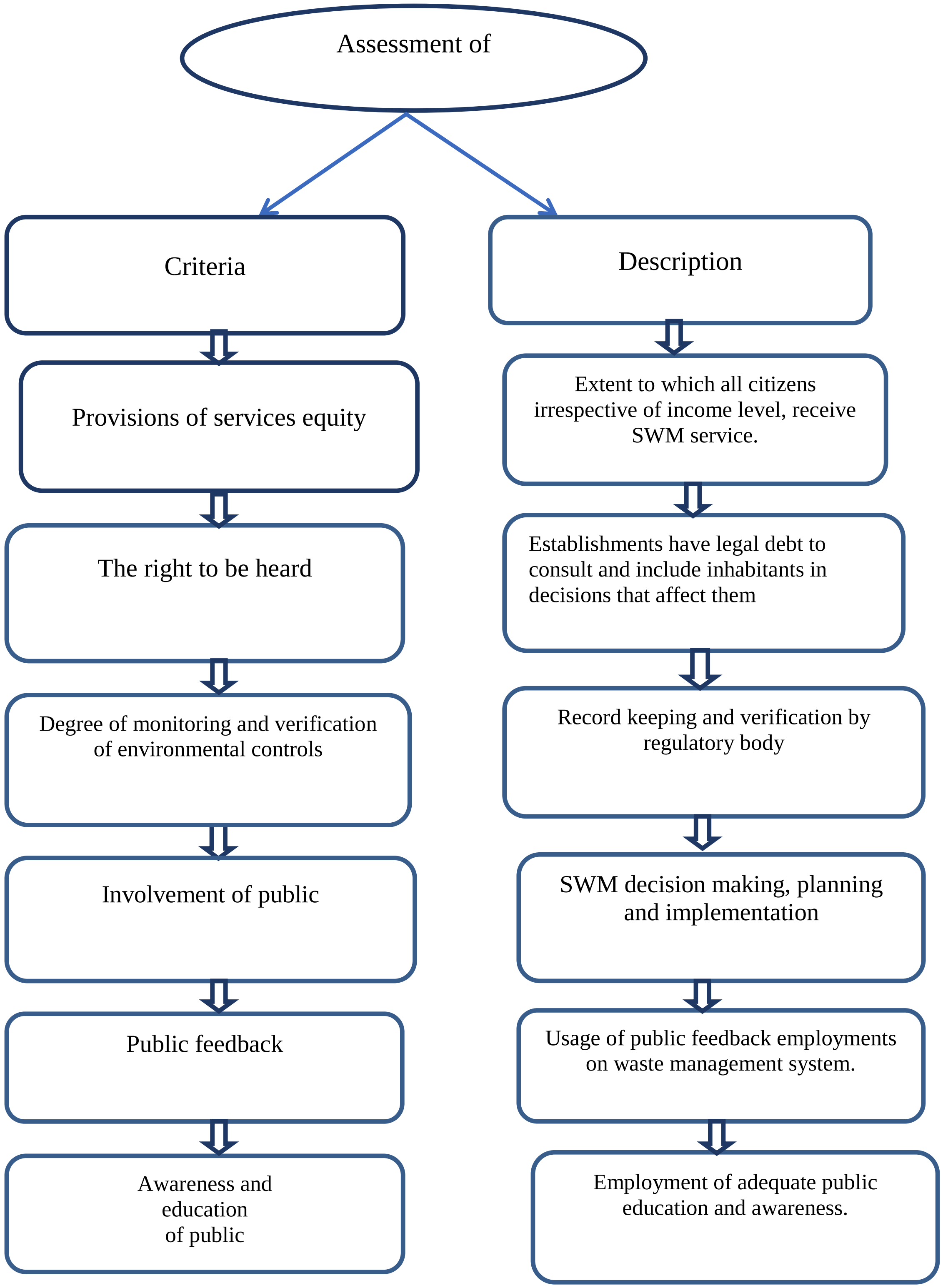


Figure 3.7: 4U: Degree of user inclusivity [52]

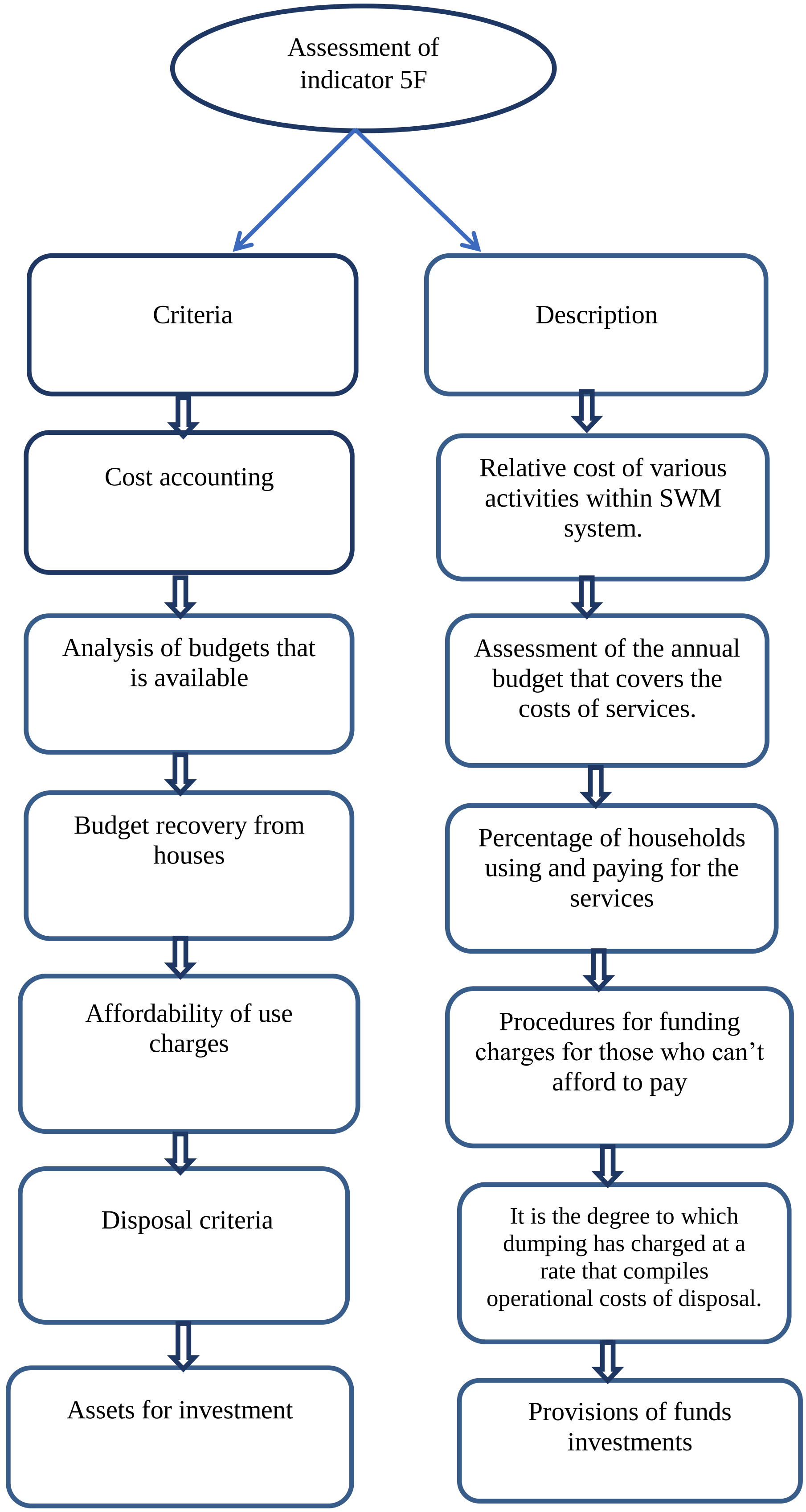


Figure 3.8: 5F: Degree of financial sustainability [52]

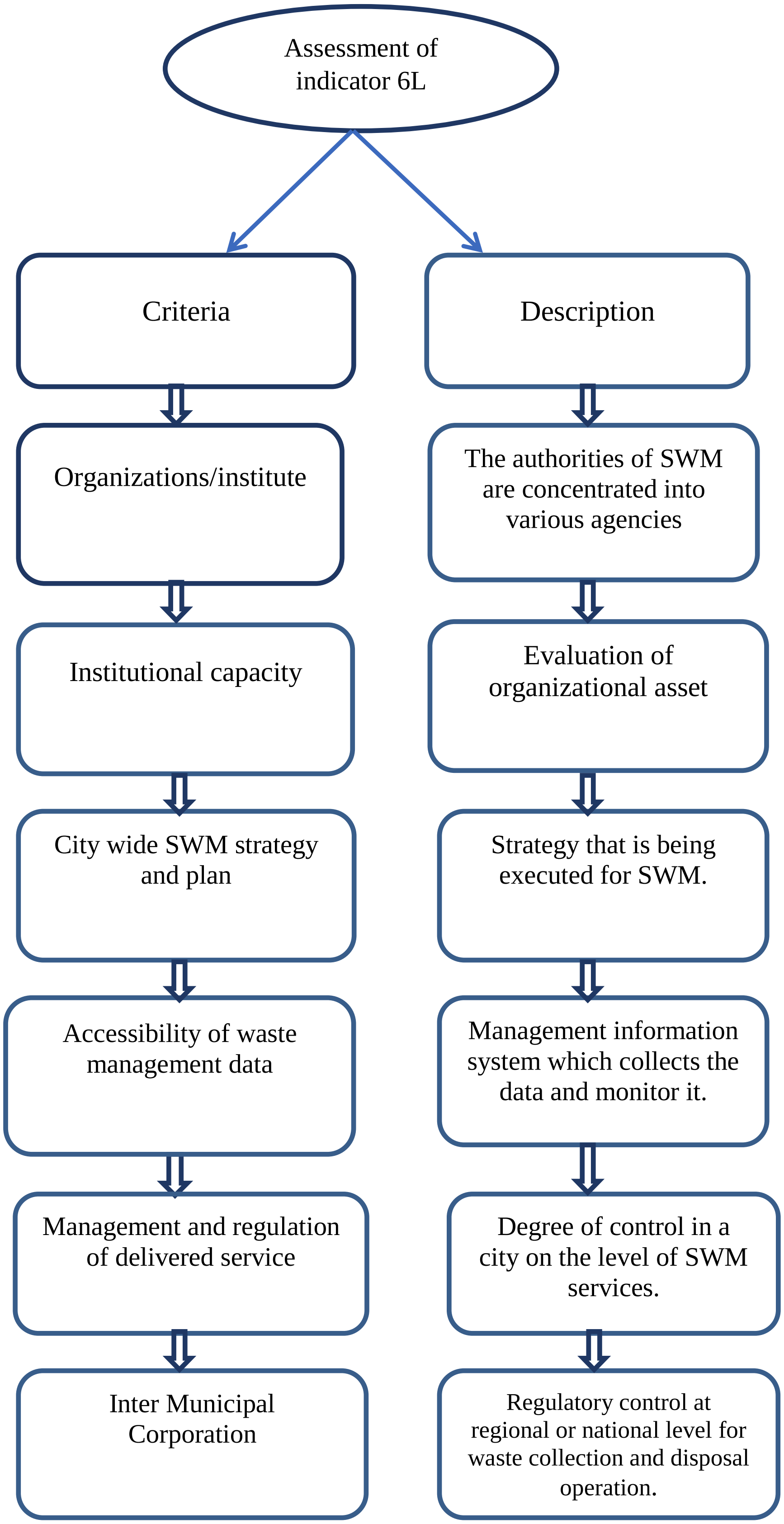


Figure 3.9: 6L: Degree of local institutions [52]

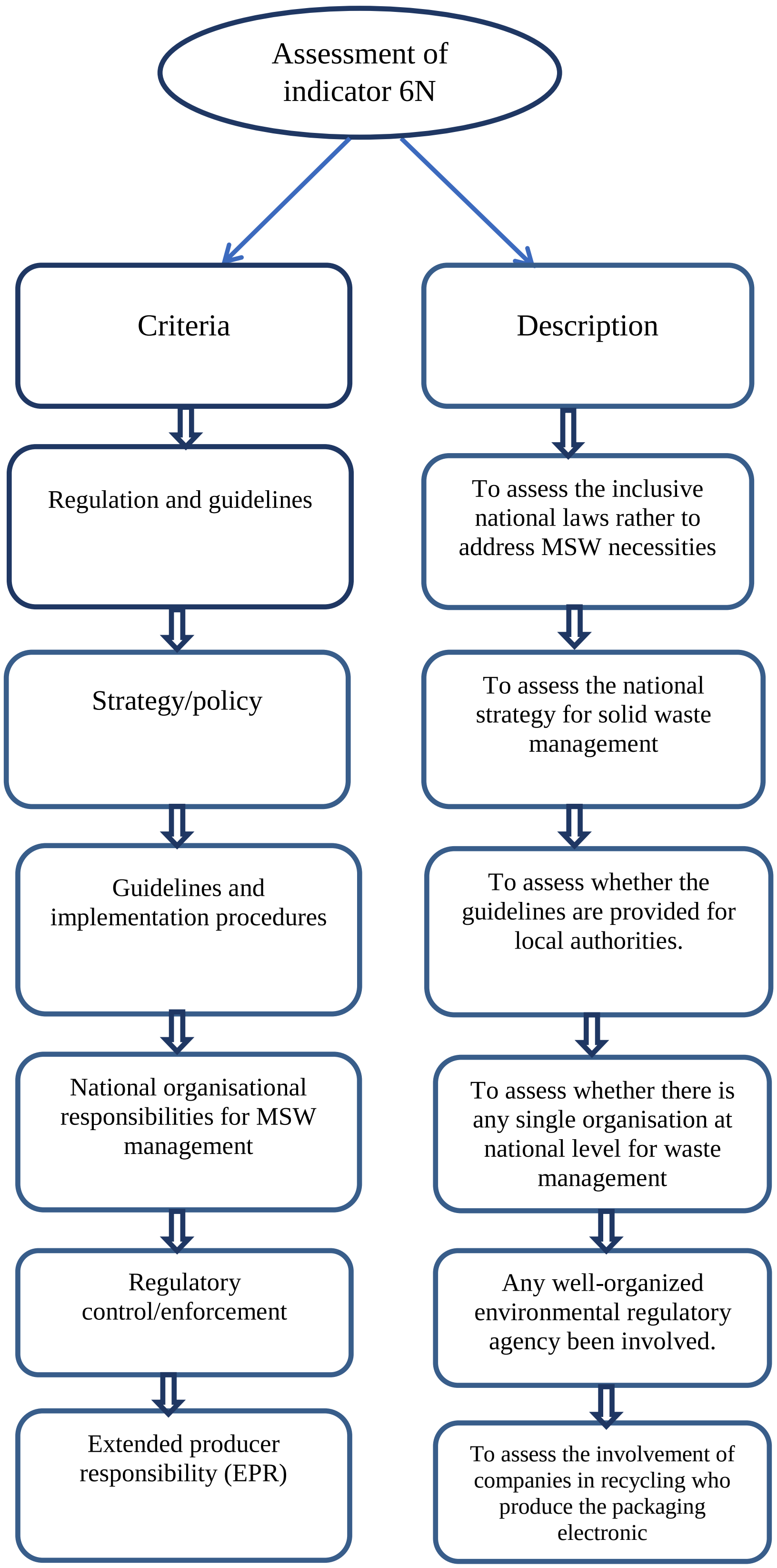


Figure 3.10: 6N: Degree of legal framework [52]

3.5 Matrix method

The outcomes attained by utilizing benchmark indicators are mainly semi-theoretical in its presentation. The present study compiles the use of matrix method for an enhanced understanding of the evaluation of prevailing MSW management. In this matrix method, the grading system utilized in the benchmark indicators is named as low(L), Low/Medium(L/M), Medium (M), Medium /High (M/H) and High (H). A5 point categorization was allocated to the 'benchmarks 'wherein the scores assigned were (Low=1, Low/Medium=2, Medium=3, Medium/High=4, High=5).

3.6 Results and Discussions

3.6.1 Valuation of current MSW managing processes in study locations

3.6.1.1 Financial provisions

The expenses sustained by respective district in Himachal Pradesh vary significantly. In this context, Kullu region are having maximum functional costs on the basis of waste generation while Hamirpur has the lowermost operational cost. Usually, an inadequate financial provision is made for the management of MSW for the particular sites that are mainly utilized for payment of manpower resources as well as for the collection procedures. Hence, this leads to discrepancy of the financial necessities that are replaced by income making methods like assortment charges and employment of appropriate revenue schemes.

3.6.1.2 MSW generation

The production of MSW for four study regions has been brief in Tables 3.3.

Table 3.3: Generation of MSW in study locations of HP

Name of the city	Population of towns	Generation of waste (tons/day)	Per capita waste generation (Kg/capita/day)
Solan	39,257	22	0.43
Mandi	26,423	21	0.45
Sundernagar	24,345	20	0.44
Baddi	29,912	18	0.42

It is perceived from Table 3.3 that Solan has a fairly increased per capita MSW production in comparison to Sundernagar and Mandi. Additionally, it is noticed that Baddi has lesser population than Solan town but have higher waste production rate on per capita basis due to presence of increased hazardous waste as Baddi town is the industrial hub of the state Himachal Pradesh.

Additionally, there is no such existing data of waste characterization at the above study locations in HP currently. Further, it was experienced that organic fraction was moderately higher in all the four study regions because of closer vicinity of the waste disposal locations to the fruit and vegetable markets. Further, it is observed that fraction of plastics relatively low in the waste of Himachal Pradesh but little higher fraction has been found in Sundernagar because it is known the education hub of Himachal Pradesh. However, Baddi region comprised of more quantity of plastic waste because Baddi lies in between the boundary of Himachal Pradesh and Haryana and the use of plastic has not banned in Haryana state. Further, it was perceived that bottles and metal waste also in slightly higher proportions in Sundernagar due to the juices and brews plants are set up in the respective place and found lesser in Baddi region because these wastes have been already collected by the rag pickers before reached into the dumpsites. Hence, to summarize, a thorough physico-chemical characterization of MSW generated at these locations needs to be determined.

Further, it has been notified that the source separation of MSW produced was completely absent in the study locations in HP. The total unsegregated MSW produced from houses as well as from other sources has been transported to the disposal sites of the study regions. However, the absence of waste segregation at source increases the load burden on the dumping sites therefore effectually decreasing their life duration.

3.6.1.3 MSW collection and storage processes

The proper collection of waste is one of the key processes in the effectual management of MSW. The waste management system proves valuable only when the infrastructural setup is coordinated with the production of waste generated. Moreover, the existing infrastructure is not well equipped to manage high magnitudes of waste produced in India subsequently leading to its disposal in non-engineered dumpsites. The waste is collected through handcarts in the selected locations of the state HP. Further, it was perceived from the study that the door collection efficiency in Solan and Baddi town is about less than 20% and in Mandi and Sundernagar town it is reported as approximately 38%. Cleanliness employees are allocated to every area of the respective sites and every study location has approximately 20-25 wards. The waste collectors at the study locations are determined to be about 2.7 per 1000, 2.4 per 1000, 2.2 per 1000 and 3.4 per 1000 persons for Solan, Baddi, Sundernagar and Mandi regions respectively. Therefore, the total number of workers are extremely low and lower and highly inadequate. Lack of tie-ups with municipalities with local NGO's does further magnify the management issues. In this context, the absence of nominated storages sites for waste collection and storage at four study locations leads to haphazard disposal of MSW in the open dumpsite causing environmental distresses. Further, it was perceived that the waste that is produced at study locations was higher than the volume of dustbins and there is insufficient number of collection bins present at the study locations. Moreover, the municipal authorities have made no provisions for separate waste collection bins for biodegradable as well as for non-biodegradable waste respectively. Furthermore, the dustbins used for the gathering of waste are open or exposed containers without any cover system consequently leading to scavenging actions of stray animals that affects the scattering of waste near the proximity of dustbins. However, in general the collection efficacy of the waste generated at the study regions has been reported approximately 60%. The containers used for collection of waste in selected locations have been demonstrated in Figure 3.11.

(a) Solan (b) Mandi

(c) Sundernagar (d) Mandi

Figure 3.11: Containers for collection of waste in selected locations of HP

Further, the overall collection efficacy on the basis of per capita has been demonstrated in Figure 3.12 (a) & (b).

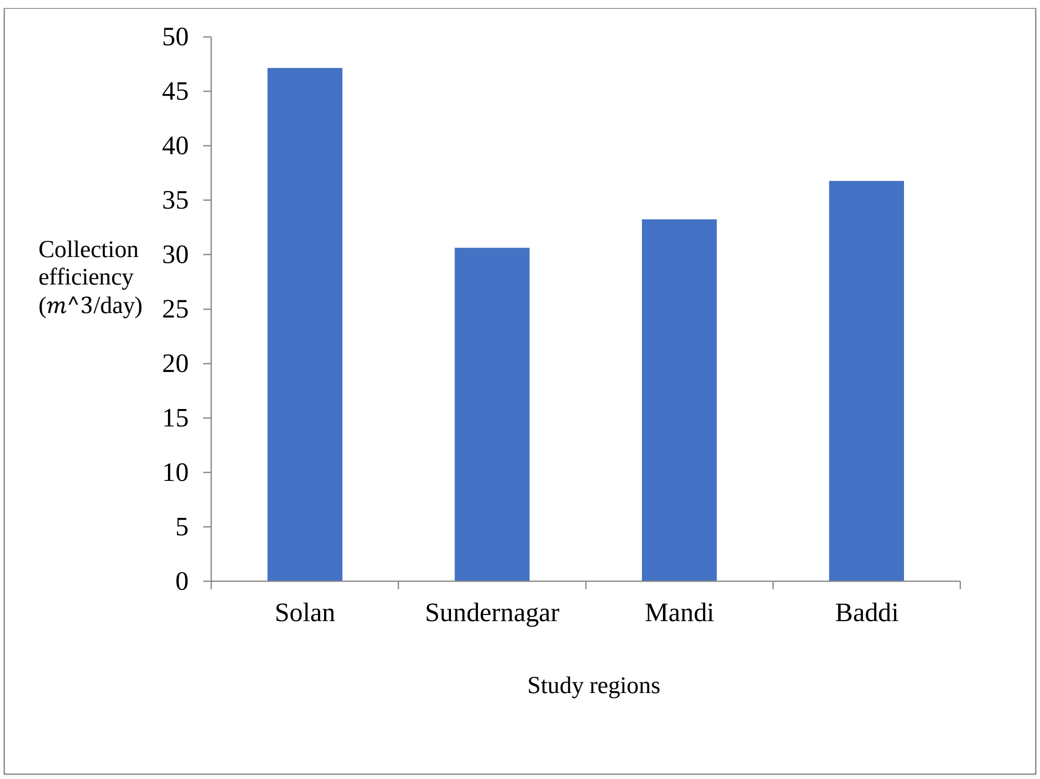


Figure 3.12 (a): Collection capacity of MSW in study locations of HP

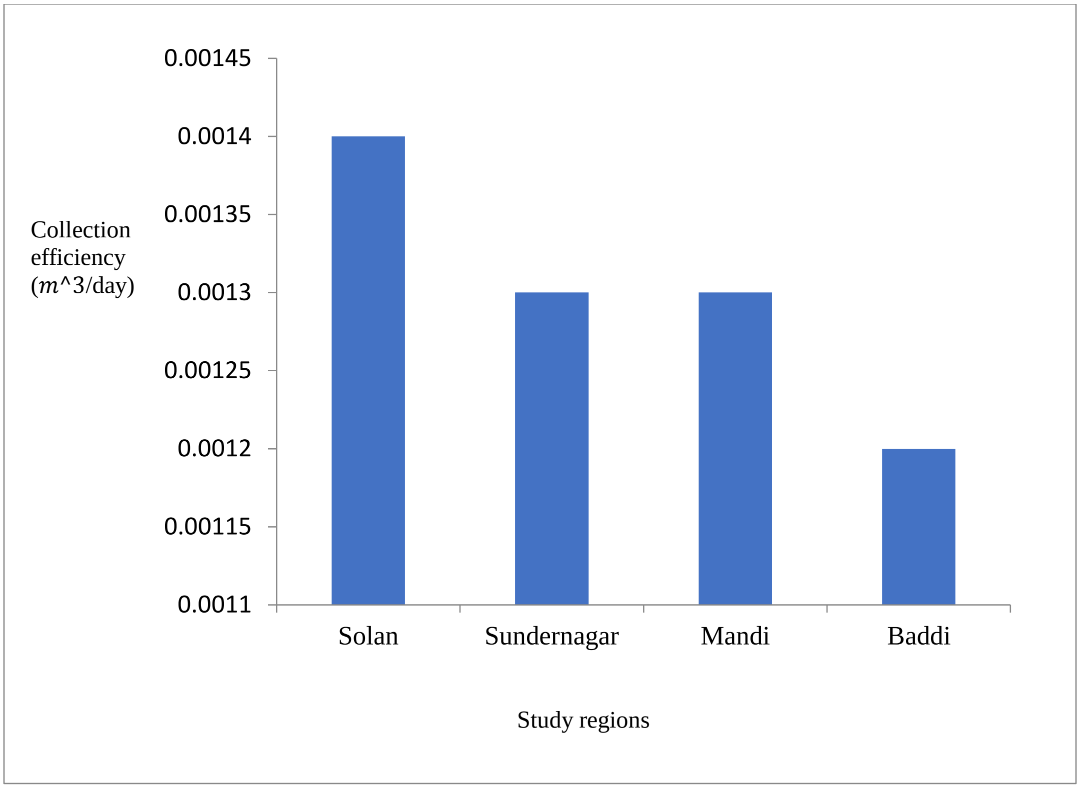


Figure 3.12 (b): Collection capacity on the basis of per capita of MSW in study locations of HP

3.6.1.4 MSW transportation

The most problematic issue accompanying with waste transportation is inadequate capacity of vehicles, insufficient quantity of collection vehicles and lack of maintenance. Hence inadequate number of vehicles as well as drivers for operating such vehicles is one of the major reasons of inefficiency of the overall collection systems. Most of the existing vehicles are in crumbling conditions and also lack on-maintenance and non-cleaning after waste disposal. Further, vehicles including tractors, trucks, and compactors employed for the carriage methods are open body type causing spillage of waste on the streets and roads. The variety of vehicles for selected regions has been demonstrated in Figure 3.13.

(a) Solan (b) Mandi

(c) Sundernagar (d) Baddi

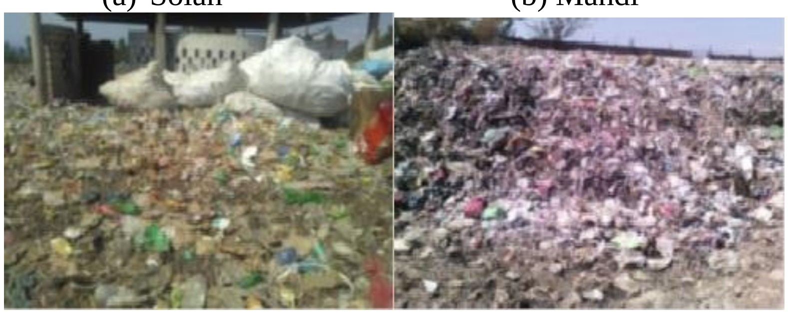
Figure 3.13: Vehicles for waste transportation in selected study region of HP

3.6.1.4 MSW disposal

Unscientific and illegal disposal of MSW is severe health concern as well as an environment issue because of percolation of pollutants by means of leachate into aquifers and subsoil. All the waste generated from the households is directly disposed of in open dump sites with no precautionary actions is experienced to avoid the contamination of leachate into the environment in the respective study locations of Himachal Pradesh. The various disposal locations in the selected regions have been demonstrated in Figure 3.14.

It is perceived that the land accessible for the dumping of waste is approximately 5 to 6 acres for all the four study regions and the operations at these dumping sites began in the year 1994 onwards as per the conversion with the consultants of municipalities of particular selected locations. It is observed by the conversation with sweepers and MC's officials that dumped waste is heterogeneous in nature and even less than 10% waste is recycled in the informal manner. Hence it is conveyed that reprocessing and recovery of waste are insignificant in the respective study regions of Himachal Pradesh.

(a) Solan (b) Mandi



(c) Sundernagar (d) Baddi

Figure 3.14: Open dumps for disposal of waste in study regions

Additionally, the waste that is dumped is not covered by protective layered. soil, sand and it is entirely exposed to the atmosphere and hence provide shelter to ailment vectors. In the nutshell, it can be concluded that the main reason for the lower efficiency of waste management in study regions are because of inadequate resources; inadequacy in collection equipment's and waste storage facilities, inadequate machineries and absence of treatment processes.

3.6.2 '*Wasteaware'* Benchmark Indicators

3.6.2.1Examinationof MSW management utilizing 'Wasteaware' benchmark parameters

The 'wasteaware' benchmark indicators for study locations including background information of the cities have been reported below in the Table 3.4 (a).

Table 3.4 (a): 'Wasteaware' Benchmark indicators for study locations in HP

No.	Category	Indicator	Solan	Mandi	Sundernagar	Baddi	Chandigarh City
Background Information of the City							
B1	Country Income level	World Bank Indicator level	Lower-Middle	Lower-Middle	Lower-Middle	Lower-Middle	Lower-Middle
		GNI per Capita	99,184.87 INR	99,184.87 INR	99,184.87 INR	99,184.87 INR	99,184.87 INR
B2	Population of the City	Total population of the city	39,256	26,422	24,344	29,911	1,055,450
B3	Waste generation	MSW Generation (tons/year)	8030	7665	7300	6570	135050
W1	Waste per capita generation	MSW per capita (tons/year)	153.3	160.6	160.6	157	128
W2	Waste composition	3keyfractions–as % wt. of total waste generated					
W2.1	Organic	Organics (food and green wastes)	56%	54%	52%	52%	52%
W2.2	Paper	Paper	18.2%	20%	18%	16%	6%
W2.3	Plastics	Plastics	14.50%	15%	12%	13.5	7%

The first component of 'wasteaware' indicators depicts background information of the city includes population of the cities, waste generation, per capita waste generation and waste composition. The waste produced in the study regions are substantially lesser than the inclusive waste produced in Chandigarh city. This is due to the reason that large variation in the population in between Chandigarh as well as in the study regions in Himachal Pradesh.

The second component consists of qualitative indicators includes waste collection coverage, quality of waste collection services, controlled treatment and quality of 3R's provisions. The description of all the parameters in quantitative indicators has been summarized in Table 3.4 (b)

Table 3.4 (b): 'Wasteaware' Benchmark indicators (Quantitative indicators)

Sr. No.	Parameters		Solan	Mandi	Sunder nagar	Baddi	Chandigarh
1.1	Public health – Waste collection	Waste collection coverage	60% (L/M)	60% (L/M)	60% (L/M)	60% (L/M)	90% (M/H)
1C	-	Quality of waste collection service	81% (M)	79%(M)	77% (M)	74% (L/M)	90% (M/H)
2	Environment control methods	Controlled treatment	30% (L)	30% (L)	20% (L)	17% (L)	30% (L)
2E	-	-	0% (L)	0% (L)	0% (L)	0% (L)	0% (L)
3	3Rs– reduce, reuse, recycle	Recycling rate	0% (L)	0% (L)	0% (L)	0% (L)	0% (L)
3R	-	Quality of 3R's provision	10% (L)	15% (L)	10% (L)	10% (L)	17% (L)

It was notified from 'Wasteaware' benchmark indicators examination that there is much lesser collection efficiency of MSW and waste collection and treatment facilities thereby characterized in (Low/Medium) index comparatively to Chandigarh which have more collection efficacy than our study locations and lies in (M/H) index. However, for the quantitative parameters including 3R's facilities, the study regions as well as Chandigarh has been characterized in the (L) index. Further, the 'Wasteaware 'evaluation also discloses that the recycling provisions are almost negligible in the study regions of Himachal Pradesh.

The third component of 'Wasteaware' benchmark indicators is qualitative indicates includes four parameters named as user inclusivity, provider inclusivity, national framework and local institutions. The 'Wasteaware' benchmark indicators of the qualitative indicators have been summarized in Table 3.4 (c).

Table 3.4 (c): 'Wasteaware' Benchmark indicators (Qualitative indicators)

Sr. No.	Parameters		Solan	Mandi	Sunder nagar	Baddi	Chandigar h
4U	User inclusivity	User inclusivity	69% (L/M)	70% (L/M)	55% (L/M)	52% (L/M)	75% (M)
4P	Provid er inclusivity	Degree of provider inclusivity	65% (L/M)	66% (L/M)	60% (L/M)	61% (L/M)	78% (M)
6N	Nationa l framew ork	Adequacy of national SWM framework	55% (L)	58% (L)	55% (L/M)	52% (L/M)	60% (L/M)
6L	Local institutions	Degree of institutional	62% (L/M)	65% (L/M)	72% (M)	58% (L/M)	75% (M)

The results obtained from 'Wasteaware' benchmark indicators (qualitative indicators) revealed that the quality of qualitative parameters lies in the low/medium index for the four study regions of Himachal Pradesh. However, for Chandigarh city, the qualitative indicators lie under the category of medium index (M) [138]. Hence, Chandigarh city has improved quality of qualitative indicators because of upgrading waste management system as compared to Himachal Pradesh.

3.6.2.2 Matrix Method for quantification of indicators

By utilizing matrix method, the 'weights' has allocated to parameters including quantitative as well as qualitative of '*wasteaware*' benchmark indicators in the study regions and its comparison analysis with Chandigarh city that have been concise in Table 3.5 and the overall scores by utilizing 'matrix' method have been demonstrated below in Table 3.6.

Table 3.5: Assignment of weights by utilizing 'Matrix 'method [4].

No.	Category	Indicator	Solan	Mandi	Sundernagar	Baddi	Chandigarh City
Quantitative Indicators (Public Health, Environmental Control, 3R)							
1.1	Public health – Waste collection	Waste collection coverage	60% (L/M) (2)	60% (L/M) (2)	60% (L/M) (2)	60% (L/M) (2)	90% (M/H) (4)
1C		Quality of waste collection service	81% (M) (3)	79% (M) (3)	77% (M) (3)	74% (M) (3)	90% (M/H) (4)
2	Environmental control– waste treatment and disposal	Controlled treatment and disposal	30% (L) (1)	30%(L) (1)	20% (L) (1)	17% (L) (1)	30% (L) (1)
2E		Degree of environmental protection in waste treatment and disposal	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)
3	3Rs– reduce, reuse and recycling	Recycling rate	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)	0% (L) (1)
3R		Quality of 3Rs provision	10% (L) (1)	15% (L) (1)	10% (L) (1)	10% (L) (1)	17% (L) (1)
Qualitative Indicators (Governance Factors)							

4U	User inclusivity	User inclusi vity	69 L/M) (2)	70% (M) (3)	55% (L/M) (2)	52% (L/M) (2)	75% (M) (3)
4P	Provider inclusivity	Degree of provider inclusivity	65% (L/M) (2)	66% (L/M) (2)	60%(L/M) (2)	61% (L/M) (2)	78% (M) (3)
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	52% (L) (1)	58% (L/M) (2)	55% (L/M) (2)	52% (L) (1)	60% (L/M) (2)
6L		Degree of institution al coherence	62%(L/M) (2)	65%(L/M) (2)	72%(M) (3)	58% (L/M) (2)	75%(M) (3)

Table 3.6: Summary of scores obtained using matrix method [4].

S. No.	**Category**	**Indicator**	**Solan**	**Mandi**	**Sundernagar**	**Baddi**	**Chandigarh City**
Quantitative Indicators							
1.1	Public health – Waste collection	Waste collection coverage	2	2	2	2	4
1C		Quality of waste collection service	3	3	3	3	4
2	Environmental control – waste treatment and disposal	Controlled treatment and disposal	1	1	1	1	1
2E		Degree of environmental protection in waste treatment and disposal	1	1	1	1	1
3	3Rs – reduce, reuse and recycling	Recycling rate	1	1	1	1	1
3R		Quality of 3R's provision	1	1	1	2	1
Total Score			9	9	9	9	12
Maximum Score			30	30	30	30	30
Weightage (%)			**30**	**30**	**30**	**30**	**40**
Qualitative Indicators							

4U	User inclusivity	User inclusivity	2	3	2	2	3
4P	Provider inclusivity	Degree of provider inclusivity	2	2	2	2	3
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	1	2	2	1	2
6L		Degree of institutional coherence	2	2	3	2	3
Total Score			7	9	9	7	11
Maximum Score			20	20	20	20	20
Weightage (%)			**35**	**45**	**45**	**35**	**55**
Total Score (Overall)			9+7 = 16	9+9 = 18	9+9 = 18	9+7 = 16	12+11 =23
Total Maximum Score			30+20 =50	30+20 =50	30+20 =50	30+20 =50	30+20 =50
Overall Weightage (%)			**32**	**36**	**36**	**32**	**46**

The overall results of Matrix method revealed 32% efficiency for Solan and Baddi sites and 36% efficiency for Sundernagar and Mandi sites. However, this has been significantly lower than Chandigarh city (overall score of 46%). The matrix method also reported that overall management of MSW at our study location categorized under low index whereas Chandigarh city lies under the category of Low/Medium index. Further analysis revealed that weightage obtained from quantitative parameters of 'Wasteaware' analysis were same for all the study locations (30%) whereas it was slightly more for Chandigarh (40%) as it is a planned city and thereby has a slight advantage in comparison to other Tier-II and Tier-III cities. Interestingly, it was observed that for governance parameters both Mandi and Sundernagar scored 45% whereas Solan and Baddi scored 35% but the outcomes were significantly lower than Chandigarh (55%).

3.6.3 Recommendations for the efficient MSW Management in the study regions in Himachal Pradesh

It was perceived by the matrix method evaluation that MSW management efficacy in the study regions is enormously deprived and the inclusive score being lower than 40% in the study regions. Following are some recommendations for the enhancement of prevailing MSW management system in the study regions of Himachal Pradesh.

3.6.3.1 Source segregation

It was perceived from the survey conducted in the study regions that segregation at the source during the collection procedure from households was entirely absent in all study regions. In this context, source separation is the mandatory step for the efficient management system of MSW. Moreover, source segregation of waste is neither time consuming process nor an expensive process hence can be effectively employed in the domestic levels. The waste that is not segregated or sorted at source and dumped as an open dumping proves extremely detrimental because this affects the treatment procedures of the MSW. The waste segregation into two sets including biodegradable as well as non-biodegradable which may assist enormously in improvement and enhancing the treatment processes. It is reported from the study that major fraction of produced MSW is organic in nature as per the perspective of Indian cities and thus highly suitable to biodegradation techniques for the production of energy. The anaerobic waste treatment led to the production of methane and hence for bio methanation plants should be mounted for the production of biogas that may employ as the source of energy. Furthermore, fertilizer and compost generated from the MSW is a worthy source of nutrients and hence can be efficiently utilized as natural soil enricher.

Additionally, the sorting and separation of MSW may lead to major benefits including reduction in consumption of waste and increment in the financial potentials for the rag-pickers. Furthermore, it also minimizes the load of waste on the landfill sites hence increasing the lifespan of the current landfills as well as the reduction in green-house gas emissions. Hence, segregation at source is exceedingly well acclaimed solution that can be initiated at all the household levels in the vicinity of study regions as well as in entire districts of Himachal Pradesh for the betterment of MSW management. It can be attained by accompanying trainings, workshop programs and attentiveness movements in the study regions as well as in the other districts of Himachal Pradesh.

3.6.3.2 Utilization of Transfer stations

It has been observed in HP that there exist small scattered dumpsites along the entire state. Such increased scattered dumpsites are difficult to manage and hence there should be installations of transfer stations for waste sorting. The main objective of these transfer stations should be to ensure that all recyclables (both organic and inorganic) are completely separated and only inert waste are dumped in the landfill sites. This will substantially increase the lifespan of the landfill and will lead to ‘zero waste’. Further, often due to the absence of sufficient land to construct transfer stations; certain municipalities utilize mobile compactor trucks with primary collection vehicles for improving the systems until permanent transfer stations can be constructed.

3.6.3.3 Waste Audit

The major drawback in designing of an efficient and operational waste management system in the selected regions is the non-availability of consistent data comprised of the waste volume, characterization of waste as well and other sources of waste. Hence forth, waste audit by the municipalities during different seasons should be carried out at the study locations in Himachal Pradesh.

3.6.3.4 Enhancement in current infrastructure

The present study depicts that the prevailing infrastructural facilities comprised of manpower are entirely inadequate for the waste management in the study locations. Henceforth, it is suggested to utilize of color-coding underground dustbins for the waste collection. These dust bins should be at the distance of at least 100 m apart from each other. Moreover, separate containers are to be utilized for wet and dry waste such that these dustbins can increase convenience to the public for dumping their wastes accordingly. However, it was perceived from the survey that the actual situation is entirely diverse and hence no endorsements have been executed presently in the study regions. Henceforth, it is recommended that the municipal authority of the respective zones must take suitable steps to avoid spreading of trash here and there which cause environment pollution. There must be sufficient and covered dust bins for the minimization of disease-causing vectors. Additionally, there should be separate waste assortment vehicles for the transfer of biodegradable fraction to the bio methanation plants. It is revealed that at present such recommendations have not applicable in the study locations for the improvement of the prevailing MSW managing processes. In this regard, it is proposed that municipalities must take extreme care about up keep of the worn-out vehicles. Furthermore, suitable training must be provided for the rag-pickers for the assurance of the increased efficacy of segregating the wet and dry waste.

3.6.3.5 Installation of RDF plants

As per the terrain conditions of Himachal Pradesh and the physical as well as chemical composition, it is suggested that ‘reduced derived fuel’ plant can be set up here in the selected regions considering the plane sections. For practical purposes, a single transfer station can be operational for Sundernagar and Mandi while the other can be serve for Solan and Baddi for the treatment and processing of wastes for the production of reduced derived fuel.

3.6.3.6 Engineered landfills

Ultimately, this is acclaimed that sanitary engineering landfill system with leachate collection provision, adequate liner facility, gas collection facility and final cover system should be merged in HP for the efficacy of waste management

.

Summary

The inclusive study revealed out that the production rate in Himachal Pradesh on the daily basis is observed as 350 TPD whereas the waste production rate in individual study region of Himachal Pradesh reported as 22 tons/day. However, the collection efficacy of the waste is reported 60-70% in the study regions that proves ineffective for the efficient MSW management. This low collection efficacy is may be due to inadequate and lack of collection dust bins, inadequacy of machineries, a smaller number of trucks for waste transportation. Additionally, the research also highlighted ‘wasteaware’ benchmark parameters and ‘matrix ‘system for examination of the MSW management for the respective selected locations in HP. It is observed from using these methods that the study regions of Himachal Pradesh exhibit poor performance of ‘Environmental control processes’ such as assortment and processing of waste, waste disposal facilities, 3R’s provision (reduce, recycle, reuse) in Himachal Pradesh. Furthermore, the study proposes few recommendations that must be taken by municipal authorities of the particular study regions for betterment of MSW management. As a whole, there should be proper facility of ‘liners’ and ‘leachate collection and removal facility’ for the adequate management of leachate production. In this context, categorization of waste is the first step involved in improving the management of existing practices and this has been discussed in details in the following chapter.

CHAPTER 4

CHARACTERIZATION ANALYSIS OF MUNICIPAL SOLID WASTE IN HIMACHAL PRADESH

4.1 Introduction

The enormous growth in MSW and its inadequate management is a major environmental issue being experienced at the global level and also for developing nations. This is predominantly due to the inadequacy of appropriate treatment technologies and suitable alternatives for developing countries like India [139]. Hence, it is mandatory to generate baseline data regarding municipal solid including its generation and characterization analysis that can lead to improved MSW management system [140,141, 142]. As summarized from Chapter 3, the existing performance of management of MSW is very low and one of the possible methods for its improvement would be to categorize the waste generated at the study locations.

Thus, it is mandatory to categorize the waste characterization. The organic waste fraction in the municipal solid waste particularly in Indian cities is higher than the waste in developed countries [42]. In this context, the environment friendly services for the treatment and disposal of waste are of immediate importance in Indian context.

Furthermore, the study regions in Himachal Pradesh follows a certain characteristic pattern of waste production as the population of HP is broadly dispersed that leads to evolution of dumpsites and moreover these particular locations experience extensive temperature variations and difficult terrain conditions that affect the implementation of appropriate strategies for management of MSW generated. Additionally, the study regions are ‘en-route’ of other tourist spots thereby frequently misrepresenting the total volume and the character of waste Hence, MSW produced in the study regions are generally categorized as mixed waste without any distinguishing classifications. The waste characterization is a major factor in making an effectual, cost effective and environment friendly waste management system [31,143]. Additionally, physic-chemical characterization of waste can help policy makers and city organizers to reduce landfill waste and start-up recycling programs.

The present study emphases on the characterization, methane and energy potential of MSW produced at the study regions based on the seasonal variation including summer, rainy and winter to eradicate the biasness.

4.2 Materials and Methodology

4.2.1 Sampling Procedure

The sampling procedure implemented in the study was as per the guidelines recommended in ASTM-D5231-92[144, 145, 146]. According to the method prescribed in ASTM-D5231-92, MSW was collected from the transporting vehicles of municipal solid waste at the time of unloading the waste in the dumping sites. As per the procedure prescribed, around 1000 kg of the waste were unloaded from the conveying vehicles and the entire material was spread out on the plastic sheet and mixed the waste to attain the homogeneous mixture of waste. Out of 1000 kg of total waste, 100 kg of waste samples were collected each day for the 10 days of sampling period in order to acquire representative waste sample. The sampling process comprised of forty samples (n =10 for each of the four sites) employed for the study. Further, the waste samples thus attained after the completion of sampling procedure were segregated and sorted by manual way into various components by the help of 'rag- pickers' employed by municipalities of the particular selected locations.

Further, the chemical characterization of waste comprised of 2 kg of homogeneous organic sample that were placed to cover an area of $10m^2$ from where10 samples of 2 kg were randomly sampled. Additionally, 10 samples were entirely mixed to obtain representative sample which was conveyed to the laboratory in tight plastic containers for the chemical characteristic's assessment such as proximate and ultimate analysis. Further, heavy metal analysis study was also carried out of the MSW samples collected from all four study regions.

4.2.2 Characterization of MSW

The physical composition of municipal solid waste is important as it helps in determining the selection of equipment, operation of equipment and waste to energy facilities for energy recovery. In this context, composition of waste, moisture content and density of waste are most significant parameters because they highly affect the extent and rate of waste decomposition.

Physical characterization

The physical characterization of waste includes the categorization of samples into various components such as biodegradable waste, non-biodegradable, recyclable items and inert materials. The samples were segregated into various components such as compostable, paper, plastic, glass textile, metal, rubber, debris etc. Finally, the weight of each component was acquired to determine the physical characterization and then the samples were conveyed immediately to the laboratory for the quantification of moisture content analysis.

Further, the determination of density of waste is essential for the design of an effective waste management system. Density plays an important role in the designing of engineered landfill [42]. The changes in the density may occur as the waste moves from the source to the dumping site due to handling, wetting and drying by weather vibrations in the transportation vehicles. The apparatus used for the density determination is wooden box of 1 m^3 capacity and spring balance weighing up to 50 kg. The municipal solid waste was collected from different parts of the heap of waste to obtain a composite sample. The wooden box of capacity $1m^3$ is placed and the composite municipal solid waste is poured into the box. The box is filled up to the top and compacted properly. After compaction, the sample is weighed with the help of the spring balance. The waste is filled in the box for three times and hence the average reading is noted. The mass per cubic meter is obtained and density of MSW is calculated.

Chemical Characterization

The chemical characterization of waste including proximate as well as ultimate analysis and it is accomplished to define the fraction of elements and ash content of the MSW. The sample was prepared according to the ASTM standards [146-149]. Additionally, some other parameters were also assessed such as moisture content, volatile matter, ash-content, fixed carbon and elemental analysis includes carbon, hydrogen, nitrogen, sulfur and oxygen (C, H, N, S and O respectively). However, the gross calorific value was determined by using bomb calorimeter in the laboratory.

Moisture Content

Moisture content indicates the estimation of total solids content in MSW. The moisture content of the sample was determined by heating a known weight of waste in an oven at temperature of 105°C until constant weight was obtained [150].

The calculation of moisture content of MSW is as follows:

Moisture content (%) = Wet weight of oven dried sample /weight of sample x 100

Ash Content

Ash content was assessed by heating the sample at 750°C in muffle furnace for one hour, until the waste is absolutely changed into ash. Ash content is estimated as below:

Ash content (%) = 100-Loss on ignition

Volatile Matter

The material remained after the waste is exposed to a temperature of 950°C for approximately seven minutes.

Fixed Carbon

It depicts the remains of combustible matter that can be burned in the solid state not as gaseous form or vapors.

Calorific Value

Calorific Value is the amount of heat produced from combustion of a unit weight of sample and expressed in kcal/kg. The calorific value was determined by using Bomb calorimeter. Calorific value is determined to know if the MSW is amenable for production of RDF. The sample is suitable for incineration process if the calorific value is more than 2000 kcal/kg [42].

Elemental Analysis

The elemental analysis was carried out wherein the samples were dried at 75°C and crushed into smaller pellets, powdered and hence sieved through 2mm and 1mm sieves. The elements including carbon, hydrogen, nitrogen sulphur and oxygen (C, H, N, S and O) were evaluated by using Elemental analyser.

4.2.3 Sampling and Estimation of Methane gas emission

4.2.3.1 Generation of methane in anaerobic condition

The valuation of methane gas emission (landfill gas emission) is a significant aspect in effectual management of MSW as methane is the source of greenhouse gas emission and is an issue of concern if not regulated [151]. However, if sufficient amount of methane is produced, it can be harnessed as a green fuel. The present study includes the valuation of potential for methane generation from all the study regions based on seasonal variations. The sample was prepared by collecting 30g of organic fraction of waste from all four dumpsites of the study regions. These samples were then transferred to a digester having capacity of 250 ml. Then 50 ml of distilled water was added in the digester to prepare the final volume up to 300ml. The samples were preserved at room temperature and hence assessed for methane gas generation [152].

4.2.3.2 Instrumental analysis of methane generation

After completion of digester procedure, the methane was drawn using syringes, of 10μl and were transferred in plastic bottle and hence inserted to Gas chromatography equipment (GC, Shimdzu, PerkinElmer) using Supelco Carboxin TM 1000 column using gas standards and fitted with Flame Ion Detector (FID) for the estimation of methane gas generation from the organic waste [152]. The temperature conditions of FID detector were maintained at 200˚C of 1ml volume whereas oven temperature was maintained at 120˚C. The above experiment was repeated thrice and the average values were recorded.

4.4 Results and Discussions

4.4.1 Physical Characterization

Waste characterization is reliant on types as well as sources of waste. The nature of the dumped waste in the landfill will subsequently affect the gas generation and leachate production by means of the relative proportions of degradable and non-degradable components. The analytical results of physical characterization over three seasons for all the study regions have been illustrated in Tables 4.1 to 4.3.

Table 4.1: Physical composition of MSW in *summer season*

Parameters	Solan	Mandi	Sundernagar	Baddi
Density (kg/m³)	552±1.35	540±2.82	512±1.27	487±0.98
Organic waste (%)	57.67±0.52	56.00±0.63	52.83±0.98	50.83±0.75
Paper (%)	17.17±0.75	18.17±0.75	20.83±0.75	11.50±0.55
Plastic (%)	6.49±0.55	6.33±0.82	6.67±0.52	13.67±0.82
Glass (%)	3.33±0.52	3.17±0.55	3.17±0.41	3.17±0.41
Metal (%)	1.67±0.53	2.17±0.55	2.16±0.75	2.00±0.63
Inert (%)	5.67±1.68	6.00±0.52	6.00±0.63	9.00±0.89
Rubber (%)	2.67±0.52	3.17±0.41	3.17±0.75	1.83±0.41
Textile (%)	5.33±2.67	4.99±0.52	5.17±0.75	8.00±0.63

Table 4.2: Physical composition of MSW in *rainy season*

Parameters	Solan	Mandi	Sundernagar	Baddi
Density (kg/m³)	524±2.74	520±4.86	492±2.15	480±2.33
Organic waste (%)	55.00±0.71	54.60±1.54	51.14±0.56	50.40±0.55
Paper (%)	18.80±1.30	17.00±1.87	19.60±1.52	10.60±0.89
Plastic (%)	4.20±0.84	7.40±1.52	5.26±0.71	14.40±1.67
Glass (%)	2.60±0.55	3.20±1.30	2.80±0.81	2.20±0.45
Metal (%)	3.20±0.84	2.80±0.84	3.80±0.45	3.40±0.89
Inert (%)	7.00±0.71	6.80±0.84	7.80±0.45	8.60±1.34
Rubber (%)	3.20±0.84	2.20±0.84	2.80±0.85	2.60±0.89
Textile (%)	6.00±1.22	6.00±1.22	6.80±0.84	7.80±0.84

Table 4.3: Physical composition of MSW in *winter season*

Parameters	Solan	Mandi	Sundernagar	Baddi
Density (kg/m³)	514±4.92	490±2.69	482±1.26	465±3.32
Organic waste (%)	53.40±0.55	52.00±1.14	50.40±0.55	49.00±0.71
Paper (%)	12.20±1.10	17.00±1.87	17.80±01.10	8.40±0.55
Plastic (%)	4.60±0.89	7.40±1.52	4.40±0.55	16.40±1.14
Glass (%)	6.60±0.55	3.20±1.30	6.30±0.84	5.00±0.71
Metal (%)	3.80±0.84	2.80±0.84	5.00±0.71	2.80±0.84
Inert (%)	8.00±0.71	6.80±0.84	6.90±0.89	7.80±0.84
Rubber (%)	3.80±0.84	2.20±0.84	2.70±0.84	1.80±0.84
Textile (%)	7.60±0.55	8.60±1.22	6.50±1.00	8.80±1.30

However, the physical characterization results have been also demonstrated graphically in Figures 4.1 to 4.4

The analytical study revealed that the waste of Himachal Pradesh has a high proportion of organic content of the total waste generated. The organic fraction is comprised of waste such as vegetables, food waste, fruits as well disposable and rotten fruits and vegetables from farmers market near the vicinity (*sabzi-mandi*). The average value of organic waste over the three seasons at the study locations were observed to be 55.35% for Solan, 54.20 % for Mandi, 51.87% for Sundernagar and 50.40% for Baddi respectively.

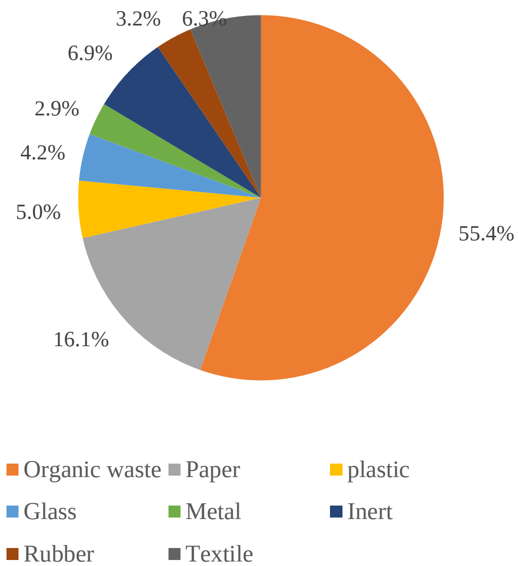


Figure 4.1: Pie chart showing composition of MSW in Solan

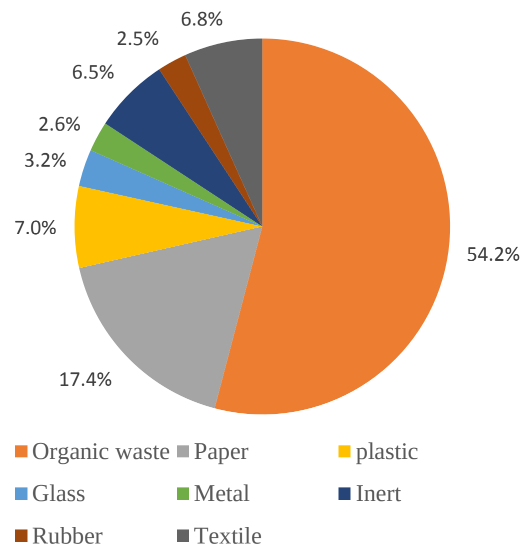


Figure 4.2: Pie chart showing composition of MSW in Mandi

In this context, the proportion of organic fraction was perceived to be marginally higher in Solan and Mandi comparatively to Sundernagar and Baddi due to the reason that the dumping sites in two regions are adjacent to the fruit and vegetable markets of city and the rotten and degraded food products are directly dumped in the dumpsite.

The seasonal variation in the physical composition of MSW reported that the biodegradable waste fraction to be higher in summer season whereas less in winter season because of high temperature and consumption of more goods, fruits and vegetables in summer season. An inflow of tourists during the summer season may also be a consequence in increased fraction of waste during the summer season. However, the literature studies revealed the lesser proportion of organic waste in Indian cities including Jalandhar (34%), Varanasi (32%), Bhopal (41%), Kolkata (50%), Chandigarh, Mohali, Panchkula (43-54%).[42, 153, 154,155] as compared to our study locations in Himachal Pradesh.

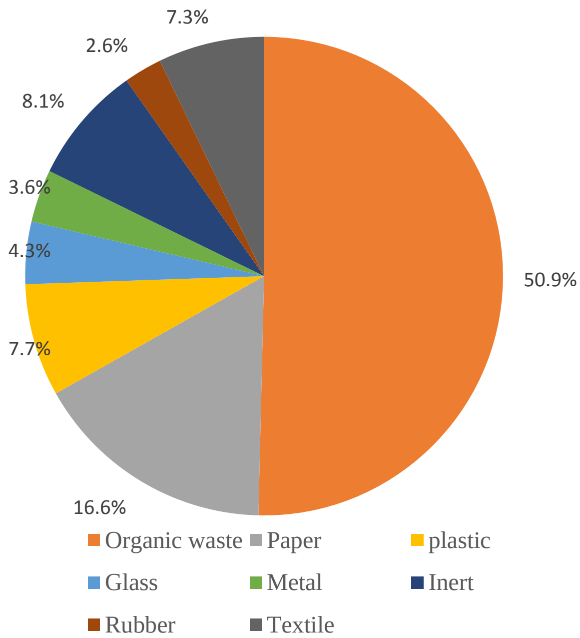


Figure 4.3: Pie chart showing composition of MSW in Sundernagar

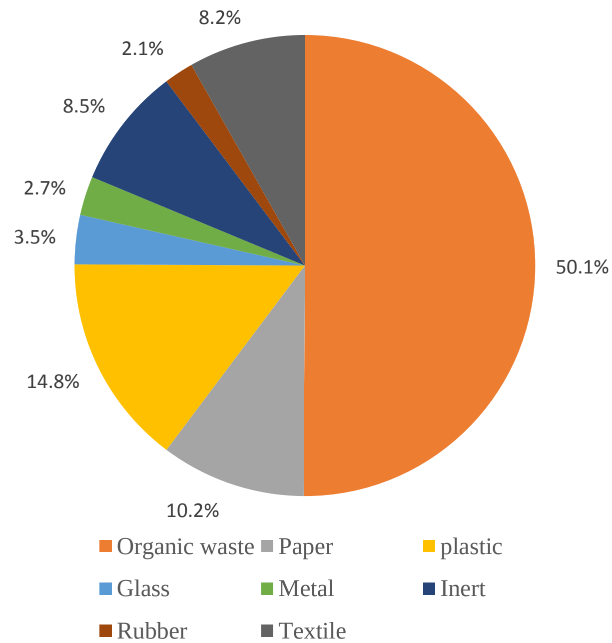


Figure 4.4: Pie chart showing composition of MSW in Baddi

Further, paper waste formed the second highest fraction out of the total MSW produced and includes all form of paper products including printed paper, newspapers and magazines in the study locations of Himachal Pradesh. The average values were estimated to be 16.05, 17.39, 19.74 and 10.60% for the study regions including Solan, Mandi, Sundernagar and Baddi. The highest waste fraction observed in Sundernagar town due to the reason that it is considered as educational hub that comprised of plenty of schools, colleges, institutions, offices etc. that adds large fraction of waste. However, the quantity of paper waste was observed to be higher in summer season than that of rainy season and winter seasons whereas the particular proportion illustrates slight increment for Solan town in rainy season. However, such similar values were observed for characterization studies conducted for nearby Tricity locations such as Chandigarh, Mohali and Panchkula (15-17%) [150].

The average proportion of plastics in the study regions varied between 5 to 15%. The study revealed the higher fraction of plastic waste for Baddi region and its progressive increment with seasonal variations. However, the utilization of plastic bags and pouches have been banned in Himachal Pradesh since 2003, however the location of the Baddi study area is such that it lies in the border regions of Himachal Pradesh and Haryana state, wherein the usage of plastics are in practice till date hence leading to excessive fraction in the particular study region. The results have been compared with literature which revealed that the fraction of plastic waste in Chandigarh (7%), Jalandhar (9%), and Bhopal (10%) were also comparatively lesser than Baddi town however more than the other study regions of Himachal Pradesh. In this context, these waste fractions should be recycled to diminish the transportation costs and thus increment in the lifespan of the respective dumpsites.

Further, the inert as well as textile waste was reported in the range of 5-9% for the study locations in Himachal Pradesh. Interestingly, Baddi town is having higher proportion of inert waste and textile waste because of more constructional and industrial activities in the town. The fraction of metallic objects, glass bottles were observed to be in lesser fractions at all dumpsites because of informal recycling of these by rag-pickers which serve as an extra source of income for them.

4.4.2 Chemical Characterization

The chemical characterization analysis of MSW is mandatory for the improvement of treatment strategies thereby execution of waste to energy facilities like bio methanation, refuse derived fuel (RDF) and vermicomposting for the observation of chemical actions. The results of chemical characterization including both proximate and ultimate analysis along with summer season for all the study regions has been shown in Table 4.4 and for rainy season and winter season the results have been presented in Appendix-A (Table 1, 2).

Table 4.4: Chemical characterization of municipal solid waste in summer season

Proximate analysis of municipal solid waste					
Parameters	**Units**	**Solan**	**Sundernagar**	**Mandi**	**Baddi**
pH	-	6.78±0.37	6.23±0.92	6.57±0.18	5.78±0.52
Moisture content	% by wet weight	51.00±0.66	44.00±1.00	48.00±0.33	43.00±2.67
Ash Content	% by dry weight	21.32±0.58	22.22±0.58	24.67±1.53	25.00±2.00
Volatile matter	% by dry weight	26.00±1.00	30.20±1.00	24.00±1.00	28.67±0.58

Fixed carbon	% by dry weight	1.68±0.58	3.58±0.58	3.33±0.58	3.33±1.84
Calorific value	(kcal/kg)	2359±142.34	2528±272.02	2429±126.56	2598±36.86
Ultimate analysis of municipal solid waste					
Parameters	**Units**	**Solan**	**Sundernagar**	**Mandi**	**Baddi**
Carbon	% by dry weight	43.82±2.11	41.74±0.65	48.58±1.73	49.36±1.67
Nitrogen	% by dry weight	1.29±0.11	1.18±0.22	2.01±0.07	1.78±0.06
Hydrogen	% by dry weight	4.45±0.45	3.59±0.38	4.07±0.16	5.21±0.77
Potassium	% by dry weight	0.70±0.10	0.80±0.10	0.73±0.06	0.83±0.06
Phosphorus	% by dry weight	0.61±0.04	0.29±0.01	0.35±0.02	0.83±0.12
Sulphur	% by dry weight	0.18±0.02	0.22±0.02	0.19±0.01	0.25±0.01
Oxygen	% by dry weight	12.30±0.67	14.38±1.25	12.23±0.83	10.27±0.03
Mineral Content	% by dry weight	40.60±2.08	41.20±4.26	38.03±0.67	34.02±1.49
C/N	-	28.37±0.67	21.13±1.22	25.27±0.55	30.13±1.07

The moisture content of waste for the study locations was observed to be higher for all the three seasons mainly due to the highest fraction of organic waste that presents in the waste sample. However, the average range of moisture content of MSW varied in the range of 42 to 51% for three seasons in four study regions. It was observed that negligible significant variation in the moisture content was observed based on the seasonal variation in the study regions. In comparison with the literature study which revealed that slighter moisture content for different cities including Bhopal (28%), Chandigarh (35% - 59%) and Jalandhar (25% - 34%) [42,153, 154,155]. Further, moisture content increases the weight of municipal solid waste thereby increase the collection and transportation costs.

Additionally, the average value of volatile matter in the study locations lies in the ranges of 23 to 28% that is similar to the volatile matter reported (17-28%)for the nearby locations including

Chandigarh, Panchkula and Mohali [150] and also for Jalandhar city (18-25%) [42]. However, based on seasonal variation it is observed that the higher volatile matter was observed during summer season. Further, the volatile matter of MSW is because of the presence of biodegradable fraction in MSW whereas the volatile content is the indication of the amount of heat energy which can be generated from the MSW [156].

The ash content of MSW for the study regions varied in the range of 23-29% that is considerably lesser than the reported study for Jalandhar (38-47%) [42] but were found similar to the ranges observed for the Tricity of Chandigarh, Panchkula, Mohali (22 -35%) [150]and Dhanbad city (24.71 -31.69%) [152]. Further, the ash content was reported as more for the winter conditions in all of the study regions. This is due to the reason that people in the particular locations burn wood for heating purposes during the winter seasons. The ash content is significantly influenced by inert materials and since the inert fractions in the study locations are relatively low, the ash content was not overly exceeded. As per USEPA suggestions, waste is having ash content in the range of 5 -15% is best suited for incineration [157].

Further, the amount of fixed carbon in the study regions lies in the range of 1.68 -4.86%. The variation in seasons revealed that the amount of fixed carbon in three regions were higher during the winter season because of wood burning that acts as a source of heat in the winter season. The average lowest value of fixed carbon was observed for Solan and the highest value were observed for Baddi and are correlated to moisture content which were the highest for Solan and least for Baddi. The higher value of fixed carbon is the indication of a longer retention time in the combustion chamber to reach complete combustion. Further, a higher value of fixed carbon is indicative that the waste is resistant to aerobic or anaerobic degradation [158].

Further, the average calorific value of the fuel for all the three seasons including summer, rainy and winter season in the study locations were reported in the range of 2327-2667 kcal/kg. The average calorific value for Solan was observed to be least whereas the highest value was reported for Baddi town. This is particularly due to the reason that MSW had the highest moisture content in Solan and lesser for Baddi town thereby affecting the calorific value of fuel. The occurrence of moisture contents in waste has a tendency to reduce the calorific value of the waste because the calorific value is inversely proportional to the moisture content of the waste. Seasonal variation showed that there was some very slight increment but insignificant change in the calorific value of waste in winter as comparison to the summer season. The results of elemental analysis revealed the average carbon content reported in the range of 39-49% in the study locations of Himachal Pradesh primarily because of occurrence of higher fraction of organic waste in the MSW. However, highest range of carbon content was observed during summer seasons due to more consumption of fruits and vegetables in the season. Comparison with reported literature showed similar such trends for studies carried out in Indian context [42, 150, 152].

The average composition of nitrogen content was evaluated as 1.23% for Solan, 1.11% for Sundernagar, 1.61% for Mandi and 1.73% for Baddi town respectively. However, potash, phosphorous and sulphur content has been observed in the trace fractions and the average values were in the ranges of 0.74 to 0.91%; 0.36 to 0.92; and 0.16 to 0.33 respectively. The maximum fractions were observed in Baddi region because of being an industrial area. Seasonal variation showed slight increase but insignificant change in winter season.

The C/N ratio was observed in the range of 23.92-33.03 in the study regions and is the indicative of its suitability for the composting process [42, 150, 152]. The average values of C/N obtained were 30.14 for Solan, 23.92 for Sundernagar, 26.56 for Mandi and 32.04 for Baddi region of Himachal Pradesh. However, based on seasonal variation, the results showed a slight but insignificant change for C/N ratio during winter season. The literature studies conducted on C/N ratio of waste reported same characteristics in some of the Indian cities i.e. in between 20 - 40 and the indicative of the generated waste is amenable for the composting phenomena [42, 153, 154, 155].

Additionally, it is significant to assess the heavy metal concentration present in the waste because their presence is detrimental the digestion process of MSW. The heavy metal analysis for summer season has been illustrated in Tables 4.5 for all the study regions and the heavy metal analysis for rainy season and winter season have been presented in Appendix - B (Table 3, 4).

The results revealed that the concentrations of heavy metals have been found within the permissible limits hence the municipal solid waste may be viable for composting phenomena. The dumpsite of Baddi town has more chromium and iron due to the tendency for industrial and pharmaceutical activities in the particular town. Further, it is observed that out of the four study regions, Baddi region is having highest concentration of Fe because there is involvement of many steel industries in Baddi region of H.P.

Table 4.5: Heavy metal analysis of municipal solid waste in summer season

Parameters	**Solan**	**Mandi**	**Sundernagar**	**Baddi**	**Permissible limits (Mandal et al., 2014)**
Cadmium	0.78±0.33	0.63±1.76	0.56±0.05	0.89±0.66	5.00
Chromium	39.85±1.68	28.47±0.33	19.93±1.67	58.05±0.85	50.00
Copper	30.06±0.89	21.53±0.67	14.62±4.66	43.12±1.67	300.00
Iron	2304.69±16.87	2218.57±14.67	1894.39±32.15	4135.06±22.46	-
Manganese	26.89±6.83	20.67±2.33	17.69±1.78	32.36±6.87	-
Nickel	21.82±0.33	11.86±1.67	9.89±1.67	34.12±2.33	50.00
Lead	16.43±0.67	7.56±0.67	11.28±1.33	29.48±1.67	100.00
Zinc	34.87±2.56	27.04±0.38	29.25±5.25	42.92±2.62	1000

Note: All the units are in mg/kg

4.4.3 Landfill gas emissions

The assessment of sanitary landfill gas (SLF) emissions has been estimated for waste dumping sites of the study locations in Himachal Pradesh including Solan, Sundernagar, Mandi and Baddi by utilization of gas chromatography analyser. The concentration of methane production has been assessed for the study regions over the three seasons thereby the average concentrations based on seasonal variation have been observed in Table 4.6.

Table 4.6: Estimation of methane gas emission

City Name	**Methane generation (ppm methane /g of waste)**			
	Summer Season	Rainy Season	Winter Season	Average
Solan	17.02±0.76	16.64±1.98	13.69±0.98	15.78±1.24
Mandi	15.28±1.23	14.79±0.56	13.03±1.45	14.37±1.08
Sundernagar	14.91±0.98	13.72±0.33	12.98±0.86	13.87±0.72
Baddi	12.02±1.02	11.63±0.78	11.05±0.67	14.37±1.08

Furthermore, the average of the methane production was observed to be15.78 ppm methane /gm of waste for Solan, 14.37 for Mandi, 13.87 for Sundernagar and 14.37 for Baddi town wherein these values represented ppm of methane generated per gram of MSW. These values concurred with the literature study wherein a study at Dhanbad concluded that the methane emissions from the MSW were 18.18 ppm methane/gm of waste and 20.08 ppm methane/gm of waste respectively for two different study areas in Dhanbad city [152]. In principle, the amount of methane gas emission is proportional to the biodegradable waste [159] and inversely proportional to the ash content as conveyed by many literature studies [42, 150]. The highest concentration of methane gas emission was observed for Solan study area as it has the highest fraction of waste. Further, the seasonal variation illustrates that considerable increment in methane emission during the summer and lesser in winter conditions because of the reduction in the activities of bacterial activities.

4.5 Implementation of different Waste-to-Energy Techniques in Himachal Pradesh

4.5.1 Biological Treatment Processes

The physical characterization analysis revealed that there is high proportion of organic fraction in the MSW at all study regions and hence have the capability to produce energy. In principle, both anaerobic and the aerobic process can be utilized to treat the organic waste fraction. However, the anaerobic process consumes lesser energy comparatively to aerobic process thereby converts the organic waste into biogas [160] that can be utilized as green fuel for generating heat or electricity.

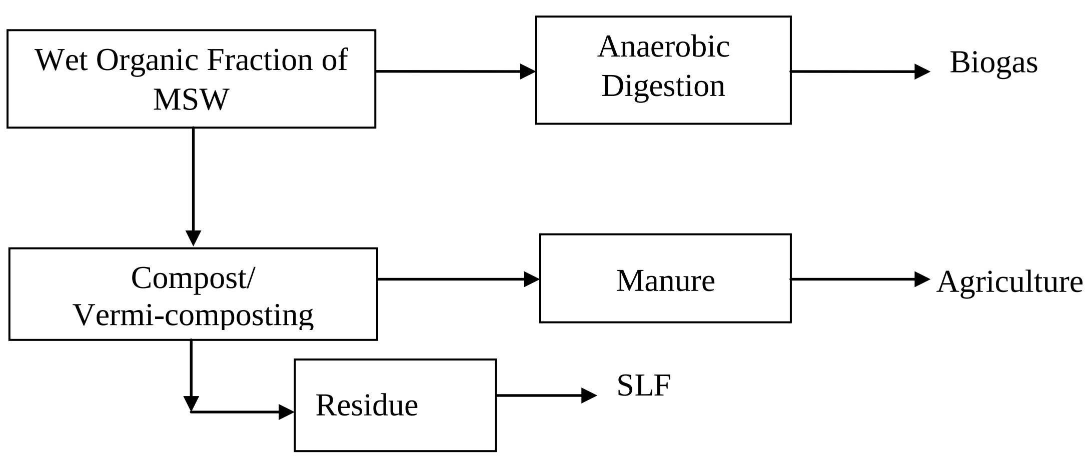


Figure 4.5: Pathways for the generation of biogas/compost using wet waste

The flow charts illustrate preferred pathways or the generation of biogas and compost by using wet fraction and generation of energy using dry waste has been shown in Figures 4.5 & 4.6.

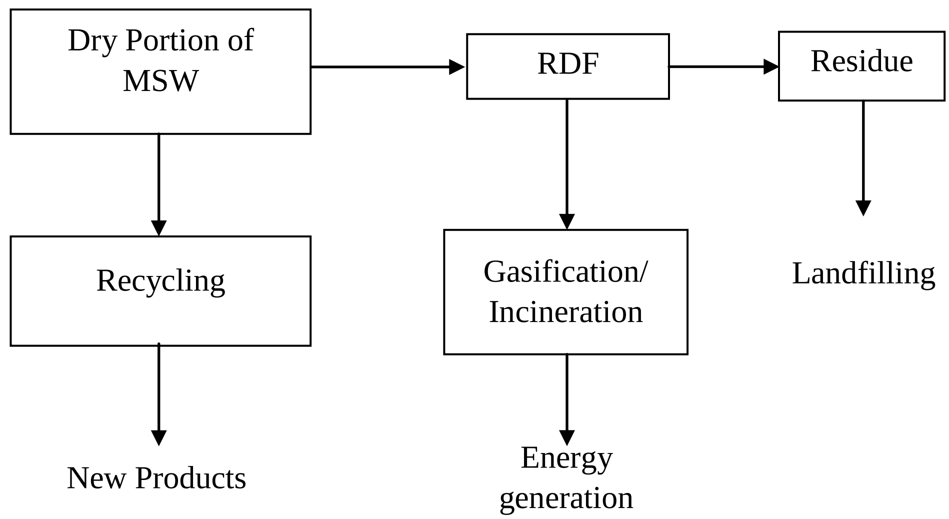


Figure 4.6: Pathways for the generation of energy and new products using dry waste

4.5.1.1 Anaerobic process

Generally, biogas generation depends on the MSW characterization comprised of wet as well as dry process. Wet process is used when the solids concentration is low whereas the dry process is utilized when the solid concentration is on the higher side. In this context, '*bio methanation plants'* are frequently mounted to produce biogas where it is utilized as green fuel.

The anaerobic degradation of the waste depends on various factors such as pH and temperature. However, insufficient pH may cause the production of volatile fatty acids in the acetogenesis phase rendering the methanogens ineffective by lowering the pH value hence methane generation is quite lower. Further, methanogens that are involved in the anaerobic technology for producing methane gas are primarily effective at mesophilic temperature conditions for the generation of biogas. In this regard, the selected study locations are having extremely cold temperatures in winter seasons often lasting up to two or four months that could brutally affect the methane production. In such critical cases, the anaerobic digesters need to be provided to counter such temperature conditions. Further details have been discussed elsewhere for adequate provisions for generation of biogas [4]. The advantages and disadvantages relatable to methane generation at various operating temperatures have been presented in Appendix-B (Table 5).

4.5.1.2 Aerobic process

The physical composition analysis of MSW in Himachal Pradesh reported that waste is rich in biodegradable fraction. In this regard, composting is a practicable alternative for the degradation of organic waste [4]. Composting phenomena involves the degradation of biodegradable fraction under controlled environmental conditions. It is important to note that the organic waste used for any of the processing facility should be segregated properly. However, implementation of pile composting phenomena in the selected study regions can be applied because it is cheap as well as suitable for all the selected study locations [161].

The composting process is an aerobic process that needs appropriate ventilation and airing for the microorganisms in order to maintain effectual degradation [162]. In this context, the various literature studies revealed that the pile composting is one of the best ways to process organic waste in order to economy and ease [162]. Apart from this, multi-bin system is also an effectual composting technique that may be recommended for the processing of waste in the selected study regions of Himachal Pradesh. This process involves the compost generation in faster way than that of single-bin composting technology. In this phenomenon, biodegradable waste is first put into the pile and when the sufficient wastes are collected, then the material is rotated into the next bin for faster decomposition and another pile is started in the cleared bin.

4.5.1.3 Vermicomposting

Vermicomposting process includes the conversion of waste into the manure by virtue of microorganisms as well as earthworm's activities [138]. In the selected study regions, some vermicomposting facilities are in existence but they are not in working conditions because of the lack of trained manpower, lack of awareness among people, improper maintenance of the pits. Further, one of the drawbacks that was noticed during the characterization study that the municipal solid waste holds some fraction of heavy metals that obstruct the usage of biodegradable waste for composting phenomena, hence proper sorted and segregation of waste should be there before vermicomposting is carried out.

4.5.2 Thermal Treatment Processes

4.5.2.1 Incineration

The incineration process comprised of the burning of the waste in a combustion chamber heated at a temperature of 1000^0C by utilizing of flue gas and heated air. Once the process has been accomplished, heat and energy produced is harnessed by utilizing superheated system in a cogenerated system [35]. In this context, one of the major drawbacks of this particular is the emissions of the greenhouse gases at higher extent that is the substantial environmental problem of concern [163]. However, incineration process is also frequently abutted with the gasification process to remove the volatile heavy metals [164].

4.5.2.2 Pyrolysis

Pyrolysis is the phenomena in which the combustion process takes place in the absence of oxygen. In this phenomenon, the burning of waste takes place in the chamber at the temperature ranged from 300 to 800^0C. The biodegradable waste is degraded first at the temperature of 300^0C thereafter rest of the fraction of municipal solid waste is heated at 800^0C cause the generation of final products. In this context, segregation and sorting of waste is an imperative aspect that should be considered prior to the usage of these particular waste processes in techniques [139]. The final product is ***Syngas*** that comprised of CH_4, CO_2, CO and H_2having higher calorific value of 20MJ/Nm^3 [165]. The ***syngas*** may be utilized in many different power applications such as industrial boilers, turbines and other power consuming machinery [166, 167].

4.5.2.3 Installation of RDF facilities

Currently, there exists no such waste processing facility of MSW in the selected locations of H.P. The installation of Refuse Derived Fuel (RDF) plant is one of the viable alternatives utilized for waste processing due to the lesser content of metal waste and larger fraction of other waste such as paper, plastics, textiles etc. At present, only one RDF plant in North India that is situated in Chandigarh city (Green Tech Fuel Processing Plant) in working condition and the details of the plant have been reported in literature [87]. Further, the calorific value obtained for Chandigarh is 2208 kcal/kg [150] and compared to the calorific values for the selected study locations in H.P. In this regard, similar RDF plant capacity based on the same design principles maybe implemented for the selected regions in H.P. Further, two reduced derived fuel plants should be fabricated wherein one plant functions for Solan and Baddi region and the other plant should function for Sundernagar and Mandi region.

4.6 Suitability of the WTE options based on the characterization results

The average calorific value of municipal solid waste is about 3350 kJ/kg in India [168] that is considerably lower than the calorific value i.e. 8000 to 10000 kJ/kg obligatory for incineration technologies besides additional fuel costs will be acquired. The average calorific value of MSW in the study regions varied from 2352 to 2625 kcal/kg hence the use of aerobic composting with have also been suggested [44]. However, the occurrence of more biodegradable fraction of the waste considerably diminishes the advantages of the incineration process.

In this regard, the most effective WTE possibilities could be utilization of RDF facilities or using a bio refinery wherein both the organic and inorganic fraction can be harnessed to produce biofuels and *syngas* respectively.

4.6.1 Collection and Utilization of Landfill Gas Emissions (LGE)

The landfill gases are produced mostly because of microbial actions to the waste. Arobic conditions are more predominant firstly but with increment in time, anaerobic conditions are more predominant that cause the production of landfill gases [169-171]. As our characterization studies have revealed the higher fractions of biodegradable waste, so it is expected to have large proportion of methane gas. In such case, the landfill gas should be taken out by utilizing suitable procedures from the landfill sites; the collected gas should be properly cleaned to eliminate the impurities mainly particulate matters.

4.6.2 Construction of engineered landfill

Landfill is considered most of the viable option for the final disposal of the municipal solid waste. Land filling shall be conceded out mainly for the construction and demolition wastes. Apart from this, waste should be covered at the end of each working day with the available soil and should have the minimum thickness of 10 cm [172]. After the accomplishment of landfilling process, a final cover system should be intended to lessen the immigration of leachate. However, the final cover should have a barrier layer of clay having 60 cm thickness [120]. On the top of barrier soil layer there should be a drainage layer having thickness of 15 cm thereafter a vegetation layer having thickness 45 cm for the vegetation growth and plantation. Furthermore, it is suggested to design small or cellular sanitary landfill in the sloppy terrain in H.P. so that it would be easy to operate. Hence, in the nutshell, land filling is the practicable alternative for the final disposal of municipal solid waste.

Summary

The waste characterization analysis of the study locations revealed that all the regions had a higher proportion of biodegradable waste fraction in the generated waste thereby act as impending source of biogas production. Furthermore, it has been perceived that the C/N ratio of waste in all the selected regions varied in the optimum ranges. Additionally, high correlation existed between the biodegradable fraction, emission of methane as well as the moisture content. The higher proportion of biodegradable fraction entails a higher tendency for the emission of methane. Further, chemical characterization evaluation illustrates seasonal variation for parameters including ash content as well as fixed carbon because of the wood burning for heat purposes during particularly the winter season. Furthermore, heavy metal assessment demonstrates that the values currently existed within the limits but may be of concern in the future if no corrective steps are taken due to the usage of biodegradable material in compost may become constrained. The average calorific value over the study locations were determined to be 2508kcal/kg. The average methane generation over the study locations is 14.6 ppm/g of waste which is significant enough to be harnessed as green fuel. In this context, suitable WTE technologies for the study locations have been proposed and discussed. Since the biodegradable fraction is high in the waste, it is amenable for composting particularly with some of the study locations having composting pits pre-installed before but many of them non-functioning now. In this context, the next chapter deals with the compost characteristics and its classification for reuse.

CHAPTER 5

CHARACTERIZATION OF MSW COMPOST BY AN INDEXING APPROACH

5.1 Introduction

The existing waste management scenario in a developing country like India is very unsatisfactory [4]. The MSW management is a challenging concern where in somewhat improved management system in metro cities mainly because of improved resources. However, the inadequacy in waste management comprised of poor collection and considerably lesser treatment facilities of MSW that has led to global warming reason being the biodegradable fraction of waste is the chief cause of gas emission [173]. Furthermore, final dumping of MSW in illegal way is the problematic issue [174]. So, there is as dire need of processing and management of waste in adequate manner.

The waste characterization is an imperative aspect in persuasive MSW management processes [175-177]. In this context, the reported literature for waste characterization in India revealed higher fraction of biodegradable waste followed by paper and inert waste [4]. As concluded from the previous chapter (Chapter 4) the MSW generated is amenable for composting with already existing composting pits but mostly non-functional the quality of compost at two of the sites has been discussed.

In this regard, the waste compositional study analysis [4] reported that the waste of Himachal Pradesh is rich in organic waste whereas paperboard waste attains the second largest fraction of waste after organic fraction. However, characterization based on chemical analysis of MSW reported that the ample moisture content present in MSW that is found appropriate for composting process [4].

Additionally, composting is a degradation phenomenon in biological manner that transforms the biodegradable waste into stable products having nutrients by means of micro-organisms which may be utilized for the nutrition of soil [64]. The composting that utilize air to biologically degraded solid wastes in controlled manner is aerobic composting, while composting that is managed in the absence of oxygen is anaerobic composting [64].

Further, compost is a good natural soil enricher because it provides nutrition comprised of NPK that enhances quality of soil by amassed air in gas well as water holding ability [178]. The compost produced from mixed waste without any sorting and segregation is often of poor quality. In this regard, specific standards i.e. FCO standard (1985) have been utilized for grading the compost as per its usage. In this context, a method for compost classification was proposed to provide best resource utility to compost manufacturers and was based on the computational values of ***clean index*** (CI) and ***fertility index (FI)***. This proves beneficial for the end users in identifying the compost applications in food crops, gardening etc. [67]. The current study emphases the characterization and spectroscopic valuation of compost generated from the MSW of study locations in Himachal Pradesh.

5.2 Materials and methods

5.2.1 Mechanism of compost technique in selected locations

In general, composting technique in the state of HP follows aerobic composting with windrow technique that comprised the piling of biodegradable fraction in elongated row with 4 to7 feet high and 14 to16 feet long pile [62]. It was observed from the survey in study regions that the piles were of slight lesser in dimensions than the standards mentioned above because of lesser quantity of MSW being produced in these particular locations. Further, the spinning of windrow after 15-20 days of stabilization process was carried out manually for the enhancement in aeration, appropriate blending and exclusion of moisture content at respective selected locations. Afterward, the stable product is screened after 6 weeks and further cured for a period of 14 days. Finally, at the completion of the composting phenomena, separation and sorting of final unwanted products is accomplished by eradicating paper, plastic and remains observed in the prepared compost. The downside in the prevailing arrangement of composting was noticed i.e. the composting process has been carried out on mix fraction of waste and that sorting was carried out after generation of final compost material.

5.2.2 Sampling Procedure and Analysis

The compost collection has been carried out in different phases of degradation of MSW aerobically in particular on 20^{th} day, 40^{th} day as well as on 60^{th} day of complete composting procedure according to the method defined in US Environmental Protection Agency Part 503 Rule [157]. The temperature was observed during the sample collection from the heap of compost. The moisture content was evaluated by means of 'gravimetric' technique in which the sample was oven dried at 70^0C wherein the weight loss was evaluated [179]. Apart from this, density was evaluated by utilizing measuring cylinder of capacity 100 m land by beating 30 times with the free fall of 40 mm height [167, 179]. Further, pH, electrical conductivity was evaluated as per FAI [180] and IS codes [181] whereas total organic carbon (TOC), total nitrogen (TN) and total phosphorous (TP) has been evaluated as per the procedures revealed in IS-10158 [182]. Potassium and sodium were determined by flame photometric technique [63]. However, calcium as well as magnesium content was determined by titration technique i.e. by using ammonium acetate (1:5), standard EDTA using two indicators named as Eriochrome Black-T indicator and Patton-Reeder indicators [63].

Additionally, heavy metal analysis was carried out by using Atomic Absorption Spectroscopy (AAS). In this aspect, the compost was made in powdered form and digesting three grams sample in 25 ml of triacid at 110° C by utilizing a digester according to the process illustrated in D5198-09 [183].

5.2.3 Instrumentation Analysis

In general, sophisticated instruments have been utilized for the revealing of structural behaviour variations of the compost samples thereby the finer characteristics of the equipment analysis have been demonstrated in the following section.

5.2.3.1 Evaluation of SEM-EDS of compost

SEM provides high resolution image of the solid material by focus an electron beam across the surface whereas EDS is an apparent technique that is used for the elemental identification of the material and also procure information regarding quantitative composition [184, 66]. The current analysis comprised of the variation in structural behaviour of the compost during various phases of the MSW decomposition at two study regions thereby examined through SEM and EDS techniques. Further, the compost sample was oven dried at 500^0c for 35 minutes and crumpled in small particles thereby valuations has been noticed from the particular instrument (FEG Quanta) hence acquired the morphology of the sample [4].

5.2.3.2 Evaluation of X-ray diffraction technique

X-ray diffraction is the vital tool utilized for the evaluation of atomic and molecular structure of a crystal or any other inorganic material, which causes X ray beam to diffract into specific directions and each signal in the X ray diffraction, represents the plane of crystal [64]. The structural variation during the degradation of the MSW can be estimated using XRD technique. The compost product is compacted into powdered form, the sample size was 200 milligrams and the wavelength was adjusted to 1.54 Nm for the extent of 20 minutes for each sample. The angle utilized was equal to 2θ with anode material copper with Cu target (System instruction manual PW 1349 & Operation manual PE 1612).

5.2.3.3 Atomic Absorption Spectroscopy (AAS) of compost samples

In addition, the examination of heavy metal has been carried out using an AAS having D2 background ‘correction lamp’, acetylene flame and utilized the fuel for upper absorption electro thermal atomization in graphite furnace [4].

5.2.4 Indices for evaluation of compost

The classification of the quality of the compost is determined by ‘Fertility Index’ (FI) and ‘Clean Index’ (CI) [67]. These indexes determine the usability of compost in order of different categorizations. The criterion for evaluation of the compost generally includes assignment of a ‘weighing factor’ to the various parameters assessed for the compost and which has already been discussed in details in earlier reported literature [67, 179].

Hence, the FI is evaluated by utilizing the formula as described in equation (1) [179].

$$FI = \frac{\sum_{n}^{i=1} S_i w_i}{\sum_{n}^{i=1} w_i} \qquad (1)$$

S_i= Score value

w_i = Weighing factor of the i^{th} fertility parameter

Further, the weighing factor ranges from 1 - 5 on the basis of toxic level of different parameters.

The CI values are evaluated by utilizing the formula given by Saha et al. [67] as shown in equation (2). In this context, the uppermost value of clean index demonstrated lower pollution of heavy metals [179].

$$CI = \frac{\sum_{n}^{j=1} S_j w_j}{\sum_{n}^{j=1} w_j} \qquad (2)$$

S_j= scored value

w_j = Weighingelementof the j^{th} heavy metal constraints

5.3 Results and Discussions

5.3.1 Analysis of physico-chemical analysis

The quality of compost on the basis of maturity level and nutrient level is important for the assessment of the usability of MSW compost [4]. The parameters considered in essence for the determination of the quality of the compost and have been presented in Table 5.1 and 5.2 for Solan and Mandi region of Himachal Pradesh.

Table 5.1: Physical and chemical characterization of compost in Solan (H.P.)

Physico-chemical parameters	Day- 20	Day-40	Day-60	FCO Criteria [179]
Temperature (◦c)	60±2.35	55±0.69	54±1.24	-
pH	7.84±2.35	7.33±0.68	7.08±0.93	6.5-7.5
EC (dS/m)	6.7±0.45	6.1±1.99	5.8±0.23	<4
MC (%)	45.00±0.67	39.78±2.88	33.02±0.44	15-25
Ca (mg/l)	12.08±0.34	15.02±3.13	16.24±0.99	-
Mg (mg/l)	9.72±1.67	6.84±0.89	5.59±0.23	-
OC (%)	18.28±2.38	16.14±3.14	14.22±0.66	16 (min)
N (mg/Kg)	0.64±0.29	0.72±0.14	0.80±0.34	0.5 (min)
P (mg/Kg)	2.34±1.46	1.98±0.34	0.92±0.29	0.5 (min)
K(mg/Kg)	14.1±0.25	9.2±1.45	7.40±0.99	1 (min)
C/N (%)	29.28±1.93	28.91±0.49	26.02±3.13	20 (min)

Table 5.2: Physical and chemical characterization of compost in Mandi (H.P.)

Physico-chemical Parameters	Day-20	Day-40	Day-60	FCO Criteria [179]
Temperature (◦c)	64±0.27	62±1.18	59±0.89	-
pH	8.24±0.25	7.54±1.06	7.48±2.85	6.5-7.5
EC (dS/m)	6.00±0.34	5.65±2.33	5.23±0.68	<4
MC (%)	42.92±0.33	35.17±2.13	31.00±3.05	15-25
Ca (mg/l)	15.24±1.68	17.01±2.34	17.89±0.43	-
Mg (mg/l)	10.02±0.67	8.18±0.37	7.24±1.59	-
OC (%)	17.40±0.49	14.35±1.74	12.46±0.22	16 (min)
N (mg/Kg)	0.69±0.29	0.88±0.56	0.92±1.24	0.5 (min)
P (mg/Kg)	2.86±1.04	2.12±0.12	0.78±0.64	0.5 (min)
K (mg/Kg)	16.20±2.68	12.50±0.99	9.20±1.34	1 (min)
C/N (%)	30.01±0.89	29.12±1.86	28.32±0.32	20 (min)

The results analysis revealed that the compost temperature at the end of 60th day of degradation was observed to be 54^{0}C and 59^{0}C for both study locations. However, the temperature of 60^{0}C and 64^{0}C were observed for Solan city and Mandi city on 20th day of decomposition. This significant variation in temperature may be due to exothermic process during bacterial degradation of biodegradable content [179] which shows elevated temperatures during the degradation phase in comparison to temperature after the completion of decomposition [67].

Further, organic carbon implies biodegradable content exist in the MSW compost. In this aspect, it has been noted that high fraction of total organic carbon was observed and it varied between 12 to 18% for Solan and Mandi region. In Indian context, it has been reported that total organic carbon varies between 5 - 20% [67].

Additionally, moisture content of MSW compost is mandatory parameter because it assists in determining the easiness of transporting of the end product of MSW compost material. In this aspect, moisture content ranged in between 31% to 45% for both the study locations. However, the ranges were considerably higher as compared to the standards recommended by FCO (1985) where the acclaimed value ranged between 15-25% [67]. The pH value varied in between 7.85 to 7.08 from the starting of degradation course to end period of degradation course for Solan while it was perceived as 8.24 to 7.48 from starting to end phase of decomposition for Mandi. In this context, the pH value of MSW compost was found in ‘alkaline-neutral’ range hence exhibiting degradation of biodegradable content. The literature study reported that the pH of MSW compost ranged between neutral to alkaline range in the composting plant in Delhi that was the indication of immature compost utilized for instance of manure [4]. Further, EC is considered as important parameters for the assessment of nourishment level of compost. The electrical conductivity was observed as 6.70dS/m in the 20th day of composting process, 6.10dS/m in the 40th day of composting process and 5.80dS/m in the end of 60th day of composting process in Solan town whereas observed lesser for Mandi town is. 6.00dS/m in the 20th day of composting process, 5.65 dS/m in the end of 40th day and 5.23 ds/m at the completion of composting process. However, the particular values for the selected regions somewhat surpassed than acceptable standards as recommended by FCO India.

Furthermore, the concentrations of micro-nutrients including nitrogen, phosphorous as well as potassium (NPK) are mandatory for the assessment of compost eminence utilized as manure [63]. The nitrogen content has been found to increase with the increase in composting period i.e. varying between 0.64-0.80 mg/kg for Solan and 0.69-0.92 mg/kg for Mandi. However, phosphorus (P) as well as potassium content shown decrement in the concentration with the increase in composting period.

Additionally, the Ca as well as Mg content in the compost is imperative for the growth of bacteria [64] thereby utilized to assess the fertility prospective of compost at the end of development phase. The calcium content in the compost was perceived as 12.08 mg/l, 15.02 mg/l and 16.24 mg/l in the starting to end period of composting process for Solan while it was observed 15.24 mg/l, 17.01 mg/l and 17.89 mg/l for Mandi. However, the magnesium content was observed as decreased during this period for both the selected locations in HP. Further, the OC content was determined to be 18.28%, 16.24% and 14.22% from the starting to end of the composting process for Solan while the values determined for Mandi were 17.40%, 14.35% and 12.46% during the composting process but found slight lesser than the nominal value of the FCO regulations. The C/N ratio of compost is the indicative of the development phase of compost and was determined to be 29.28%, 28.91% and 26.02% from 20th day to 60th day of composting for Solan while it was determined to be 30.01%, 29.12% and 28.32% for Mandi city of HP. It was observed from the literature study that the C/N ratio greater than 30% at the maturation phase of compost makes it inappropriate for its usage as manure or enricher [64].

5.3.2 Assessment of heavy metals in compost

The heavy metal assessment has been illustrated in Table 5.3 & 5.4 for selected locations.

Table 5.3: Evaluation of heavy metals of compost for Solan

Heavy metals(mg/Kg)	Day-20	Day-40	Day-60	FCO criteria
Pb	13.25±0.04	9.93±0.83	8.01±1.23	100
Zn	7.62±1.83	5.01±0.68	4.29±1.34	1000
Cr	2.92±0.13	2.26±0.12	1.86±1.24	50
Cd	1.32±0.23	1.21±0.02	1.18±0.13	5
Cu	7.12±2.13	5.67±2.03	2.12±1.43	500
Ni	24.02±1.34	23.12±0.68	21.78±1.89	50

Table 5.4: Evaluation of heavy metal of compost for Mandi

Heavy metals (mg/Kg)	Day-20	Day-40	Day-60	FCO criteria
Pb	8.48±1.67	5.02±2.68	2.18±0.82	100
Zn	6.12±2.32	5.27±1.23	3.26±0.37	1000
Cr	0.56±0.16	0.44±1.33	0.24±0.18	50
Cd	0.25±0.34	0.14±1.28	BDL	5
Cu	2.38±1.23	1.57±1.26	1.02±0.68	500
Ni	9.87±2.98	5.13±1.89	3.26±0.34	50

The result analysis revealed that the heavy metals in compost were observed higher for Solan region as compared to Mandi region but within the permissible limits of fertility control order standards for both the study locations. The heavy metal assessment study revealed that nickel and lead content in the MSW compost were found higher comparatively to other heavy metals because of unwarranted amount of batteries has been found in the disposal site of Solan region. Chromium has been observed in lesser concentrations at the end phase of degradation i.e. 1.86 mg/kg and 0.24 mg/kg for both Solan town as well as for Mandi town. Additionally, it has been perceived that the heavy metals diminished with increment in complete degradation period hence followed the same outline as described in the literature [63].

5.3.3 Fertility Index and Clean Index

The FI as well as the CI of MSW by-product is utilized for the determination of compost gradation that predicts its market worth. In general, compost is classified into seven categories A, B, C and D, Restricted Usage-1, Restricted Usage-2 and Restricted Usage-3 and which depends upon the evaluation of ‘Fertility indexing’ and ‘Clean indexing’. In this aspect, A to D illustrated upgrade quality and can be utilized for organic farming. However, the rest are of constrained norms. Further, the grouping of compost for their market usage and in various areas has been illustrated in Supplementary material.

Additionally, the fertility index for compost has been observed 3.5 for Solan region and can be categorized under **Class D** as outlined by FCO standard. Likewise, the fertility index for compost generated at Mandi site was determined to be 3.5 and 3.6 for samples tested after 20th day and for both 40th and 60th day. Hence, the compost can be categorized as **Class A** after full maturation period. Similarly, the clean index of the compost samples was observed to be 4.0 for Solan region and 5.0 for Mandi region respectively. The compost produced at the selected study regions meets the criteria of FCO standards since the determined heavy metal concentrations are lesser than the standards of fertility control order. The ‘fertility index’ and ‘clean index’ have been concise in Table 5.5 & Table 5.6 and the grouping of compost in illustrated in Table 5.7. Further, the grouping of compost for their market usage and in various areas has been illustrated in Appendix-B (Figure 6).

Table 5.5: Comparative analysis of ‘FI’ of compost of selected locations with Okhla compost plant, Delhi

Fertility Index (FI)				
Study regions	**Day-20**	**Day-40**	**Day-60**	**Delhi**
Solan	3.50	3.50	3.50	4.54
Mandi	3.50	3.60	3.60	

Table 5.6: Comparative analysis of 'CI' of compost of selected locations with Okhla compost plant, Delhi

Clean Index (CI)				
Study regions	**Day-20**	**Day-40**	**Day-60**	**Delhi**
Solan	4.0	4.0	4.0	2.60
Mandi	5.0	5.0	5,0	

Table 5.7: Classification of compost of selected locations

Study regions	**Category**		
Solan	D	D	D
Mandi	B	A	A

Additionally, outcomes acquired from the selected regions has been related to Okhla compost plant situated in Delhi hence 'Fertility Index' and 'Clean Index' values were reported as 4.54 and 2.60 [179] respectively. The reason being that the compost produced from the Delhi compost plant was of degraded quality reason being the more content of heavy metals thereby can be categorized under Restricted Usage (RU-3).

In the nutshell, the compost produced in Solan region is of medium quality and has medium enriching potential thereby utilized for lesser important crops. However, the compost produced from Mandi is categorized under class A i.e. having great nourishing potential and lesser amount of heavy metals thereby found appropriate for the growth food crops.

5.3.4 Evaluation of SEM-EDS analysis of compost

The micrographs of SEM revealed that the changes observed during different phases of bacterial decomposition of MSW compost for the selected locations has been illustrated in Figures 5.1 (a, b) -5.6 (a, b).

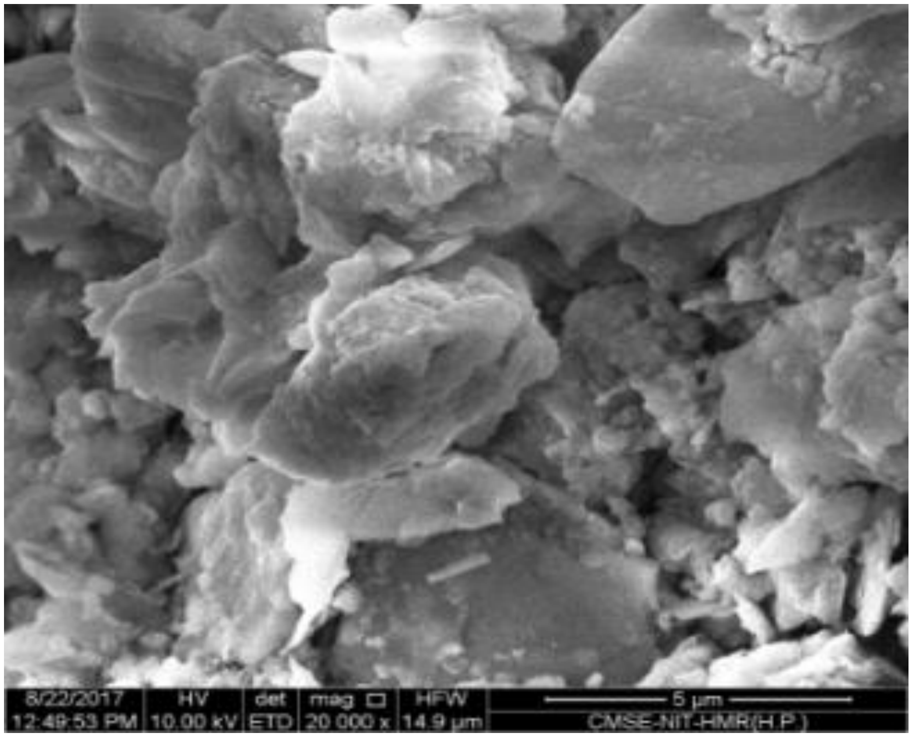


Figure 5.1(a): SEM evaluation after 20th day decomposition for Solan

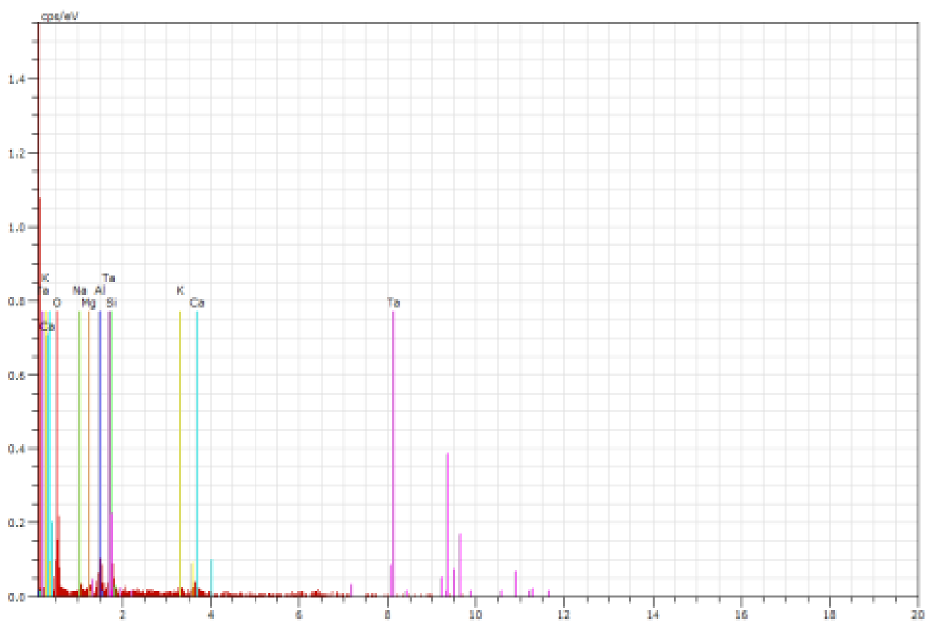


Figure 5.1(b): EDS evaluation after 20th day decomposition for Solan

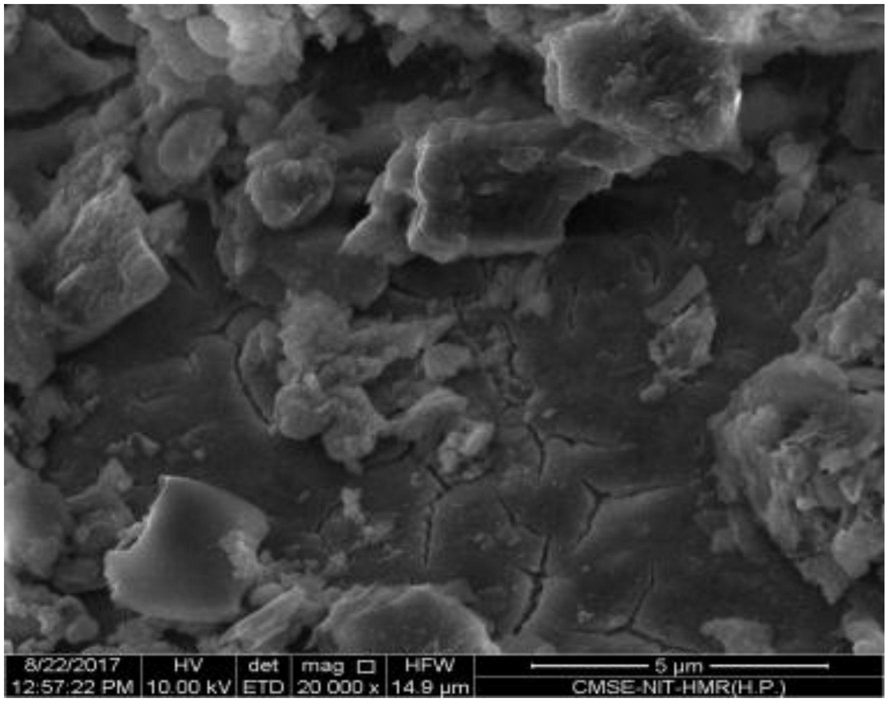


Figure 5.2 (a): SEM evaluation after 40th day decomposition for Solan

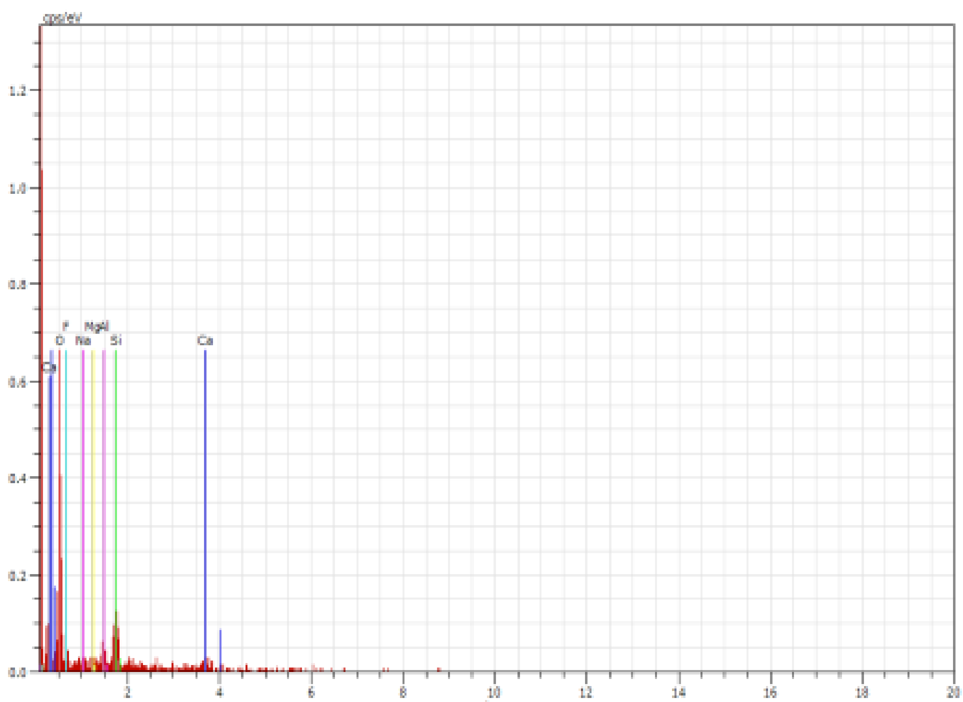


Figure 5.2 (b): EDS evaluation after 40th day decomposition for Solan

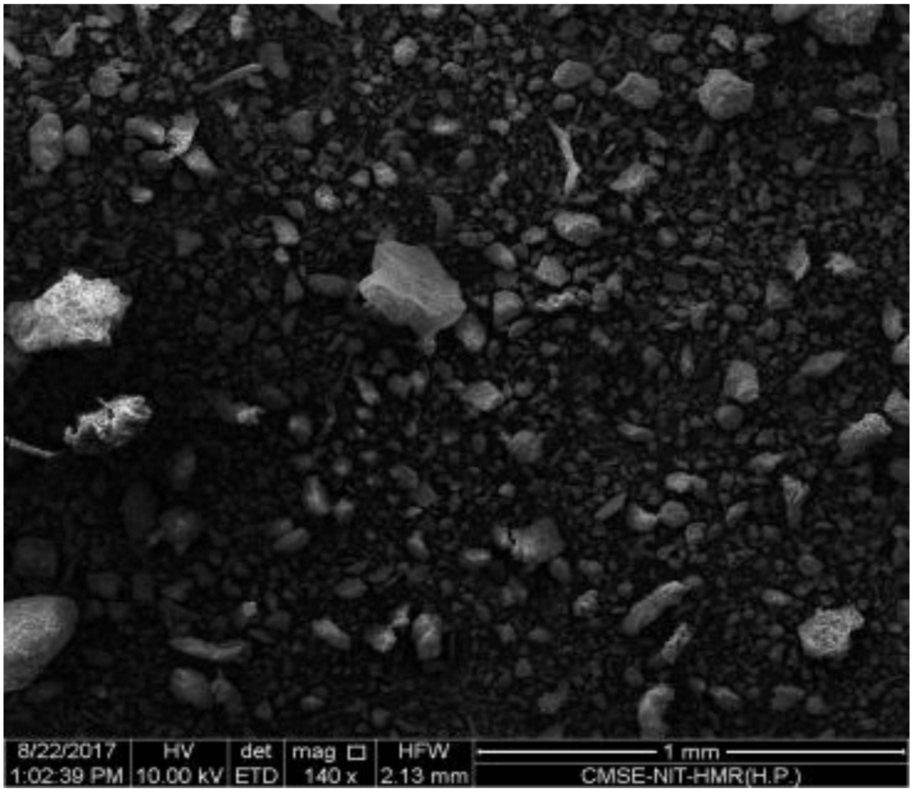


Figure 5.3 (a): SEM evaluation after 60th day decomposition for Solan

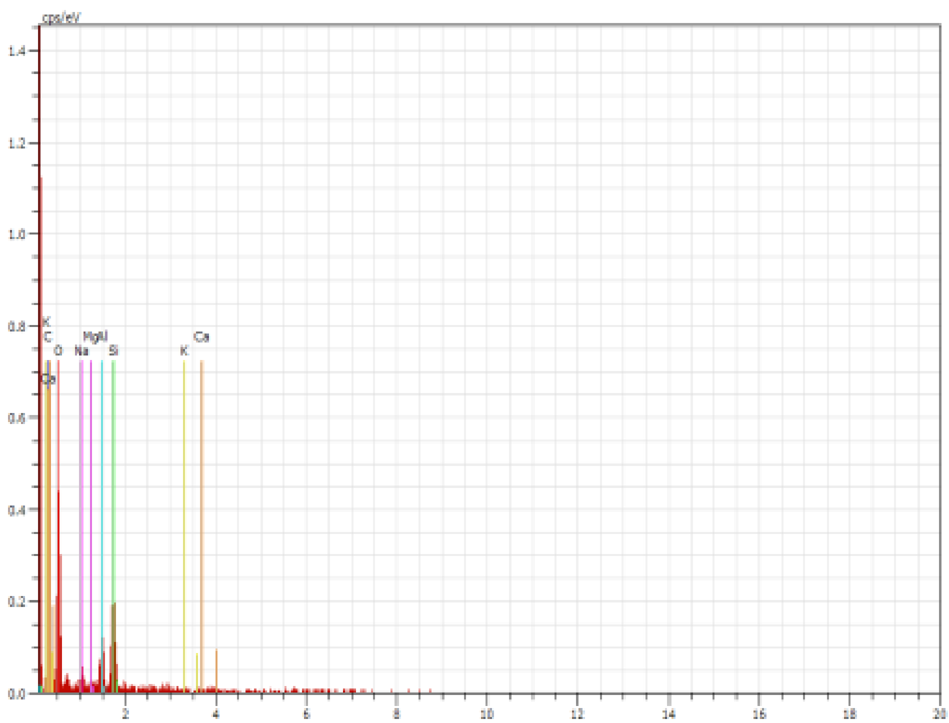


Figure 5.3 (b): EDS evaluation after 60th day decomposition for Solan

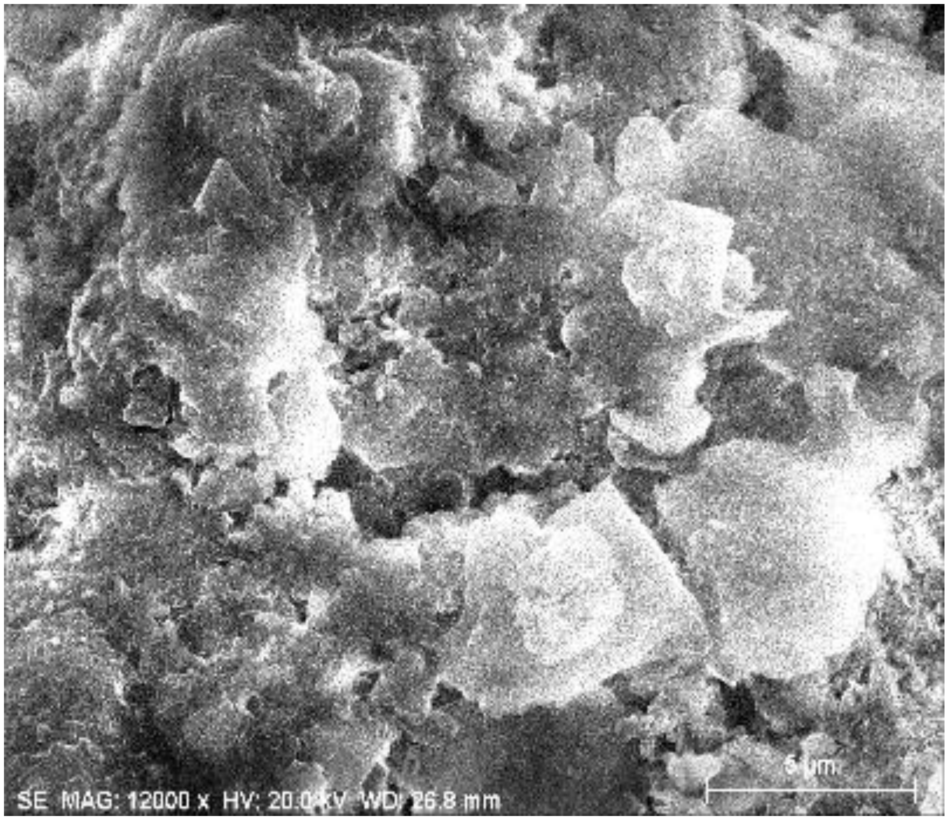


Figure 5.4 (a): SEM evaluation after 20th day decomposition for Mandi

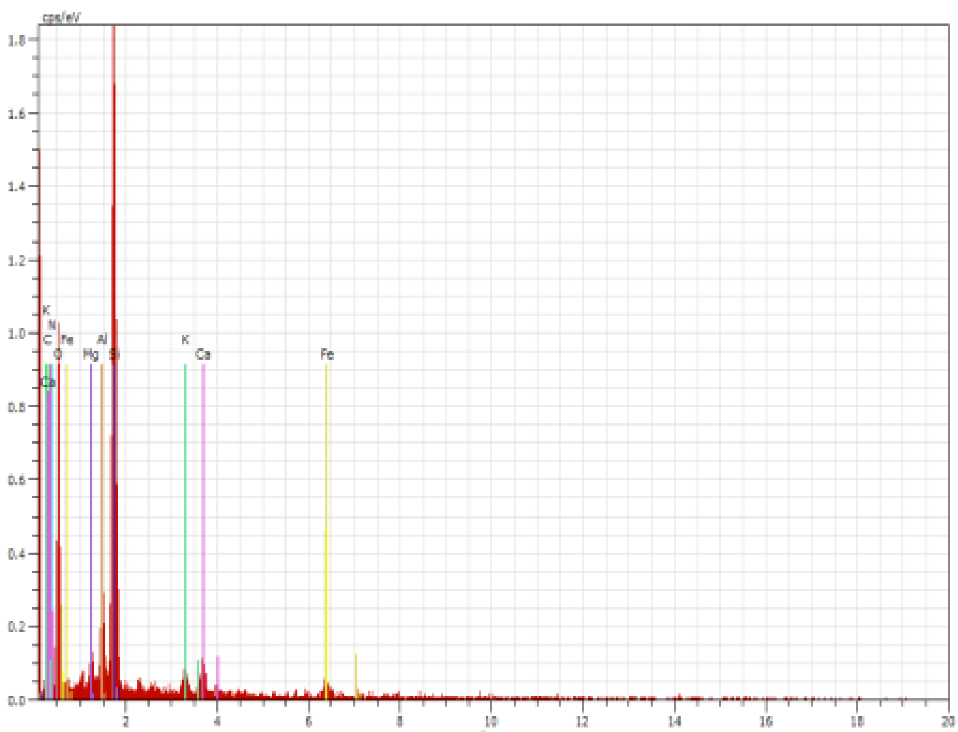


Figure 5.4 (b): EDS evaluation after 20th day decomposition for Mandi

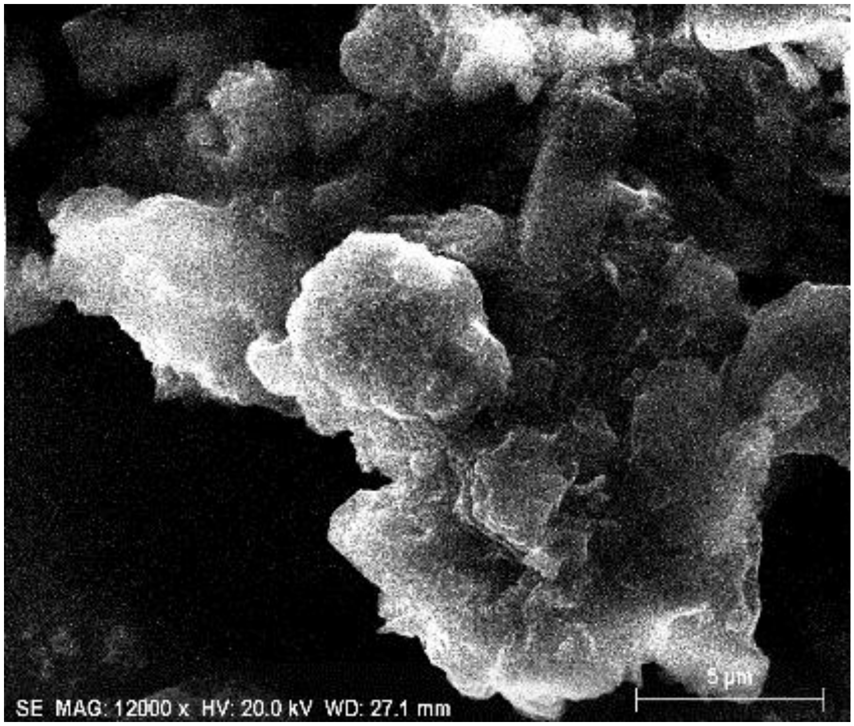


Figure 5.5 (a): SEM evaluation after 40^{th} day decomposition for Mandi

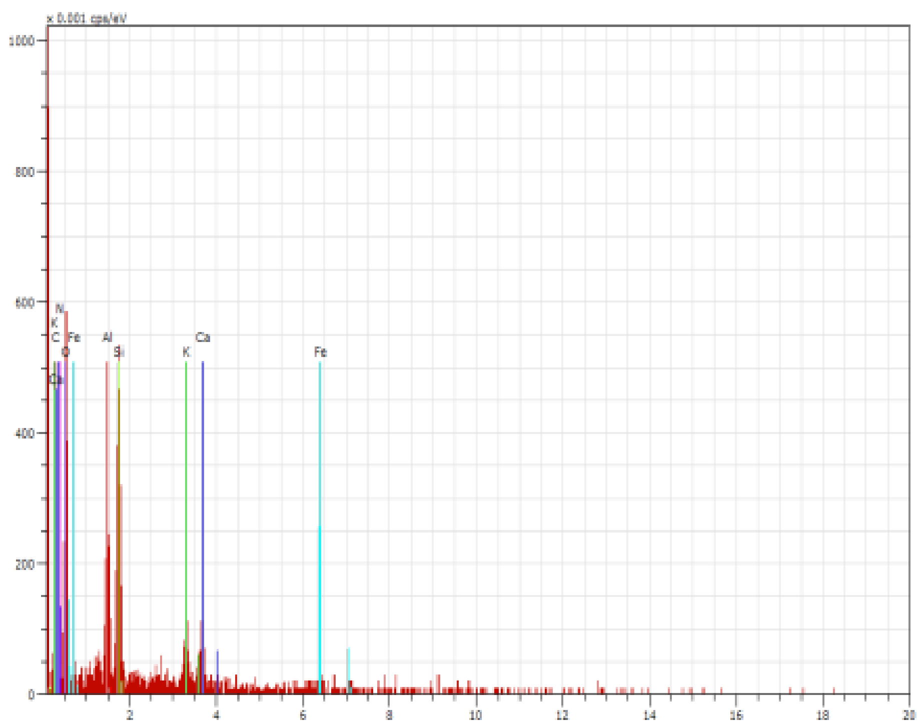


Figure 5.5 (b): EDS evaluation after 40^{th} day decomposition for Mandi

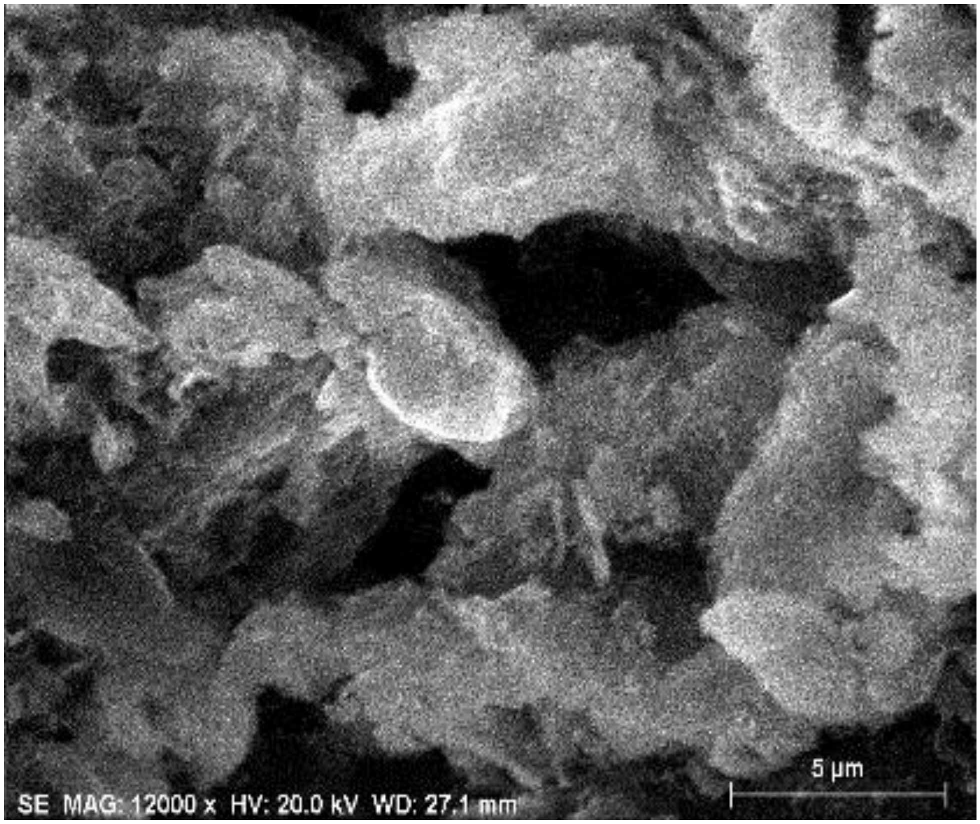


Figure 5.6 (a): SEM evaluation after 60^{th} day decomposition for Mandi

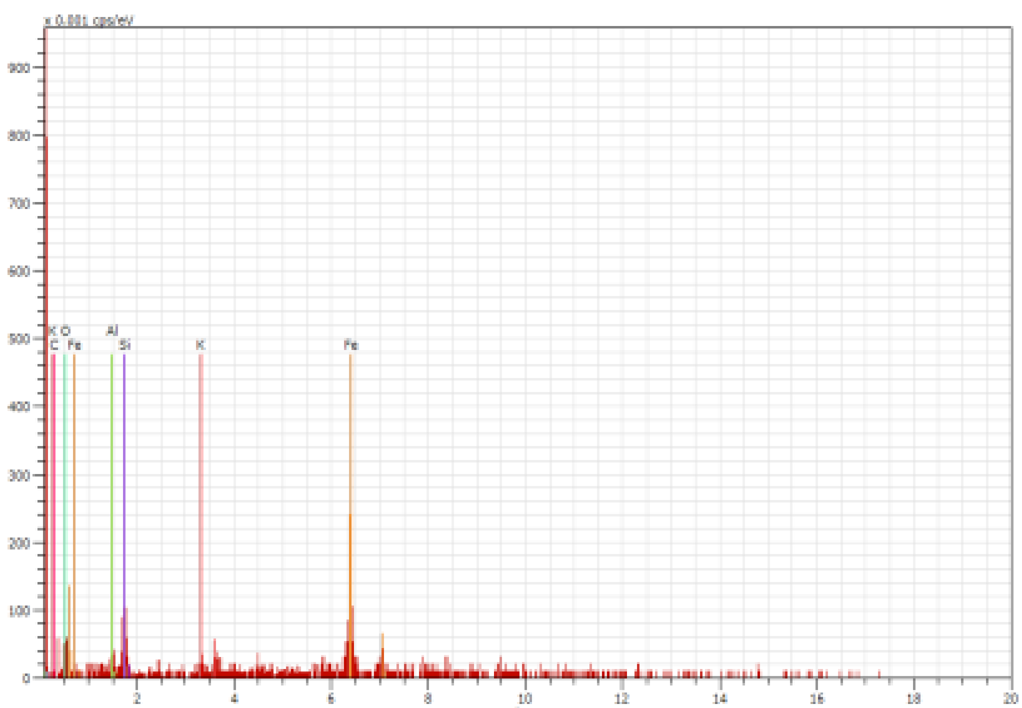


Figure 5.6 (b): EDS evaluation after 60^{th} day decomposition for Mandi

The results revealed that in the initial phase of degradation process starting from 1- 20 days, the morphology exhibited huge size of solid particles with reduced void spaces produced in the surface. Further, with the enhancement in decomposition process, the bigger sized particles started to reduce and ultimately at the end of the decomposition process (60^{th} day), the particles have been altered into finer ones having increment in the voids in the surface. Hence, it is the indicative of the compost maturation.

Furthermore, the EDS results for Solan exhibited occurrence of 8 elements including oxygen, carbon, aluminium, silicon, calcium, potassium, sodium as well as magnesium (Table 5.8).

Table 5.8: EDS evaluation for complete degradation process for Solan

S. No.	Elements	At. number	Un-norm. weight	Norm. weight	Atom percentage	Error
20^{th} day of degradation process						
1.	O	8	20.66	45.96	64.55	6.20
2.	Si	14	8.33	18.53	14.83	0.70
3.	Al	13	4.70	10.47	8.72	0.50
4.	Ca	20	4.60	10.23	5.74	0.60
5.	Ta	73	3.06	6.80	0.84	0.40
6.	K	19	2.74	6.09	3.50	0.40
7.	Na	11	0.46	1.03	1.01	0.10
8.	Mg	12	0.40	0.81	0.82	0.10
40^{th} day of degradation process						
1.	O	8	33.71	62.10	73.10	8.60
2.	Si	14	10.13	18.63	12.49	0.80
3.	F	9	3.68	6.77	6.71	2.60
4.	Ca	20	2.96	5.44	2.56	0.50
5.	Al	13	2.60	4.78	3.33	0.30
6.	Mg	12	0.70	1.28	0.99	0.20
7.	Na	11	0.54	0.99	0.81	0.20
60^{th} day of composting process						
1.	O	8	38.71	53.32	60.35	9.70
2.	Si	14	15.70	21.63	13.94	1.10
3.	C	6	7.80	10.74	16.19	4.70
4.	Al	13	6.16	8.49	5.70	0.60
5.	Na	11	2.30	3.17	2.50	0.40
6.	Ca	20	0.92	1.26	0.57	0.30
7.	K	19	0.74	1.02	0.47	0.20
8.	Mg	12	0.27	0.37	0.27	0.10

For Solan region, the oxygen content has been observed more in comparison to the other elements i.e. 60.35%. However, the carbon content has been observed as 16.19% at the 60th day of decomposition process by EDS technique whereas the organic carbon has been observed as 14.22% by Walkey method.

Correspondingly, EDS examination was conceded on the compost samples of Mandi region has been illustrated in Table 5.9.

Table 5.9: EDS evaluation for complete degradation process for Mandi

S. No.	Elements	At. number	Un-norm. weight	Norm. weight	Atom percentage	Error
20th day of degradation process						
1.	O	8	54.13	46.24	47.66	10.0
2.	C	6	30.03	25.66	35.23	7.70
3.	Si	14	19.03	16.26	9.55	0.90
4.	Al	13	3.26	2.78	1.70	0.30
5.	N	7	3.10	2.64	3.11	2.20
6.	Fe	26	2.56	2.19	0.65	0.20
7.	Ca	20	2.28	1.95	0.80	0.20
8.	Mg	12	1.54	1.31	0.89	0.20
9.	K	19	1.12	0.96	0.40	0.1
40th day of degradation process						
1.	Fe	26	16.03	47.84	23.32	1.30
2.	O	8	8.35	24.90	42.37	5.00
3.	Si	14	4.03	12.03	11.66	0.50
4.	C	6	2.20	6.56	14.86	4.10
5.	Al	13	1.88	5.62	5.67	0.30
6.	K	19	1.02	3.06	2.13	0.20
60th day of degradation process						
1.	O	8	47.15	51.50	54.53	12.40
2.	C	6	18.64	20.36	28.71	8.50
3.	Si	14	9.88	10.80	6.51	0.60
4.	Al	13	6.24	6.82	4.28	0.50
5.	K	19	3.06	3.34	1.45	0.30
6.	Ca	20	2.59	2.83	1.19	0.30
7.	Na	7	2.02	2.21	2.67	2.90
8.	Fe	26	1.97	2.16	0.65	0.30

The oxygen content has been observed as 54.55%at the end of the degradation process However, the carbon content has been observed as 28.72% at the end of degradation process whereas the organic carbon has been noticed as 12.47% by Walkey method. In this context, the organic carbon in the compost of Mandi region has been observed marginally lesser than the compost acquired from the dumpsite of Solan region. It was attributed to the fact that the biodegradable content has been found higher in the waste of Solan as compared to the Mandi region.

5.3.5 XRD evaluation of MSW compost

The X-ray diffraction investigation of MSW compost for various degradation phases in both selected locations in HP has been demonstrated in Figures 5.7 (a, b, c) -5.8 (a, b, c).

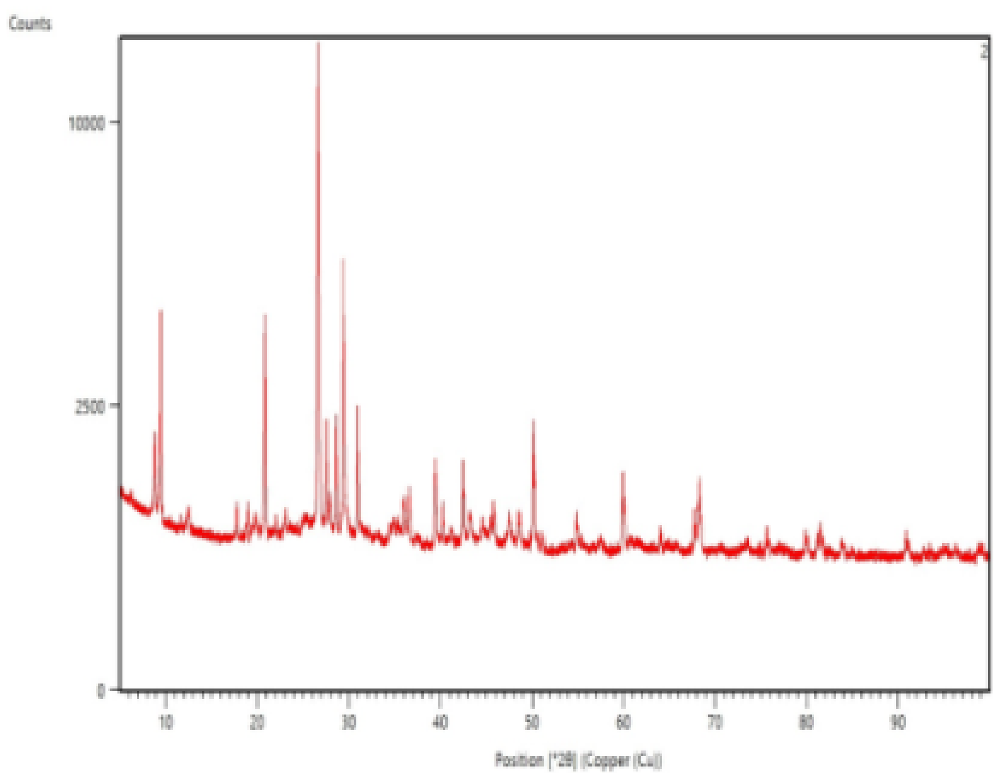


Figure 5.7 (a): XRD analysis at 20th day of compost (Solan region)

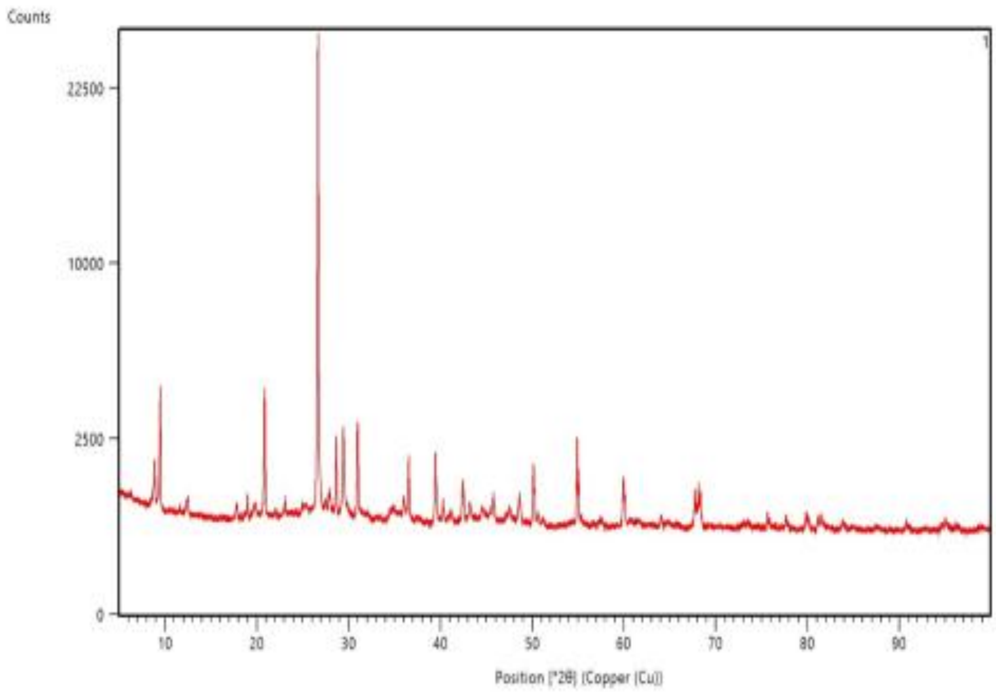


Figure 5.7 (b): XRD analysis at 40th and day of compost (Solan region)

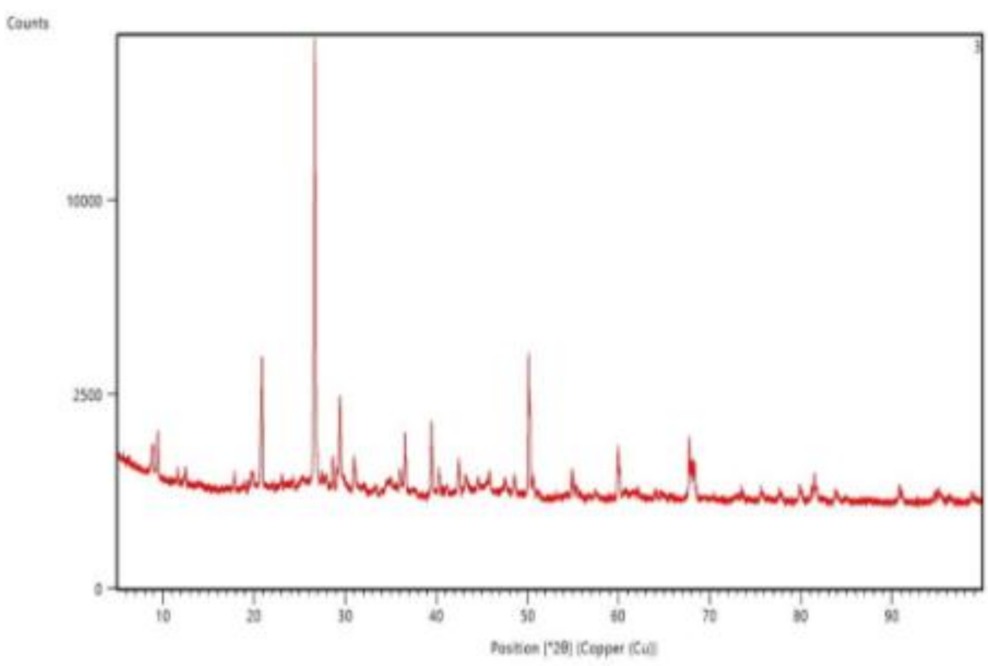


Figure 5.7 (c): XRD analysis at 60th day of compost (Solan region)

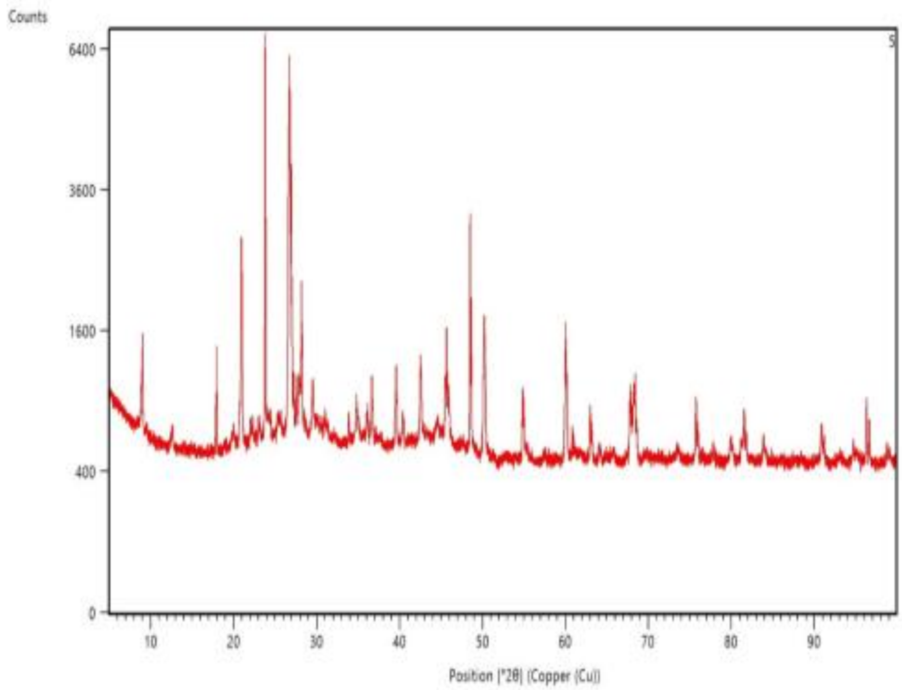


Figure 5.8 (a): XRD analysis at 20th day of compost (Mandi region)

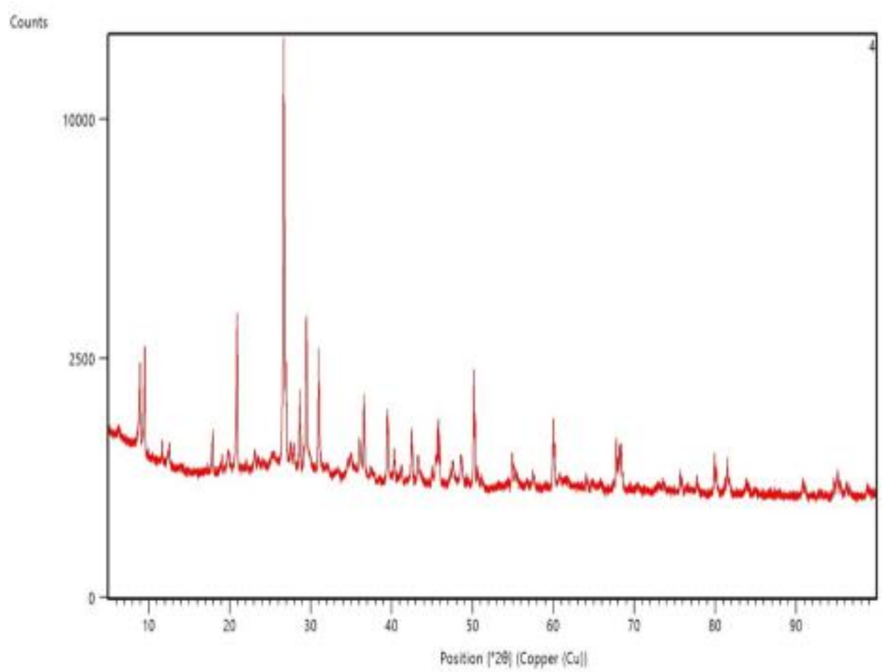


Figure 5.8 (b): XRD analysis at 40th day of compost (Mandi region)

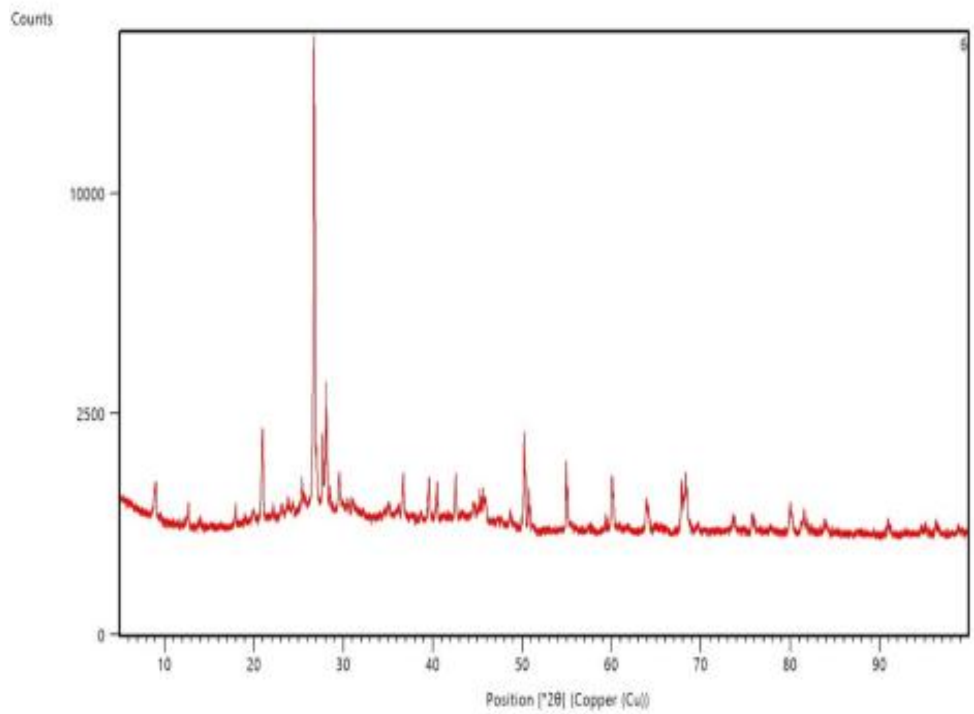


Figure 5.8 (c): XRD analysis at 60th day of compost (Mandi region)

The spectra of composting piles of both study regions revealed the acute peaks for composting samples collected on 20th day. Subsequent collected samples on 40th and 60th day at both the study locations revealed the reduced number of these peaks because of increase in the degradation process leading to formation of mature compost. The presence of minerals including quartz, calcite, dolomite etc. was due to the disposal of mix waste in the dumping site. From the overall data obtained from the X-ray diffraction spectra, it is clear that particle size of municipal solid waste decreases during the degradation process of the compost material.

Further, SEM of MSW compost collected from both the study regions reported that the large sized particles has been transformed into slighter ones from initial phase of degradation to final phase depicts the matured compost whereas XRD spectra revealed sharp peaks in the initial stage of decomposition of compost. However, reduced peaks have been displayed in the spectra up to 60th day of composting process that depicts the breakdown of particles thereby specified as matured compost. In the nutshell it was perceived that the analysis acquired from X-ray diffraction is having worthy collaboration with the scanning electron microscopy of MSW compost.

5.4 Brief discussion on the compost production of Himachal Pradesh

The study revealed that the waste that is produced in HP is rich in biodegradable fraction thereby can be converted into compost hence utilized as an enricher. In this aspect, some literature surveys have mentioned these composting processes in some of the places in Himachal Pradesh including Kullu, Solan, Shimla and Manali in earlier literature [67]. However, the present study found that of the above composting process was carried out only in Solan and Mandi region (with Solan composting about to be closed) The main cause of failure in compost plants particularly in the selected locations are due to lack of segregation and sorting of waste. Further, termination of composting plans in Shimla is because of inadequacy of land thereby most desired processing of waste is Refuse Derived Fuel technique. In the nutshell, the most common reason of termination of composting plants in Himachal Pradesh are lack of segregation, lack of manpower as well as appropriate funds [4].

Summary

The current study investigated that the physico-chemical parameters of MSW compost except EC and TOC were according to the standards of FCO. The heavy metal concentration was higher initially but with time increment some reduction in the concentration of heavy metal was noticed. Further, FI and CI analysis reported that the compost that was generated has constrained use for marketability according to the FCO criterion for Solan town while the compost generated in Mandi may be utilized for high value crops. In particular, the compost of Solan town can be utilized as enricher in gardens. However, the concentration of heavy metal for the selected locations was within the prescribed standards of FCO allocated by Ministry of Agriculture, GOI. Furthermore, SEM and XRD analysis reported that the breakdown of biodegradable matter started during the decomposition process and up to 60th day, the MSW compost transformed into smaller particles, enlarge the openings onto the particle surface thereby specified the maturity level of compost. In the nutshell, the study predicted that composting is a commendable and viable option for the processing of municipal solid waste. The effects of soil contamination due to leaching of MSW have been discussed in the following chapter.

CHAPTER 6

EVALUATION OF THE IMPACT OF OPEN DUMPS ON SOIL IN HILLY REGIONS OF HIMACHAL PRADESH

6.1 Introduction

The enormous development in industrialization and urban sectors has led to amplify the production of municipal solid waste at large extent. The waste generation is predictable to intensify considerably in the near future because of speed inhabitant's growth and higher living standard of people [1, 6, 185]. In India, the present scenario of municipal solid waste management is not so adequate. Moreover, waste has been dumped in an open land in very unsatisfactory manner without giving any prior treatment and processing to the waste. It is reported from the literature that 85% waste of Himachal Pradesh is dumped in an illegal manner, 5% is incinerable and 10% is recyclable [136].

In general, open dumping of municipal solid waste without adopting any precautionary measures being the main reason of soil contamination [186, 187]. As determined from the conclusions of the previous chapters since the study locations experience open dumping of waste soil contamination exists at all of the study locations. When rainfall occurs, it comes in contact of MSW and hence generates dark brown liquid named as leachate. This leachate percolates into deep aquifers as well as in soil strata and hence potential to pollute the groundwater reserves and soil. Leachate contains organics, inorganic content and heavy metal within it [188, 189]. In this context, the dumping sites without any sanitary designing become the point source for the contamination of environment thereby affects the human health. So, it becomes mandatory to develop facilities for the treatment and final dumping of drastically increased amount of municipal solid waste [7, 190]. The present study comprised the evaluation of geotechnical properties of soil within the dumpsite and its comparative analysis with the natural soil in selected regions of H.P. The comparative analysis has been done to check the potential of open dumps on the soil. Apart from this, the geochemical assessment of dumpsite soil has also been performed with SEM and EDS to comprehend the morphology and elemental analysis of the soil adopted from dumpsite locations.

6.2 Material and Methodology

6.2.1 Collection of soil samples

The soil samples were collected from the dumpsite and outside the boundary of 1 km from the dumpsites. The dumpsites from all the study regions include municipal waste, institutional waste and household waste. The depth of four dumpsites varied in the range of 10-15 meter and the area of dumpsites has been reported as 50-150 thousand sq. m. The samples have been collected before starting of monsoon to avoid the alteration by rain water.

Table 6.1: Depiction of four selected dumpsites

Sr. No.	Dumpsite locations	Distance from respective towns	Depth (m)	Area (acres)
1.	Solan	10 km from town	13	22
2.	Sundernagar	6 km from town	10	20
3.	Mandi	8 km from town	15	20
4.	Baddi	12 km from town	12	22

The soil samples have been collected from six different locations within the dumpsite at the depths of 0.5m, 1.0m and 1.5m from each of the four dumpsites. The soil samples have been gathered from centre and four corners from the dump site whereas one sample has been collected from the adjacent locations outside the distance of 1 km from the respective dumpsites.

6.2.2 Laboratory Examination

The geotechnical properties of soil include specific gravity, particle size distribution, liquid limit, plastic limit, plasticity index, maximum dry density, cohesion, angle of internal friction and permeability has been analyzed. The experiments have been performed as per the code provision according to Indian standard includes compaction characteristics (IS: 2720, Part-7) (1979), (IS: 2720, Part – 13) (1986), (IS: 2720, Part – 4) (1985), (IS: 2720 – 4) (1985) and (IS: 2720, Part – 7) (1983).

6.2.3 Composition of Minerals

SEM delivers high resolution image of the solid material by focus an electron beam thereby observed scattered electron signals whereas EDS provides quantitative analysis of the elemental composition of the material. The soil samples were desiccated in air and heated at 500°cfor thirty minutes and then kept in the instrument for assessment of morphology and elemental composition [191].

6.3 Results and Discussion

6.3.1 Evaluation of geotechnical properties of dumpsite soil and natural soil in Himachal Pradesh:

The variation in geotechnical behaviour of soil at various depths (0.5 m, 1.0 m, 1.5 m) has been assessed. The comparative analysis of geotechnical properties of the dumpsite soil and natural soil has been concise in Table 6.2-6.5 respectively. The graphical representation of the geotechnical properties of dumpsite soil samples and natural soil samples has been illustrated in Appendix-B (Figure 1-28) for all four study locations respectively.

Table 6.2: Variation in geotechnical properties of dumpsite soil and natural soil in Baddi (H.P.)

Sr. No.	Parameters	Baddi (Dumpsite soil)			Baddi
		0.5 m	1.0 m	1.5 m	(Unaffected soil)
1.	Specific gravity	2.0	2.2	2.24	2.57
2.	Coefficient of uniformity	6.6	6.5	6.6	6.0
3.	Coefficient of curvature	1.06	1.06	1.08	1.5
4.	Liquid limit (%)	24.0	24.3	24.7	27.0
5.	Plastic limit (%)	19.0	19.1	19.0	16.70
6.	Plasticity index (%)	5.0	5.2	5.7	11.0
7.	Optimum moisture content (%)	10.5	10.0	10.0	12.0
8.	Maximum dry density (g/cc)	1.78	1.85	1.87	2.2
9.	Angle of internal friction	35.79	35.75	34.60	34.90
10.	Cohesion (kN/m^2)	1.67	2.67	3.0	6.0
11.	CBR (un-soaked %)	12.34	16.69	17.42	17.50
12.	CBR in (soaked %)	4.52	5.35	6.7	5.9
13.	Permeability (cm/sec)	3.4x 10^{-3}	3.2 x 10^{-3}	2.7 x 10^{-3}	3.0 x 10^{-4}

Table 6.2 showed the variation in the geotechnical behaviour of natural soil and dumpsite soil in Baddi region of H.P. The result analysis depicted that the specific gravity of affected soil varied

in between 2.0-2.2 that is the indication of existence of biodegradable fraction in the dumpsite soil. The LL and PI of the dumpsite soil varied in the range of 24.0-24.7 and 5.0-5.7 respectively whereas the natural soil displayed LL i.e. 27% and PI i.e. 11%. Apart from this, the dumpsite soil displayed low maximum dry density, low CBR and higher hydraulic conductivity comparative to the natural soil. The lesser value of cohesion and angle of internal friction exhibits low shear strength comparative to the natural soil.

Table 6.3: Comparison in geotechnical properties of dumpsite soil and natural soil in Mandi (H.P.

Sr. No.	Parameters	Mandi (Dumpsite soil)			Mandi
		0.5 m	1.0 m	1.5 m	(Unaffected soil)
1.	Specific gravity	2.0	2.0	2.1	2.56
2.	Coefficient of uniformity	4.0	4.0	4.0	4.0
3.	Coefficient of curvature	1.0	1.0	1.0	1.5
4.	Liquid limit (%)	25.5	27.5	27.9	28.5
5.	Plastic limit (%)	20.0	21.4	21.8	16.0
6.	Plasticity index (%)	5.5	6.1	6.2	12.5
7.	Optimum moisture content (%)	14.0	13.0	13.0	13.0
8.	Maximum dry density (g/cc)	1.78	1.79	1.87	2.1
9.	Angle of internal friction	36.12	35.37	34.21	34.22
10.	Cohesion (kN/m^2)	1.0	2.0	3.33	4.33
11.	CBR (un-soaked %)	16.71	16.78	17.12	18.44
12.	CBR in (soaked %)	5.70	5.80	6.13	6.42
13.	Permeability (cm/sec)	3.8 x 10^{-3}	3.1 x 10^{-3}	2.7 x 10^{-3}	3.16 x 10^{-4}

Table 6.3 showed the variation in the geotechnical assessment of natural soil and dumpsite soil in Mandi region of H.P. The result analysis depicted that the specific gravity of the affected soil has been reported as 2.0 to 2.1 showed the larger fraction of biodegradable waste in the soil sample.

The LL and PI of dumpsite soil varied in the range of 26.0-28.0% and 5.5-6.2% respectively however the natural soil is played LL i.e. 28.5% and PI i.e. 12.5% respectively. Apart from this, the dumpsite soil showed low MDD, low CBR and higher hydraulic conductivity as compared to the virgin soil. The lesser value of cohesion and angle of internal friction exhibits lower shear strength on its comparison with the virgin soil (unaffected soil).

Table6.4: Comparison in geotechnical properties of dumpsite soil and natural soil in Sundernagar (H.P.)

Sr. No.	Parameters	Sundernagar (Dumpsite soil)			Sundernagar (unaffected soil)
		0.5 m	1.0 m	1.5 m	
1.	Specific gravity	2.0	2.1	2.1	2.55
2.	Coefficient of uniformity	4.6	4.6	4.6	4.82
3.	Coefficient of curvature	1.07	1.06	1.07	1.09
4.	Liquid limit (%)	25.60	26.30	26.80	28.0
5.	Plastic limit (%)	18.80	19.45	19.90	14.0
6.	Plasticity index (%)	6.80	6.85	6.90	14.0
7.	Optimum moisture content (%)	13.0	12.0	12.5	13.0
8.	Maximum dry density (g/cc)	1.84	1.86	1.84	2.1
9.	Angle of internal friction	34.21	32.62	34.21	35.70
10.	Cohesion (kN/m^2)	1.33	3.33	1.67	5.0
11.	CBR (un-soaked %)	16.13	16.20	16.80	17.51
12.	CBR (soaked %)	4.52	4.9	6.5	7.2
13.	Permeability (cm/sec)	3.6 x 10^{-3}	3.0 x 10^{-3}	3.2 x 10^{-3}	4.0 x 10^{-4}

Table 6.4 showed the variation in the geotechnical evaluation of natural soil and dumpsite soil in Sundernagar region of H.P. The analysis results indicated that the value of specific gravity varied from 2.0-2.1 in case of dumpsite. The LL and PI of dumpsite soil varied in the range of 25.60-

26.80% and6.8-6.9% respectively however the unaffected soil displayed low LL i.e. 28% and PI i.e. 14%. However, the affected soil of Sundernagar region also showed the similar trend as low maximum dry density, low CBR and higher hydraulic conductivity as compared to the natural soil. The lesser value of cohesion and angle of internal friction showed low shear strength of soil comparative to the natural soil.

Table 6.5: Comparison in geotechnical properties of dumpsite soil and natural soil in Solan (HP)

Sr. No.	Parameters	Solan (Dumpsite soil)			Solan (unaffected soil)
		0.5 m	1.0 m	1.5 m	
1.	Specific gravity	1.19	2.0	2.1	2.56
2.	Coefficient of uniformity	4.13	4.13	4.12	4.62
3.	Coefficient of curvature	1.0	1.0	1.0	1.15
4.	Liquid limit	24.0	24.3	24.7	29
5.	Plastic limit	19.0	18.6	19.0	16
6.	Plasticity index	5.0	5.7	5.7	13
7.	Optimum moisture content	12	12	12	12
8.	Maximum dry density	1.78	1.85	1.87	2.2
9.	Angle of internal friction	35.79	35.75	34.60	34.99
10.	Cohesion (kN/m^2)	1.67	2.67	3.0	6
11.	CBR (un-soaked)	12.34	16.69	17.42	17.88
12.	CBR in (soaked)	4.52	5.35	5.90	6.20
13.	Permeability	4.0 x 10^{-3}	3.4x 10^{-3}	2.0 x 10^{-3}	3.0 x 10^{-4}

Table 6.5 showed the variation in the geotechnical evaluation of natural soil and dumpsite soil in Solan region of H.P. The result analysis displayed the value of specific gravity in the range of

1.19 to 2.1 for dumpsite soil. The LL and PI of affected soil varied in the range of 24.0-24.7% and 5.0-5.7% respectively however the natural soil revealed the LL i.e.29 % and PI i.e. 13%. Apart from this, the affected soil i.e. dumpsite soil of Solan region exhibited lower MDD, lower CBR but higher hydraulic conductivity comparative to the natural soil. The reason being that the degradation of biodegradable matter thereby permeation of leachate into the sub-soil that cause change in the engineering properties of the soil. Further, it was perceived that the sample taken from the depth of 0.5 m revealed lesser strength in comparison to the sample acquired from 1.5 m depth whereas the soil acquired from 1.5 m exhibited almost similar properties as that of the natural soil.

6.3.2 Assessment of SEM & EDS analysis:

The geometric arrangement and the structural behaviour of soil has been analysed by SEM whereas element concentration was analysed by energy disperse x-ray spectroscopy. The energy dispersive x-ray spectroscopy analysis detected elements and their weight percentage such as calcium, potassium, magnesium, oxygen, silicon, sodium, iron and carbon. The SEM micrographs for the dumpsite soil has been analysed at four different magnifications (8000, 10000, 15000 and 20000) and the clear image out of four magnifications has been displayed in Figure 6.1(a)-6.4 (a) for four study regions. The micrographs thus attained by scanning electron microscopy has been displayed main portion of kaolinite mineral in the affected soil samples of four study regions in H.P. The energy dispersive spectroscopy for the dumpsite soil of four selected study regions has been illustrated in Figure 6.1 (b)-6.4 (b) respectively. However, the quantitative analysis of detected elements has been shown in Table 6.6-6.9.

SEM image of soil samples for Solan region has been presented in Figure 6.1 (a) and EDS of soil for Solan region has been illustrated in Figure 6.1 (b). However, the quantitative examination of detected elements has been shown in Table 6.6.

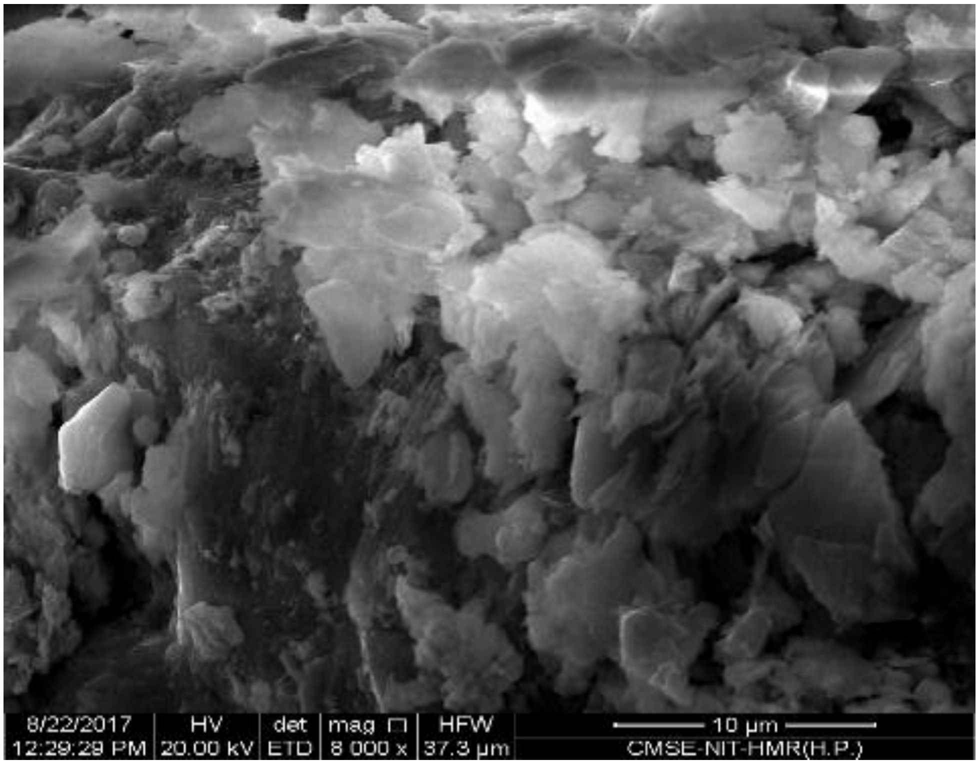


Figure 6.1 (a): SEM micrographs of soil (Solan)

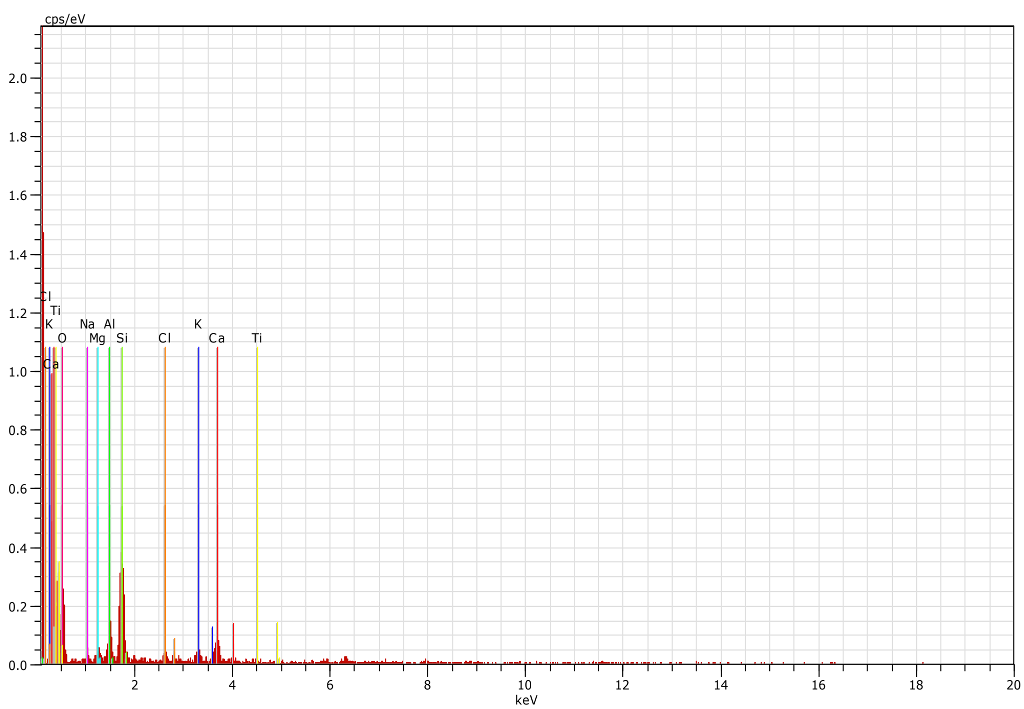


Figure 6.1 (b): EDS of soil (Solan)

Table 6.6: Quantitative analysis of detected elements

Elements	Atomic number	Series	Normalized weight	Atomic weight
O	8.0	K	54.66	69.30
Si	14.0	K	21.27	15.36
Ca	20.0	K	8.26	4.18
Al	13.0	K	7.27	5.47
K	19.0	K	2.50	1.30
Mg	12.0	K	2.21	1.84
Na	11.0	K	1.74	1.54
Ta	22.0	K	1.20	0.51
Cl	17.0	K	0.89	0.51

SEM image of soil samples for Mandi region has been presented in Figure 6.2 (a) and EDS of soil has been illustrated in Figure 6.2 (b). However, the quantitative examination of detected elements has been shown in Table 6.7.

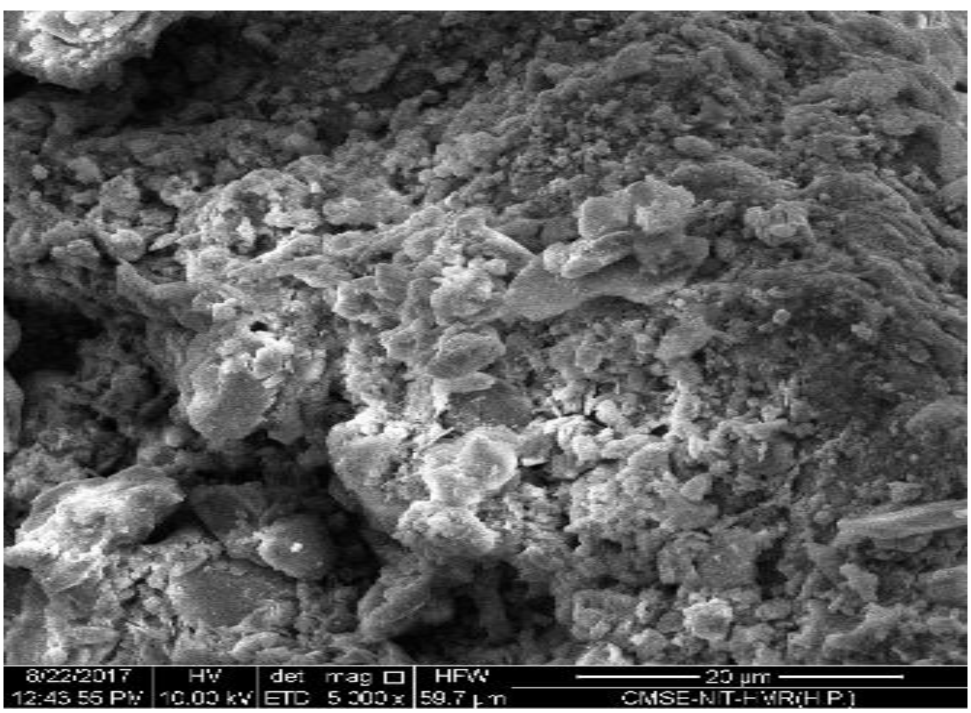


Figure 6.2 (a): SEM micrographs of soil (Mandi)

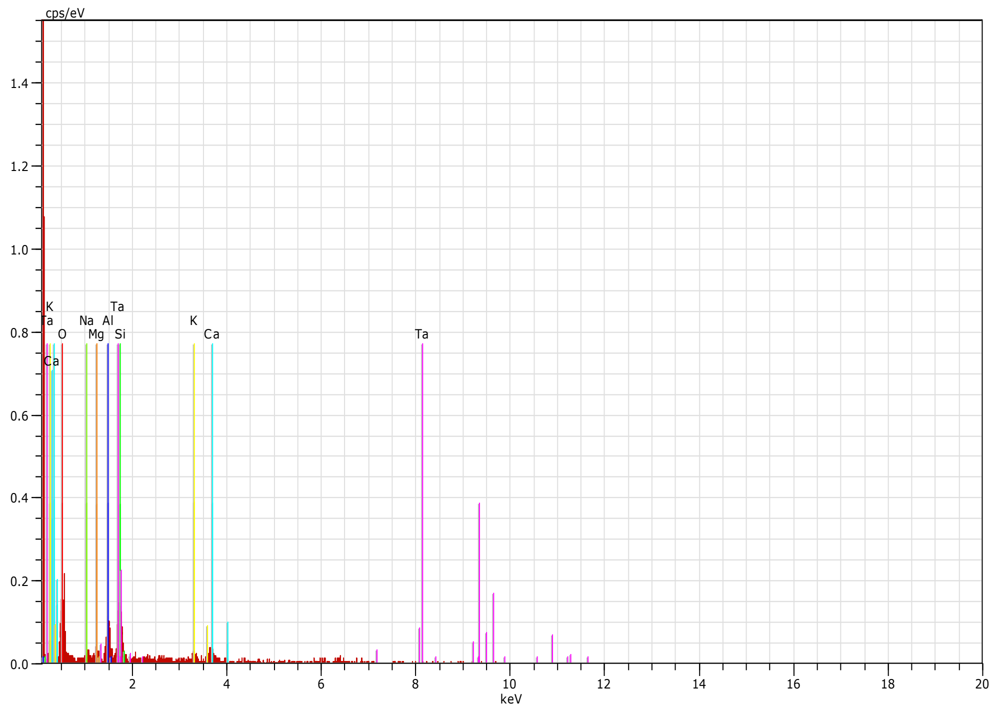


Figure 6.2 (b): EDS of soil (Mandi)

Table 6.7: SEM quantitative analysis of detected elements

Elements	Atomic number	Series	Normalized weight	Atomic weight
O	8.0	K	45.96	64.55
Si	14.0	K	18.53	14.83
Al	13.0	K	10.47	8.72
Cl	20.0	K	10.23	5.74
Ta	73.0	M	6.80	0.84
K	19.0	K	6.09	3.50
Na	11.0	K	1.03	1.01
Mg	22.0	K	0.89	0.82

SEM image of soil samples for Sundernagar region has been presented in Figure 6.3 (a) and EDS of soil has been illustrated in Figure 6.3 (b). However, the quantitative investigation of detected elements has been presented in Table 6.8.

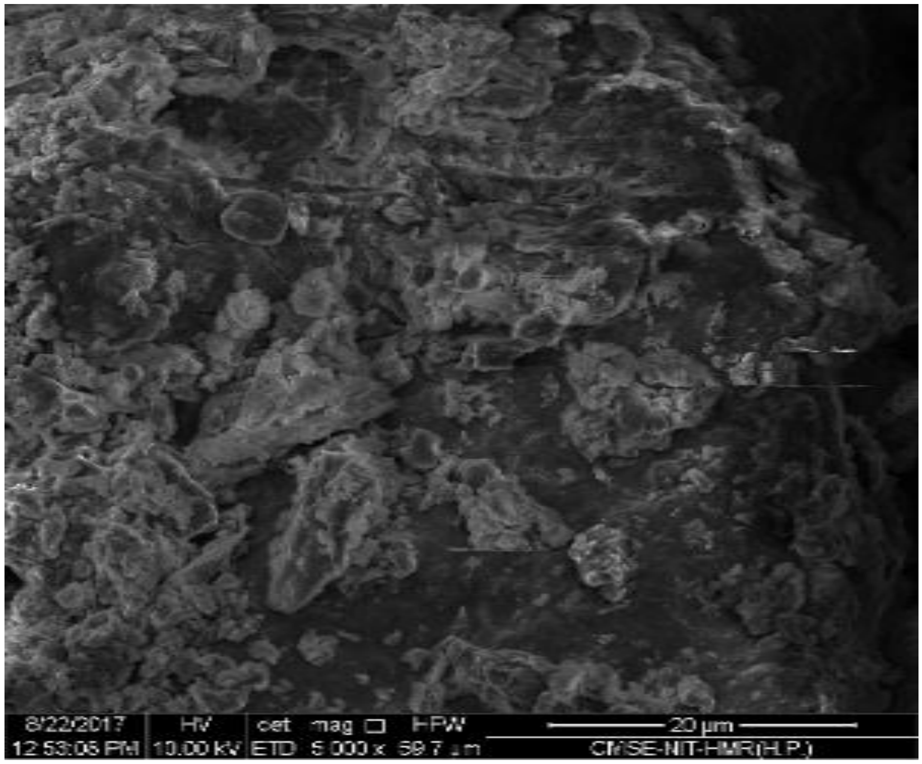


Figure 6.3 (a): SEM micrographs of soil (Sundernagar)

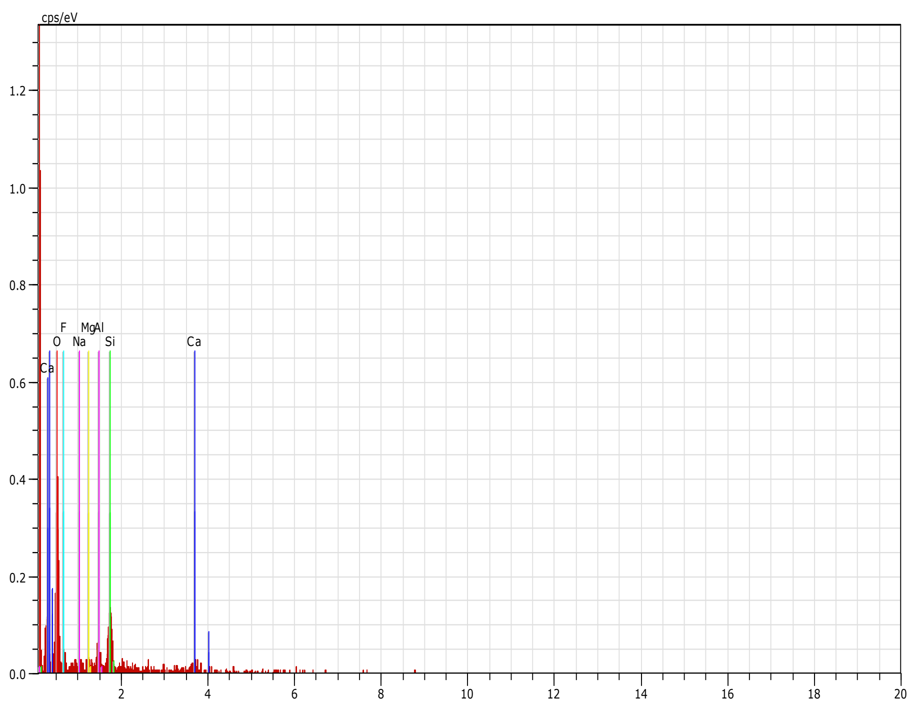


Figure 6.3 (b): EDS of soil (Sundernagar)

The quantitative analysis of detected elements has been shown in Table 6.8

Table 6.8: SEM quantitative examination of detected elements

Elements	Atomic number	Series	Normalized weight	Atomic weight
O	8.0	K	62.10	73.10
Si	14.0	K	18.63	12.49
Cl	20.0	K	5.44	2.56
Al	13.0	K	4.78	3.33
Mg	12.0	K	1.28	0.99
Na	11.0	K	0.99	0.81

SEM image of soil samples for Baddi region has been presented in Figure 6.4 (a) and EDS of soil for Baddi region has been illustrated in Figure 6.4 (b). However, the quantitative analysis of detected elements has been shown in Table 6.9.

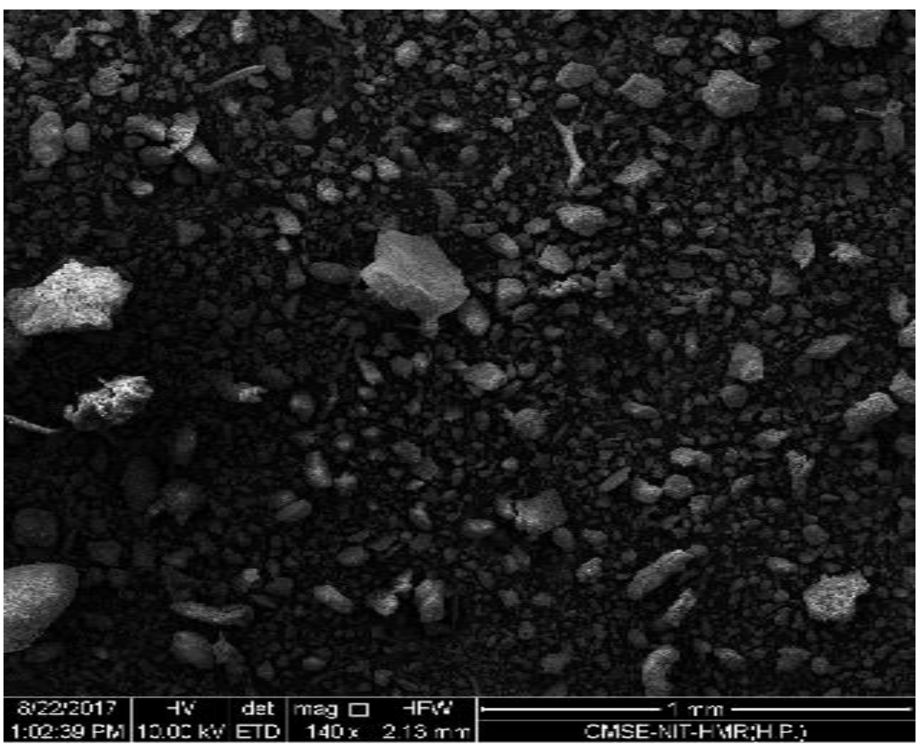


Figure 6.4 (a): SEM micrographs of soil (Baddi)

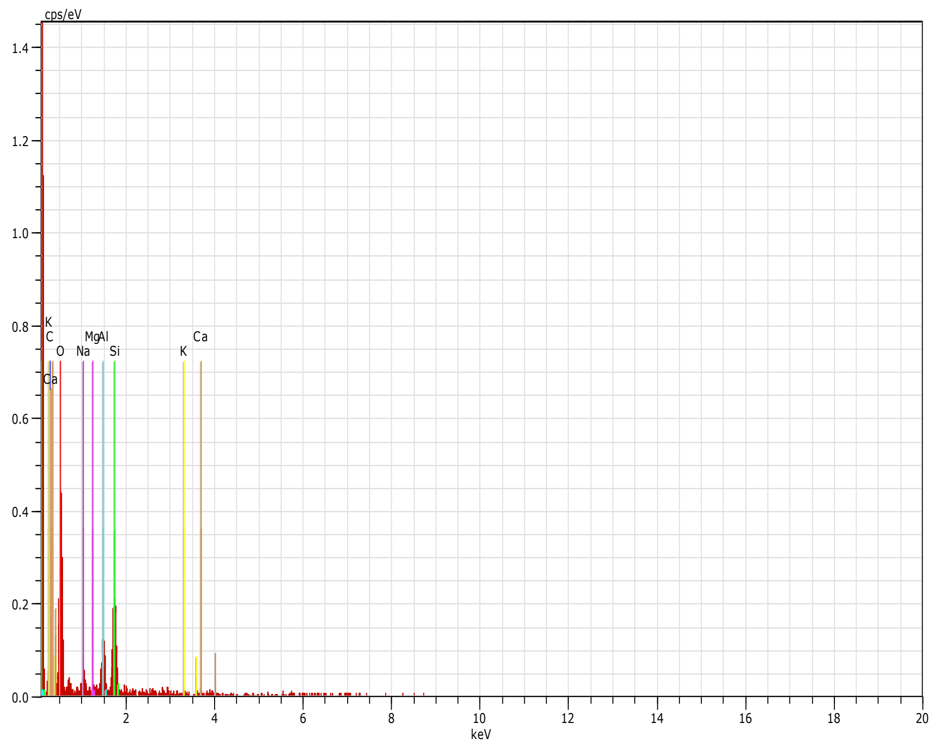


Figure 6.4 (b): EDS of soil (Baddi)

The quantitative analysis of detected elements has been shown in Table 6.9.

Table 6.9: SEM quantitative examination of detected elements

Elements	Atomic number	Series	Normalized weight	Atomic weight
O	8.0	K	53.32	60.35
Si	14.0	K	21.63	13.94
C	6.0	K	10.74	16.19
Al	13.0	K	8.49	5.70
Na	11.0	M	3.17	2.50
Ca	20.0	K	1.26	0.57
K	19.0	K	1.02	0.47
Mg	12.0	K	0.37	0.27

The quantitative analysis of detected elements revealed the type of element, series and weight and atomic numbers has been demonstrated in Table 6.6 for the dumpsite soil of Solan region in Himachal Pradesh. The energy dispersive spectroscopy by SEM detector perceived nine elements and the elements lies in k series. The percentage by atom of oxygen in soil has been observed higher than the percentage given by their respective weights.

Table 6.7 revealed that the energy dispersive spectroscopy by SEM detector perceived eight elements. The percentage by atom of oxygen in soil was higher than the percentage given by their respective weights in the dumpsite soil of Mandi region.

Table 6.8 revealed that the energy dispersive spectroscopy by SEM detector perceived seven elements and the elements lies in k series for the dumpsite soil of Sundernagar region. However, the percentage by atom of oxygen in the soil sample was found higher than the percentage given by their respective weights.

Table 6.9 revealed that the energy dispersive spectroscopy by SEM detector perceived eight and all elements lies in k series. The percentage by atom of carbon and oxygen of soil are higher than the percentage given by their weights. The more concentration of oxygen in the soil samples has been observed more because of the maximum fraction of organic fraction in the soil thereby increase in moisture content of the soil samples.

Summary

The dumping of municipal solid waste in an unscientific manner in an open land has led to severe problems to the environment and also affects human health. The soil characteristics acquired from geotechnical assessment revealed some contamination in dumpsite soil due to continuous dumping over a number of years. All the dumpsites soil showed less specific gravity comparative to the natural soil due to the presence of mix waste in the subsoil. Interestingly, the compaction characteristics and CBR value showed less maximum dry density at optimum moisture content and lesser CBR value as compared to the natural soil. The plasticity index of all dumpsites showed non-plastic behaviour of the soil whereas the natural soil shows moderate plastic behaviour. However, the dumpsite soil of four selected study regions showed more hydraulic conductivity comparative to the unaffected soil samples. Apart from this, the lesser value of cohesion and coefficient of internal friction in the affected soil sample displayed lesser shear strength comparative to the natural soil.

Municipal solid waste characterisation revealed that the waste of Himachal Pradesh is rich in biodegradable fraction and comparatively lesser fraction of other materials including metals, glass, bottles etc. However, due to drastic increment in industrialisation and urbanisation, the varieties and amount of MSW will upsurge in near future. Consequently, dumping yards will increase thus increase in the leachate concentration. The experimental analysis revealed that the soil of four study regions in H.P. may be utilized for the construction purposes. Additionally, once the disposal of waste is completed, the soil may be utilized for parking facilities, gardens and in the lighter construction purposes including shops etc.

The images acquired by SEM examination revealed the main fraction of kaolinite mineral in all the four selected soil samples. The energy dispersive spectroscopy analysis revealed the main fraction of oxygen in all four soil samples because of the presence of moisture content in the soil. The study clearly indicated that till now, only minor changes have been observed in the geotechnical behaviour of dumpsite soil. But with the increase in time, it may have severely effect on the soil properties if regular open dumping of waste will remain in practise. Hence, it is strongly recommended to design and construction of engineered landfill system to avoid the filtration of contaminants into the sub-soil thereby prevents the soil contamination. The following chapter examines the characteristics of the leachate which causes the contamination of soil.

CHAPTER 7

LEACHATE CHARACTERIZATION AND ANALYSIS OF ITS TOXICITY POTENTIAL

7.1 Introduction

The increment in the waste production is a great cause of concern for the disposal of waste as it leads to poor aesthetic appearance and is a potential environmental and human health hazard particularly for developing countries [191-196]. This is primarily because MSW comprised of many toxic chemicals and in contact with moisture leads to generation of leachate which has the potential to contaminate the surrounding soil and groundwater conditions [197, 198]. The problem is further compounded as illegal dumping of solid waste is the common form of disposal due to minimum costs involved thereby leading to a possibility of large quantities of leachate generation [197, 199]. As reported from earlier literature [150], the major fraction of solid waste generated in India and in our study locations is primarily organic in nature and due to rainfall they get dissolved in water leading to generation of leachate which can affect the quality of the groundwater depending on the permeability conditions of the soil. The previous chapter describes in details the soil contamination due to leachate characteristics and which is further characterised in this chapter.

Leachate is dark brown liquid release when rainfall comes in contact with the municipal solid waste [34, 200]. Leachate primarily consists of carbon, nitrogen, manganese and many more chemicals including solvents, organic and inorganic salts [90, 197]. Further, the leachate generated is a mixture of harmful chemicals consisting of organic, inorganics (presence of different cations and anions), heavy metals (cadmium, lead, nickel, chromium, zinc etc.) and other refractory chemicals [201, 202]. These constituents vary in proportion depending on the waste characteristics at the dumpsite, site hydrology and volume of rainfall experienced at the dumpsite [33, 83, 203]. Leachate characteristics are also affected by the ‘age’ of the landfill site and also the proportion of stabilized waste present in the dumpsite [204, 198]. In practice, for those landfill sites which are in operation for less than five years have pH values of leachate varying from 4 to 6.5 and are acidic in nature due generation of carboxylic acid [205] while older or matured landfills have pH varying between 8 to 8.5 and are more alkaline in nature due to generation of methane and are indicative that the landfill is nearing the end of its lifespan. The composition of the leachate mainly depends upon the age of dumping site, intensity of rainfall and the nature of waste that dumped continuously in the disposal sites [150]. In practice, the nature of landfill site is often determined on the pH of leachate samples produced from them with those having pH less than 6.5 being classified as *young* and greater than pH 7.5 being classified as matured landfill sites [106, 206, 207]. This is mainly due to the reason that in *young* landfill sites concentrations of Volatile Fatty Acids (VFA) are on the higher side leading to reduced pH conditions (hence acidic) around is less than 6.5 whereas in matured landfills, volatile fatty acids are gets changed in to $CH_4$and CO_2 leading to alkaline conditions and increased pH values [205].

In this perspective, ‘leachate pollution index’ is evaluated to categorize the toxicity potential of the leachate so that instant corrective actions can be implemented at the dumping locations [206-208]. The LPI is based on allocating a solitary figure ranged between 5 to100 [209, 210] like a score that exhibit pollution potential of leachate.

Henceforth, the current study has been carried out in the four selected locations in HP including Solan, Mandi, Sundernagar and Baddi. It is already discussed that the management of MSW is not so very adequate in the selected locations of Himachal Pradesh. In fact, the waste is disposed of in the open dumps without any provision of leachate assorting system as well as the liner facility. So, the leachate produced directly permeates into the aquifers thereby become biggest menace to the groundwater.

7.2 Material and methods

7.2.1 Leachate collection

The physical and chemical characterization of leachate produced in the dumpsites were evaluated to check its pollution potential based on the seasonal variation in the study areas including Solan, Mandi, Sundernagar and Baddi of Himachal Pradesh. A monitoring campaign was carried out for collection of the leachate samples covering summer, rainy and winter seasons. In this context, samples were collected during May - June 2017 (S1); July -August 2017 (S2) and December - January-2017 (S3) from the downward direction from the disposal site to characterize seasonal variations.

Further, from April 2018, about 8 TPD of municipal solid waste from Solan dumpsite were being shifted to dumpsite of Shimla city. The study was re-conducted at this particular location to observe the effect of reduced load on the dumpsite at this particular location. In this context, the leachate samples were again collected in the month of *April-May 2018* to determine the pollution potential due to reduced loading conditions at the dumpsite.

7.2.2 Leachate analysis

The samples were extracted from the three different points in the downwind direction and then mixed properly in such a way to obtain the representative mix of samples [150, 211]. The leachate samples were assembled in tight flexible elastic container, immersed in nitric acid (HNO3) for a day [24, 150, 211]. Overall thirty-six samples of leachate were gathered from four respective solid waste dumping locations covering the different seasons.

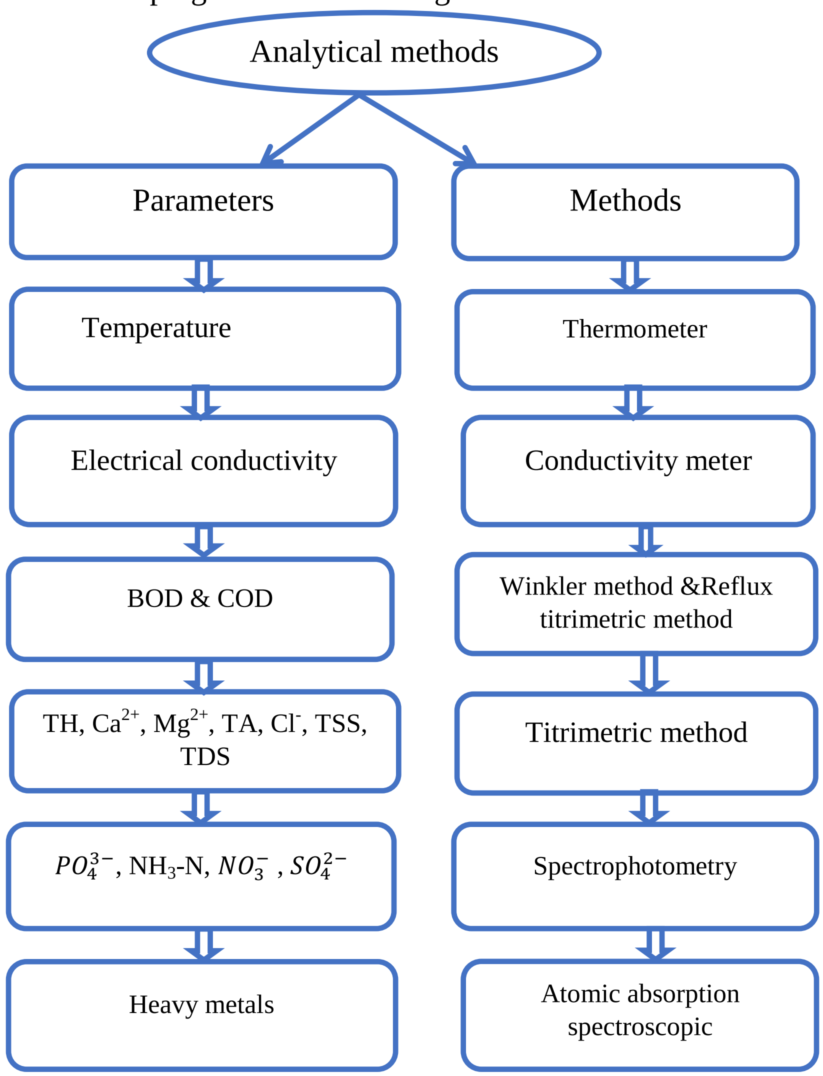


Figure 7.1: Analytical methods of the various parameters

The gathered samples were conveyed to lab and stockpiled in freezer at 4°C temperature and thereby assessed for different physical, chemical and heavy metal analysis. The method of determination of the above said parameters has been analysed according to the standard methods of American Public Health Association (APHA 2012). pH and TDS were determined by electrometric method and gravimetric method respectively. COD and BOD were determined by open reflux method and Winkler method respectively [150]. Heavy metals analysis was carried out by using Atomic Absorption Spectrophotometer *(*AAS make - GBC, Model - Avanta). The analytical methods of the various parameters have been summarized in Figure 7.1.

7.2.3 Leachate pollution index

LPI is the tool that is utilized to indicate the contamination potential of leachate generated from open dumping of MSW. LPI is an increasing scale index in which the higher value denotes the increased environmental pollution levels and is determined by Delphi Technique [206-209]. In all about 18 parameters have been proposed for utilization to determine the LPI. The details of these mentioned parameters have been discussed earlier in previously reported literature [150, 209, 212].

As observed, both physical as well as chemical parameters are considered for determination of LPI. In principle, each of these selected parameters are assigned a certain weightage depending on the importance of the parameter and if all the eighteen parameters are present in the tested samples then the summation of the weights assigned for individual parameter should be **one** [150].

The sub-index curves for individual parameter has been develop to create a relation between the pollutant and the concentration level of each parameter. The sub-index curves for the pollutants have been utilized according to the procedure outlined by Kumar and Alappat (2003a). Finally, LPI is determined using equations 1 & 2 respectively [150].

$$\sum_{i=1}^{n} wipi \qquad (1)$$

LPI = Leachate pollution index

wi = weight assigned for the i^{th} pollutants

pi = sub-index of thei^{th}pollutants

n = number of pollutants that can be utilized for the evaluation of leachate pollution index

$$\sum_{i=1}^{n} wi=1$$

Further, in case if the statistics are not available for pollutant variables, then leachate pollution index is determined by using the equation given below:

$$\sum_{i=1}^{m} wipi/\sum_{i=1}^{n} wi \qquad (2)$$

m denotes the number of pollutants, when the statistics are not accessible.

7.3 Results and Discussions

7.3.1 Leachate characterization

The physical and chemical characterization of the leachate samples collected and analyzed for the three monitoring campaigns have been summarized in Table 7.1 for all of the study locations. The *average* pH values over the three monitoring campaigns at the study locations were determined to be 8.36, 8.77, 8.17 and 9.44 respectively for Solan, Mandi, Sundernagar and Baddi. The pH value of the leachate sample at all the dumpsites showed higher values (average pH >8) indicating that the dumpsites were primarily in the methanogenic phase and they were almost reaching the end of their lifespan. Similar, pH results were reported for other similar studies carried out in the dumping site of Chandigarh and 6.8 to 8.3 in the dumping site of Chennai respectively [150, 213]. The *average* pH values over the three monitoring campaigns at the study locations were determined to be 8.36, 8.77, 8.17 and 9.44 respectively for Solan, Mandi, Sundernagar and Baddi. The pH value of the leachate sample at all the dumpsites showed higher values (average pH >8) indicating that the dumpsites were primarily in the methanogenic phase and they were almost reaching the end of their lifespan. Similar, pH results were reported for other similar studies carried out in the dumping site of Chandigarh and 6.8 to 8.3 in the dumping site of Chennai respectively [150, 213]. The *average* TDS concentrations over the three monitoring campaigns at the study locations were determined to be 3413, 3087, 2883 and 4525 mg/l respectively for Solan, Mandi, Sundernagar and Baddi. The TDS concentrations at all the study locations exceeded the disposal standards (2100 mg/l) for surface water, public sewers and disposal in land conditions. High concentrations of TDS in leachate signify discharge of ions from the disposal site which leads to increase in salinity thereby increasing its toxicity which can severely affect the characteristics of the groundwater [150]. This is also correlated by the high values of electrical conductivity observed for the leachate samples at all the study locations as it represents high ionic concentrations.

Table 7.1: Characterization of leachate based on seasonal variation for selected locations

Parameters	Solan			Mandi			Sundernagar			Baddi			Standards for disposal		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	Surface Water	Public Sewers	Disposal in land
pH	8.1	8.26	8.72	8.3	8.8	9.2	7.89	8.23	8.4	8.9	9.62	9.8	5.5-9.0	5.5-9.1	5.5-9.2
TDS	3319	3428	3492	2928	3118	3216	2812	2864	2972	4238	4606	4732	2100	2100	2100
TSS	2298	2402	2429	2214	2302	2351	2219	2342	2388	3720	3779	3872			
Cl^-	889	926	983	754	798	872	698	712	746	1248	1483	1549	1000	1000	600
SO_4^{2-}	386.7	391.8	402.18	454.2	472.8	489.3	372.4	364.8	380.9	680.3	702.2	754			
PO_4^{3-}	1.38	1.42	1.62	1.24	1.29	1.35	1.26	1.32	1.41	2.88	2.92	2.97			
TH	724.8	746.2	752.9	924.2	931.6	944.7	718.2	732.4	744.8	1092.6	1124	1328			
COD	982	1089	1202	1122	1218	1326	768	824	893	1487	1739	1822	250		
Ca^{2+}	528.4	532.2	549.6	672.2	702.4	712.8	434.2	446.1	459.3	800	782	852			
Conductivity	5684	5892	6312	5242	5289	5318	5246	5339	5578	6112	6280	6437			
NH_4-N	524.6	529.2	532.7	428	446	478	422.8	431.5	443.8	521	526	542	50	50	
BOD	673	691	716	512	528	533	437.2	439.6	461.3	627	638	649	30	350	100
TKN	472.6	481.2	487.4	504.8	513.2	527.9	403.6	411.4	423.7	637.2	648	664.4			
Cu	2.24	2.62	2.98	3.02	3.22	3.49	3.42	3.68	4.12	4.25	4.89	5.12	3	3	
Ni	0.008	0.16	0.22	0.22	0.34	0.46	0.12	0.19	0.29	0.59	0.72	0.88	3	3	
Zn	3.66	3.72	3.89	4.82	5.12	5.87	2.12	2.56	2.59	6.02	7.24	7.89	5	15	
Pb	1.39	1.78	2.46	1.24	1.89	2.21	1.08	1.26	1.34	2.12	3.54	5.82	0.1	1	
Cr	0.22	0.39	0.42	0.19	0.28	0.46	0.18	0.312	0.37	0.37	0.52	0.74			
Fe	44.82	47.31	51.02	24	38	41	31.8	37.29	38.47	56.26	59.41	62.83			
Cd	0.052	0.057	0.0614	0.032	0.036	0.048	0.023	0.028	0.029	0.082	0.084	0.092			
Cyanide	0.037	0.04	0.042	0.046	0.052	0.066	0.017	0.023	0.029	0.124	0.143	0.148			

The *average* electrical conductivity over the three monitoring campaigns at the study locations were determined to be 5963, 5283, 5388 and 6266µS/cm for Solan, Mandi, Sundernagar and Baddi respectively. Similarly, the average chloride concentrations were determined to be 933, 808, 719 and 1427 mg/l for Solan, Mandi, Sundernagar and Baddi respectively. This signifies that the chloride concentrations are within permissible limits for disposal in public sewers and inland surface waters (limit = 1000 mg/l) but unsuitable for land disposal (limit = 600 mg/l) for leachate generated from Solan, Mandi and Sundernagar study locations. For the Baddi study locations, the chloride concentrations exceed also disposal standards for all the three conditions. In general, chloride concentrations are considered to be conservative pollutants with negligible effects in long term considerations [89, 214].

The COD values of the leachate samples varied between982-1202 mg/l for Solan, 1122-1326 mg/l for Mandi, 768-893 mg/l for Sundernagar and 1487-1822 mg/l for Baddi. The values all exceed the disposal standards and are toxic in nature. Similarly, in this context, the BOD concentrations of the leachate samples from the dumpsites varied from 673-716 mg/l for Solan, 512-533 mg/l for Mandi, 437-461 mg/land 627-649 mg/l for Sundernagar and Baddi region respectively. The average BOD/COD were determined to be 0.64, 0.43, 0.54, and 0.38 respectively for Solan, Mandi, Sundernagar and Baddi. This exhibit that the leachate produced from Solan location having higher proportion of organics with it and this primarily due to dumping of rotten, unsold or putrescible fruits and vegetables being disposed of directly in the Solan dumpsite [4]. The lowest ratio was observed for Baddi dumpsite indicating a higher presence of inorganics in leachate composition which is due to dumping of large proportion of hazardous wastes generated from the industries at the dumpsite [4]. The results obtained for our study locations were in sharp contrast to similar reported earlier studies like in Chandigarh wherein the BOD/COD ratio were significantly low being less than 0.1 indicating a minimal concentration of organics in the leachate samples [150]. The NH_4-N concentrations for the study locations varied between 525-532 mg/l, 428-478, 423-444 and 521-542 mg/l for Solan, Mandi, Sundernagar and Baddi respectively over the monitoring campaign. The NH_4-N concentrations are primarily generated due to degradation of organic fractions leading to production of biogas and methane.

7.3.2 Assessment of heavy metals

The heavy metal characterization based on seasonal variation from the four study locations has been summarized in Table 7.1 and the representation of the physico-chemical parameter and heavy metal result analysis have been shown graphically in attached supplementary document representing Figures 7.2 to 7.22. The heavy metal analysis revealed that the average concentrations of Nickel and Zinc were within permissible limits at all of the study locations. The presence of zinc content is primarily owing to the occurrence of discarded batteries and lamps in the waste. Similarly, average concentrations of Copper were well within permissible limits at Solan study locations and slightly exceeded the permissible levels in Sundernagar and Mandi. The highest concentrations of copper were reported for Baddi well exceeding the prescribed standards. This is primarily because the waste from the Baddi dumpsite has some components of industrial wastes. Concentrations of copper in leachate samples primarily arise from dumping of scrap metals, discarded medicines, batteries [150]. The average Lead concentrations exceeded the permissible limits at all the study locations. The Fe content has been found on the higher side due to the reason that highest steel scraps are disposed in the dumping site and is maxim for Baddi location. The arsenic and mercury content in the leachate samples in all study regions were below detection level (BDL) however, the average cyanide concentration was on the higher side for Baddi region (0.34mg/l). In general, the heavy metals concentrations in dumpsite are usually higher in the acidogenesis phase due to the metal solubility and consequently lower pH value because of the presence of organic acids [215]. The increment in pH value and decrease in heavy metal solubility ensue subsequent decrease in the concentrations of heavy metals. High concentrations of heavy metals in the leachate sample can also be attributed to unsegregated wastes being dumped at the disposal sites. Further, more concentrations of heavy metals in leachate are indicative of inadequacy of the dumping of MSW in open dumpsites and are potential sources of environmental and health hazards and needs to be redressed [216].

Comparison with other reported literature revealed that the leachate produced from the waste disposal site in Gazipur also consists of zinc, lead, Chromium, copper and nickel content in certain amount [24]. However, the heavy metal concentrations for the study locations were comparatively less than reported for Tricity locations of Chandigarh, Mohali and Panchkula [150].

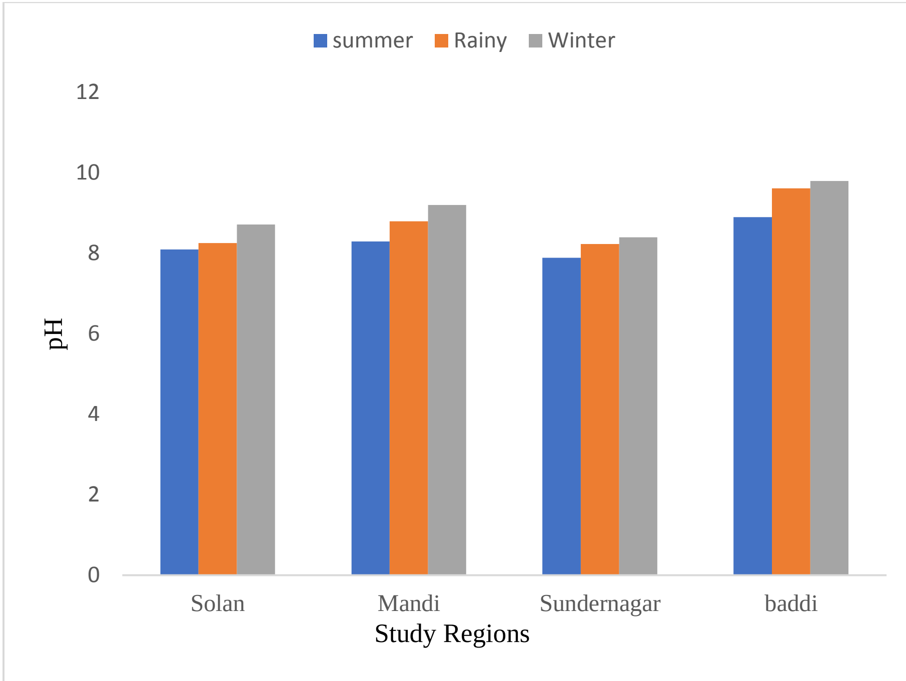


Figure 7.2: Concentration of pH of leachate based on seasonal variation

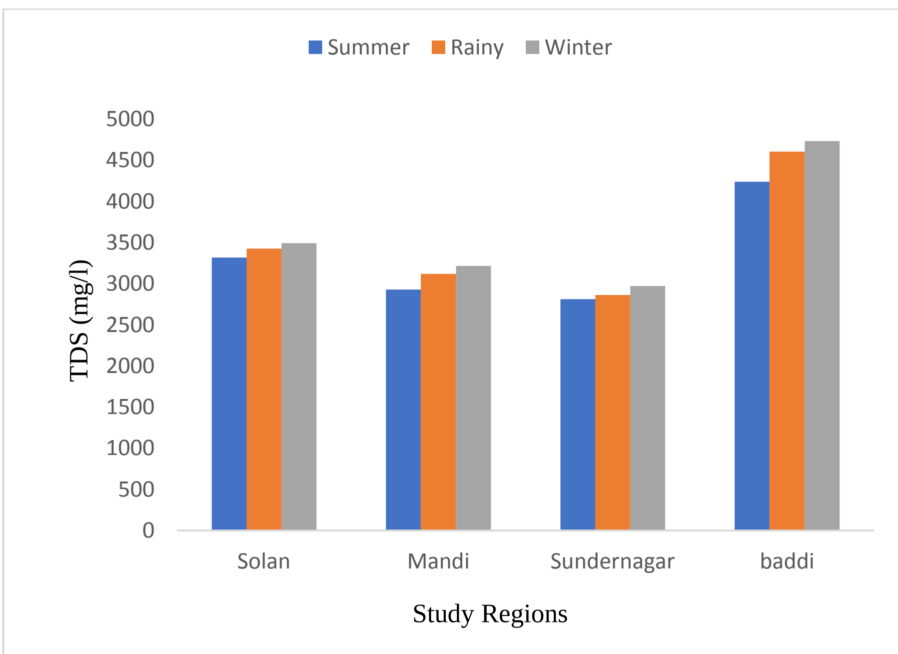


Figure 7.3: Concentration of TDS of leachate based on seasonal variation

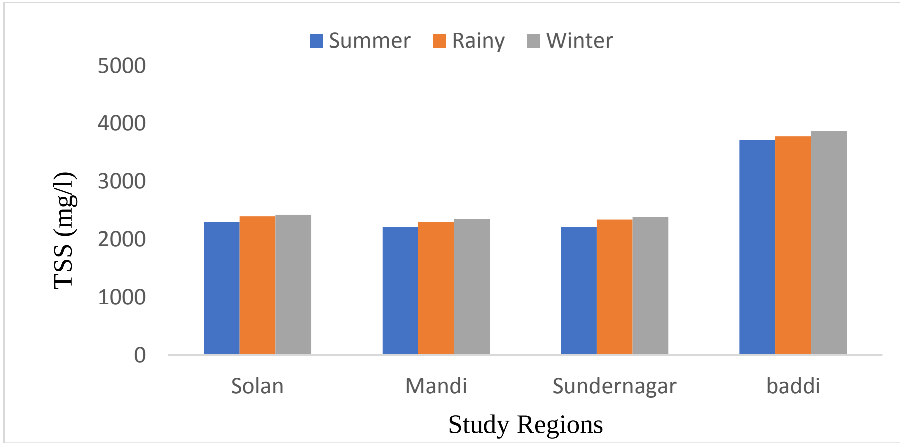


Figure 7.4: Concentration of TSS of leachate based on seasonal variation

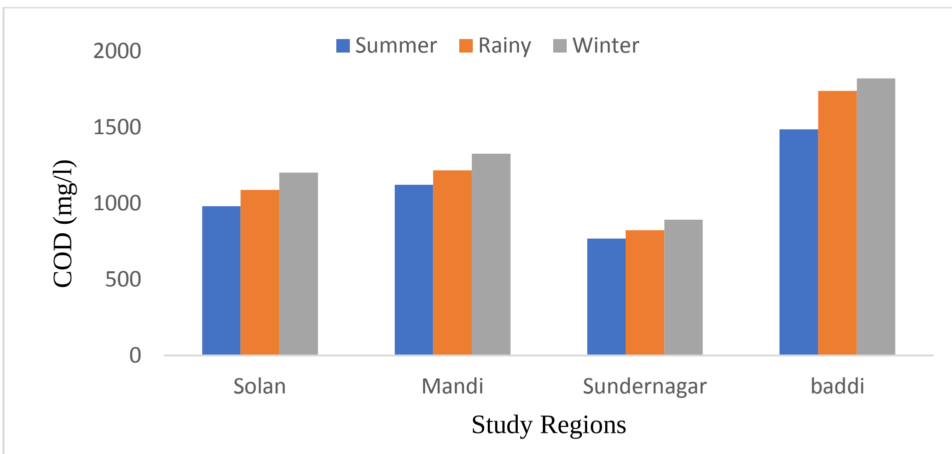


Figure 7.5: Concentration of COD of leachate based on seasonal variation

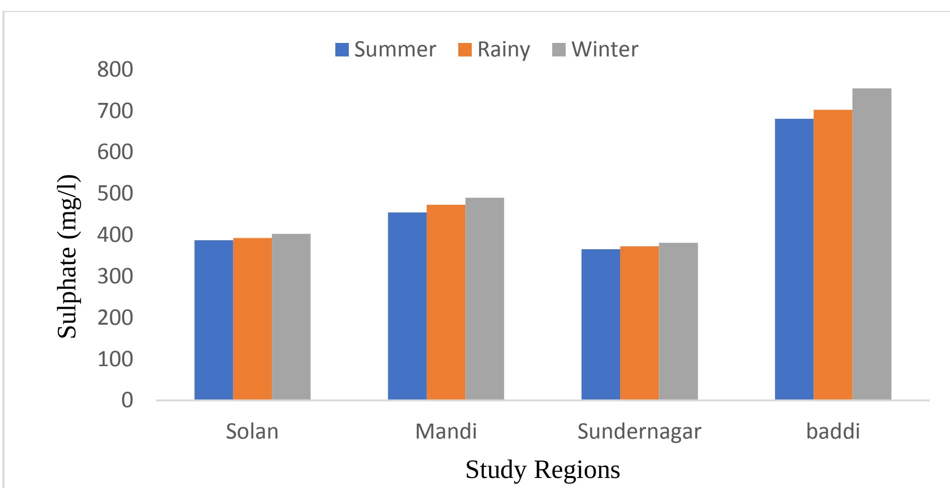


Figure 7.6: Concentration of sulfate content of leachate based on seasonal variation

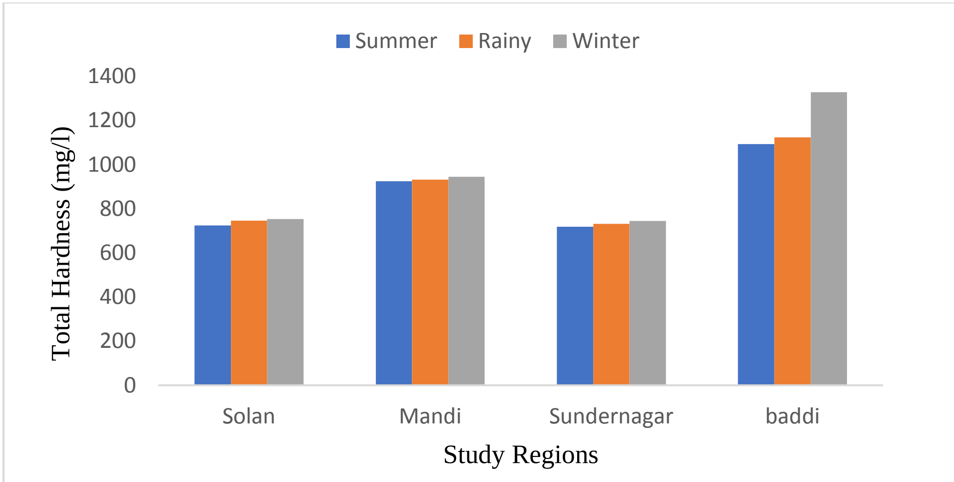


Figure 7.7: Concentration of TH of leachate based on seasonal variation

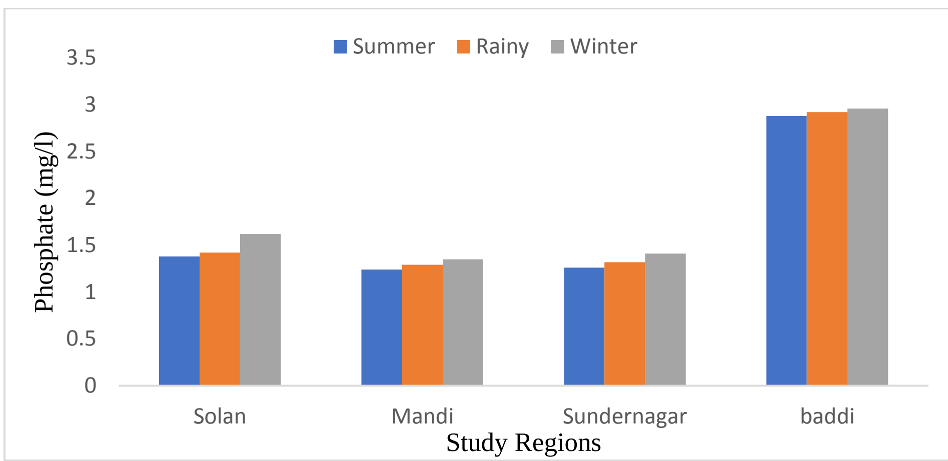


Figure 7.8: Concentration of phosphate of leachate based on seasonal variation

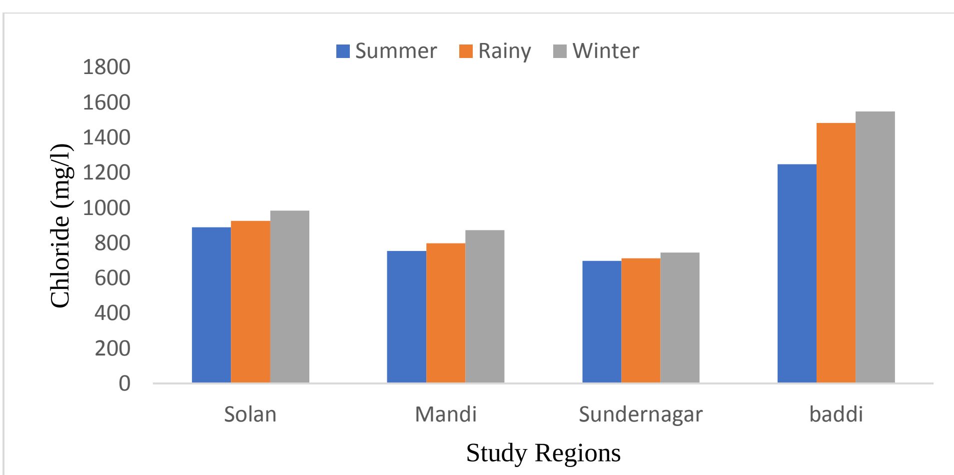


Figure 7.9: Concentration of chloride content of leachate based on seasonal variation

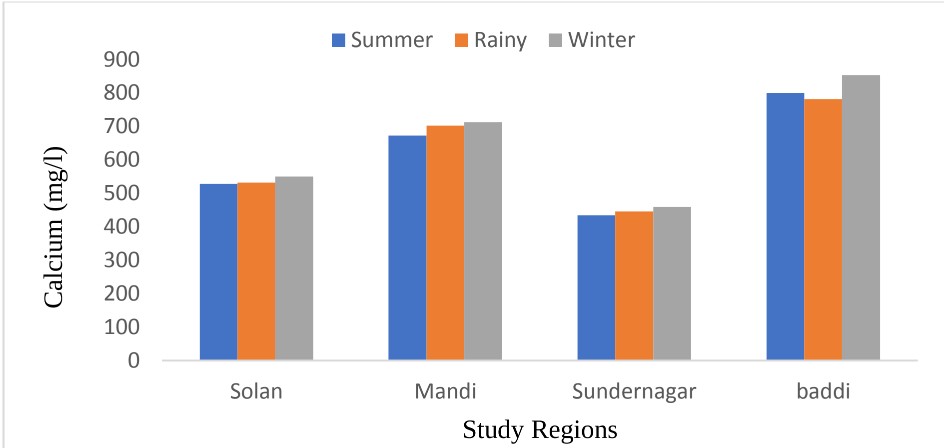


Figure 7.10: Concentration of calcium content of leachate based on seasonal variation

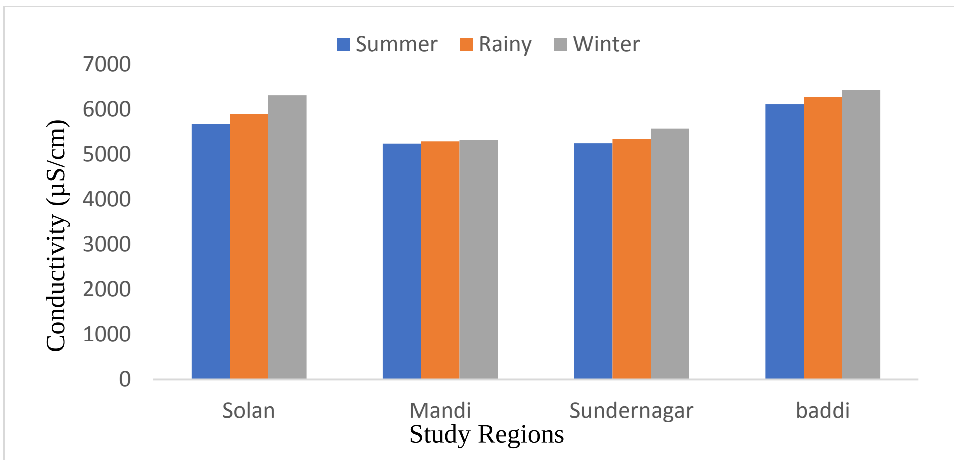


Figure 7.11: Concentration of conductivity of leachate based on seasonal variation

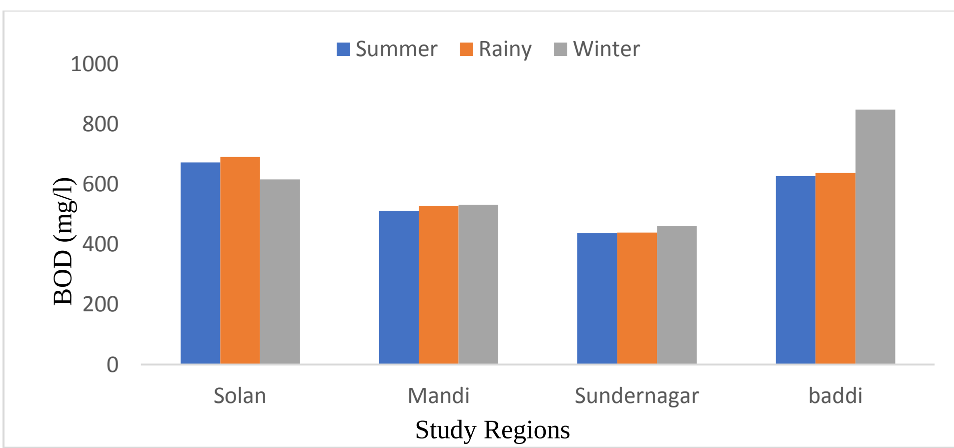


Figure 7.12: Concentration of BOD of leachate based on seasonal variation

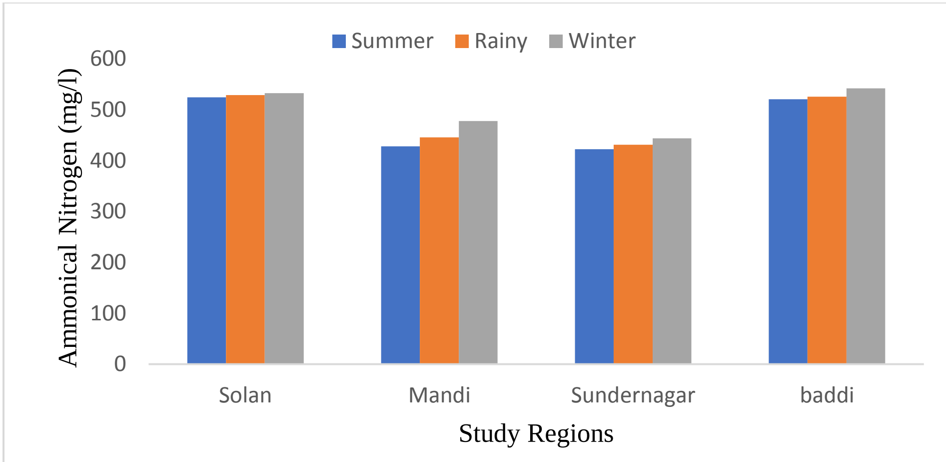


Figure 7.13: Concentration of ammonical nitrogen variation of leachate based on seasonal variation

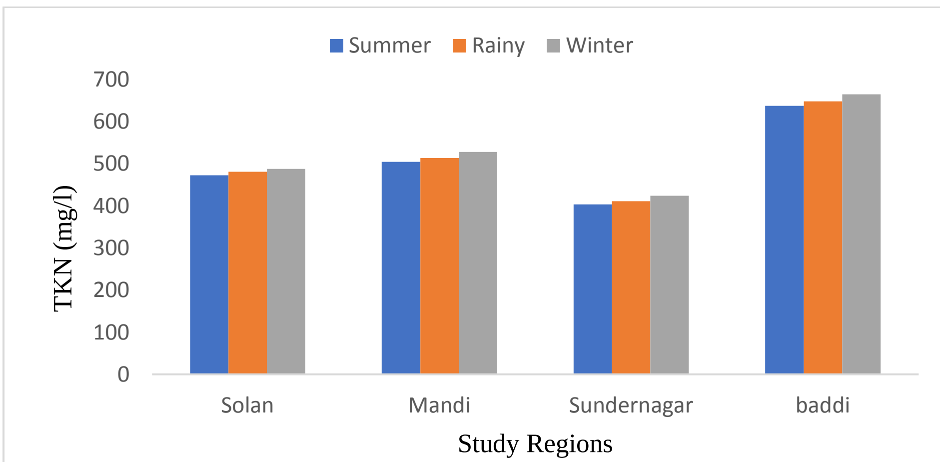


Figure 7.14: Concentration of TKN content of leachate based on seasonal variation

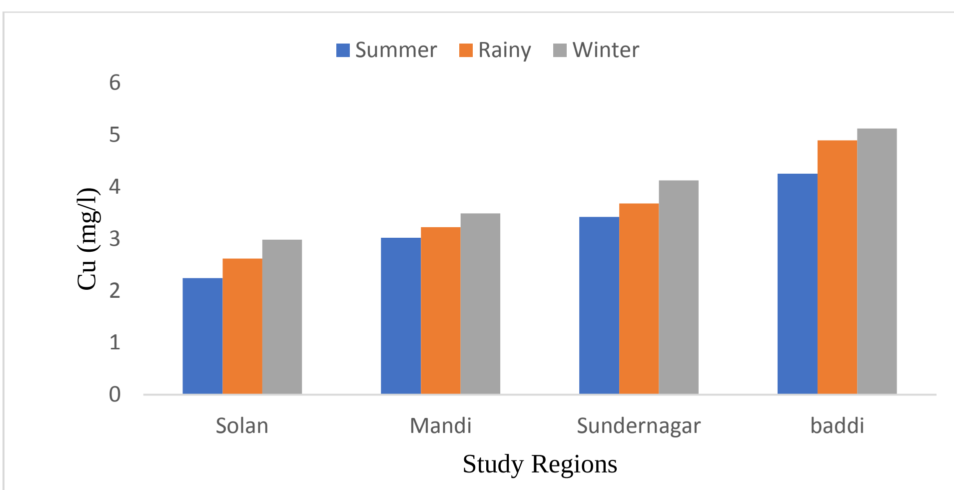


Figure 7.15: Concentration of Copper content of leachate based on seasonal variation

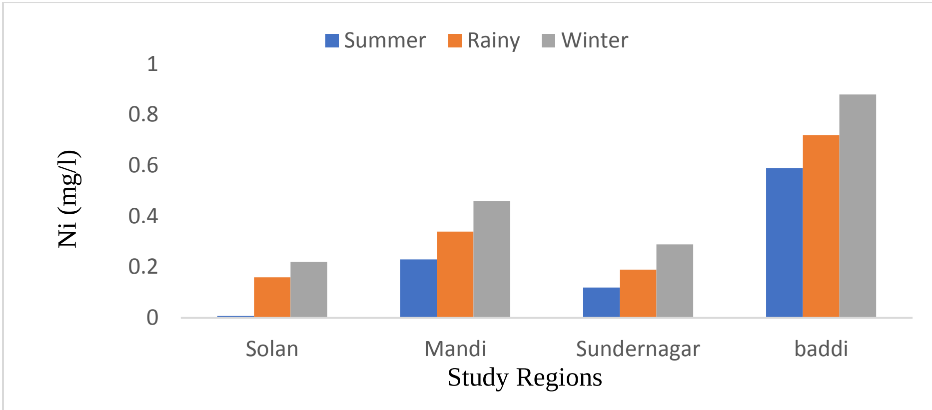


Figure 7.16: Concentration of Nickel content of leachate based on seasonal variation

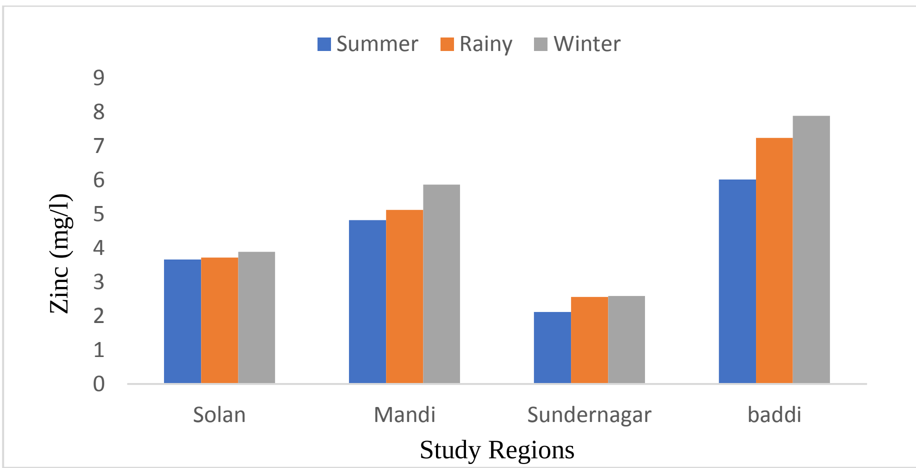


Figure 7.17: Concentration of Zinc content of leachate based on seasonal variation

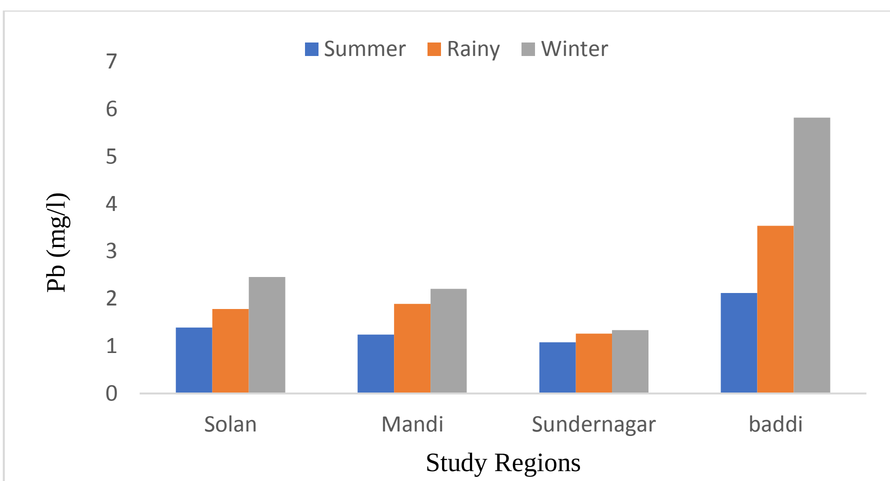


Figure 7.18: Concentration of lead content of leachate based on seasonal variation

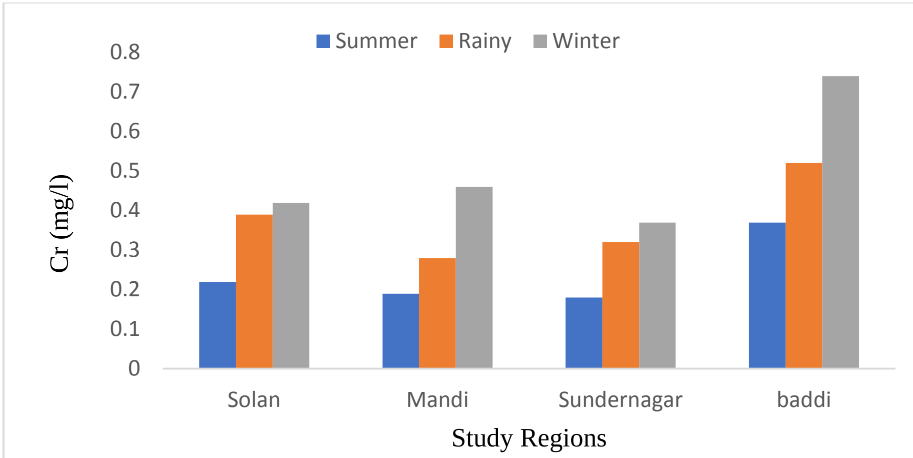


Figure 7.19: Concentration of Chromium content of leachate based on seasonal variation

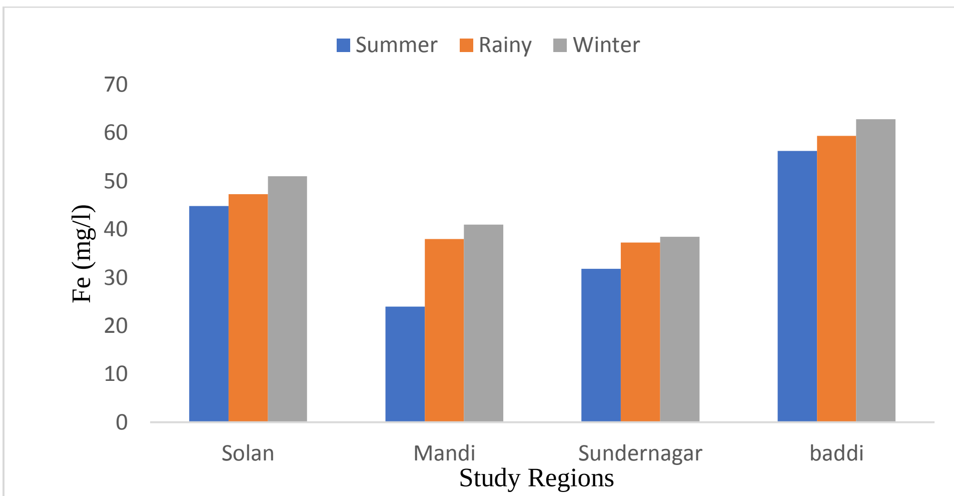


Figure 7.20: Concentration of ferrous content of leachate based on seasonal variation

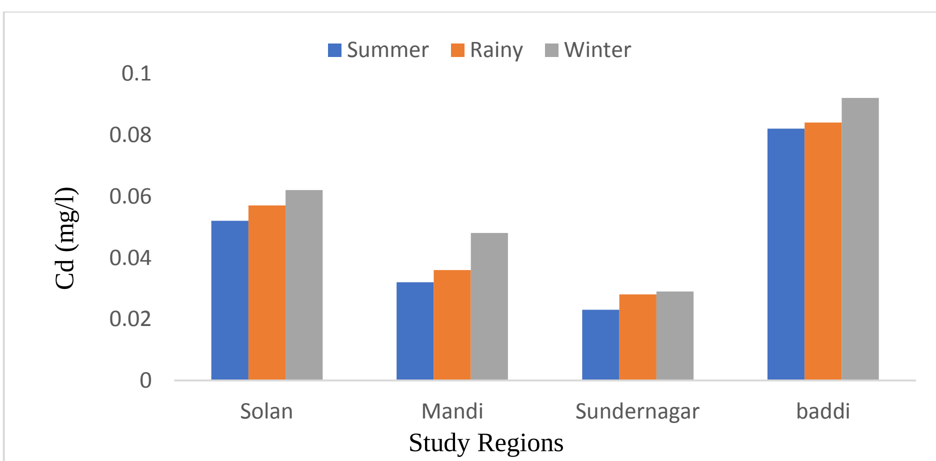


Figure 7.21: Concentration of cadmium content of leachate based on seasonal variation

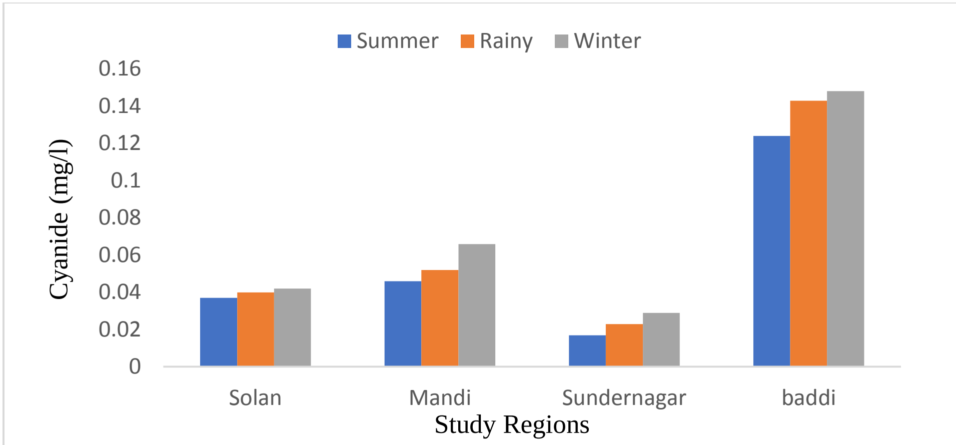


Figure 7.22: Concentration of cyanide content of leachate based on seasonal variation

The average leachate characterization based on the seasonal variation for four selected locations have been illustrated in Table 7.2.

Table 7.2: Average leachate characteristics based on seasonal variation for selected locations

Parameters	Solan	Mandi	Sunder Nagar	Baddi	Standard for disposal		
					Inland Surface Water	Public Sewers	Land Disposal
					5.5-9.0	5.5-9.1	5.5-9.2
TDS	3413.00	3087.33	2882.67	4525.33	2100	2100	2100
TSS	2376.33	2289.00	2316.33	3790.33	-	-	-
Cl-	932.67	808.00	718.67	1426.67	1000	1000	600
SO_4^{2-}	393.56	472.10	372.70	712.17	-	-	-
PO_4^{3-}	1.47	1.29	1.33	2.92	-	-	-
TH	741.30	933.50	731.80	1181.53	-	-	-
COD	1091.00	1222.00	828.33	1682.67	-	-	-
Ca2+	536.73	695.80	446.53	811.33	-	-	-
Conductivity	5962.67	5283.00	5387.67	6276.33	-	-	-
NH4-N	528.83	450.67	432.70	529.67	-	-	-
BOD	693.33	524.33	446.03	638.00	30	350	100
TKN	480.40	515.30	412.90	649.87	-	-	-
Cu	2.61	3.24	3.74	4.75	-	-	-
Ni	0.13	0.34	0.20	0.73	3	3	-
Zn	3.76	5.27	2.42	7.05	3	3	-
Pb	1.88	1.78	1.23	3.83	5	15	-
Cr	0.34	0.31	0.29	0.54	0.1	1	-
Fe	47.72	34.33	35.85	59.50	-	-	-

The physical and chemical characterization as well as heavy metal analysis of the leachate samples were again collected from Solan study location (April 2018) to observe any variations due to reduced loading conditions on the dumpsite has been summarized in Table 7.3. It was observed that there was significant reduction in concentration of physico-chemical and heavy metal parameters due to the reduced MSW load on the dumpsite. This suggests that some alternatives are needed for reducing possible MSW loading at the dumpsites.

Table 7.3: Characterization of leachate from Solan region after reduction of waste load (April 2018)

Sr. No.	Parameters	Physico-chemical characterization
1.	pH	7.84
2.	TDS	2843
3.	TSS	2027
4.	Cl^-	4.47
5.	SO_4^{2-}	239.6
6.	PO_4^{3-}	1.18
7.	TH	512.6
8.	COD	648
9.	Ca^{2+}	426.2
10.	EC	4372
11.	NH_4-N	389.4
12.	BOD	468.4
13.	TKN	309.5
Heavy metal characterization		
1.	Cu	2.06
2.	Ni	0.03
3.	Zn	2.16
4.	Pb	1.12
5.	Cr	0.14
6.	Fe	12.42
7.	Cd	0.029

7.3.3 Leachate Pollution Index (LPI)

LPI is an important tool in assessing the pollution potential of the leachate. It serves in categorizing the immediate need for treatment of such open dumpsites. The LPI for the current study was conducted as per the methodology described above using a total of 16 parameters (pH, TDS, Cl, TKN, NH_4-N, COD, BOD, Pb, Cr, Zn, Ni, Cu, Fe, Hg, As, CN). Of these 16 parameters utilized for determining LPI, three parameters (Hg, As and CN) had almost negligible contributions (due to no detection or very low concentrations) and in effect only thirteen majority parameters were effectively used. In particular, the accuracy in determination of LPI depends on the parametric data availability. To summarize, the average LPI over the three seasons were determined to be 17, 17, 14 and 22 for Solan, Mandi, Sundernagar and Baddi respectively. It is observed from the results that they exceed permissible range of the leachate disposal standards of 7.38 thereby needing suitable treatment before its disposal. Seasonal variation showed increased value of LPI over the three monitoring seasons and thereby increased pollution potential of the leachate at all the study locations due to the continuous dumping of mix municipal solid waste at the dumpsites. For the Solan study location, revised determination of LPI based on characterization of parameters for a single monitoring campaign in April 2018 showed a reduced LPI value of 15 and the result has been summarized in Table 7.4. This indicated a slight reduction in the pollution potential of the leachate due to reduced MSW loading conditions on the dumpsite.

Table 7.4: Leachate pollution index of the leachate from study regions in Himachal Pradesh

Sr. No.	Study regions	LPI (S1)	LPI (S2)	LPI (S3)	Average value
1.	Solan	15	17	19	17
2.	Solan* (after waste load reduction).	-	-	-	15
3.	Mandi	15	16	19	17
4.	Sundernagar	13	13	16	14
5.	Baddi	16	24	26	22

Monitoring carried out during April 2018

Summary

The present study revealed that disposal of waste in an open land is a big threat to the degradation of the quality of groundwater. The current study compiles the physical and chemical characterization of leachate, heavy metal analysis and leachate pollution index (LPI) for the samples collected from four study regions of Himachal Pradesh. The physical, chemical and heavy metal characterization of leachate samples extracted from study areas in Himachal Pradesh exceeded the permissible values. The LPI of the samples of the dumpsites from Solan, Mandi, Sundernagar and Baddi were determined to be 17, 17, 14 and 22 respectively which exceeded the permissible values and indicated high toxicity levels. It is recommended that the open dumping should be restricted and proper engineered landfill along with the liner system, leachate collection and transfer mechanism, energy monitoring system and final cover mechanism should be made to prevent the environmental pollution and to preserve the groundwater reserves. Similar to the effects of leachate on soil contamination as discussed in previous chapter, the following chapter presents its potential effects of groundwater.

CHAPTER 8

IMPACT OF OPEN DUMPING OF MSW ON GROUND WATER QUALITY

8.1 Introduction

Open dumps are one of the prime threats to groundwater in both globally and in Indian perspective. The open dumping of MSW leads to the percolation of leachate into the aquifers thereby polluting the groundwater. In continuation with the results obtained from the previous chapter regarding the characterization of leachate, the present chapter studies its effects on groundwater. Finally, for an overall functioning system of waste management including efficient designing and operation of landfill, the management of leachate generated is of predominant concern so as to prevent contamination of groundwater [217]. If the groundwater is polluted by leachate, its after effects can last for a long time (even few years after closure of landfill) thereby making the groundwater unsuitable for drinking or any other useful purposes [213, 196]. In this regard, there are various methods to assess the quality of groundwater quality. Water quality index (WQI) is widely used technique to assess the quality of groundwater. The quality of ground water based on the categorization of the index values achieved [206, 120]. The water quality index (WQI) and heavy metal pollution index are the vital tools to evaluate the parametric characterization of water which are easy and informative for the policy makers to identify remedies and provide efficient regulation of groundwater reserves [120, 150, 218, 219]. The water quality index provides single value, which is obtained by integrating the different water quality parameters with relevant standards, depending on the parametric concentrations present in groundwater samples.

The purpose of the present study was to assess the probable contamination of the groundwater due to leachate from open dumping of waste at the four different study locations. In this context, both WQI (water quality index) and HPI (heavy metal pollution index) of groundwater in the vicinity of the dumpsites has been assessed using three techniques to identify the existing contamination of the groundwater. In addition, Pearson's correlation coefficient, Principal

Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were also performed to emphasize the correlation between the results obtained.

8.2 Material and methods

8.2.1 Groundwater sampling and analysis

The physico-chemical characterization of groundwater was analysed to determine the possible contamination levels due to the percolation of leachate. The groundwater samples were collected from the submersible and hand pumps lying in downstream directions at various distances of 1, 2, 2.5, 3 and 4 km from the dumpsites. Sixty samples were analysed in all the three seasons including summer, rainy and winter seasons in the year of 2017. The location of dumpsites and the groundwater sampling points of respective study regions have been shown in Figure 8.1 (a-d).

Figure 8.1 (a). Location of Solan dumpsite and groundwater sampling points

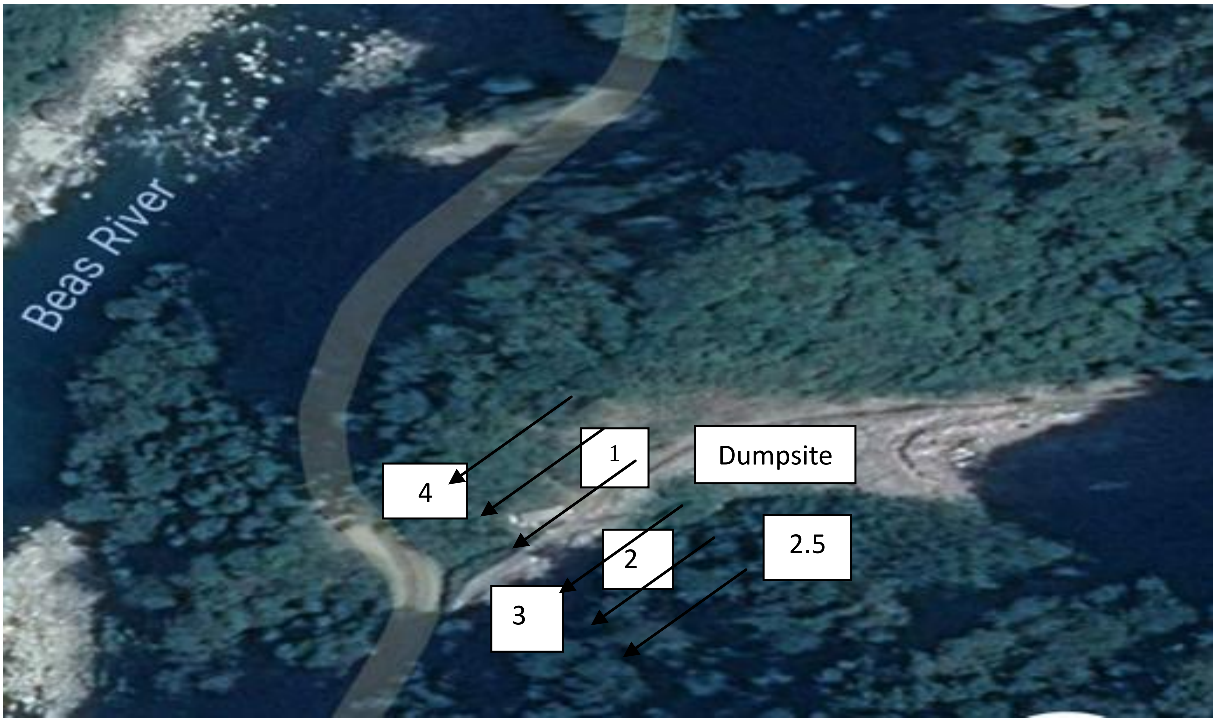


Figure 8.1 (b). Location of Mandi dumpsite and groundwater sampling points

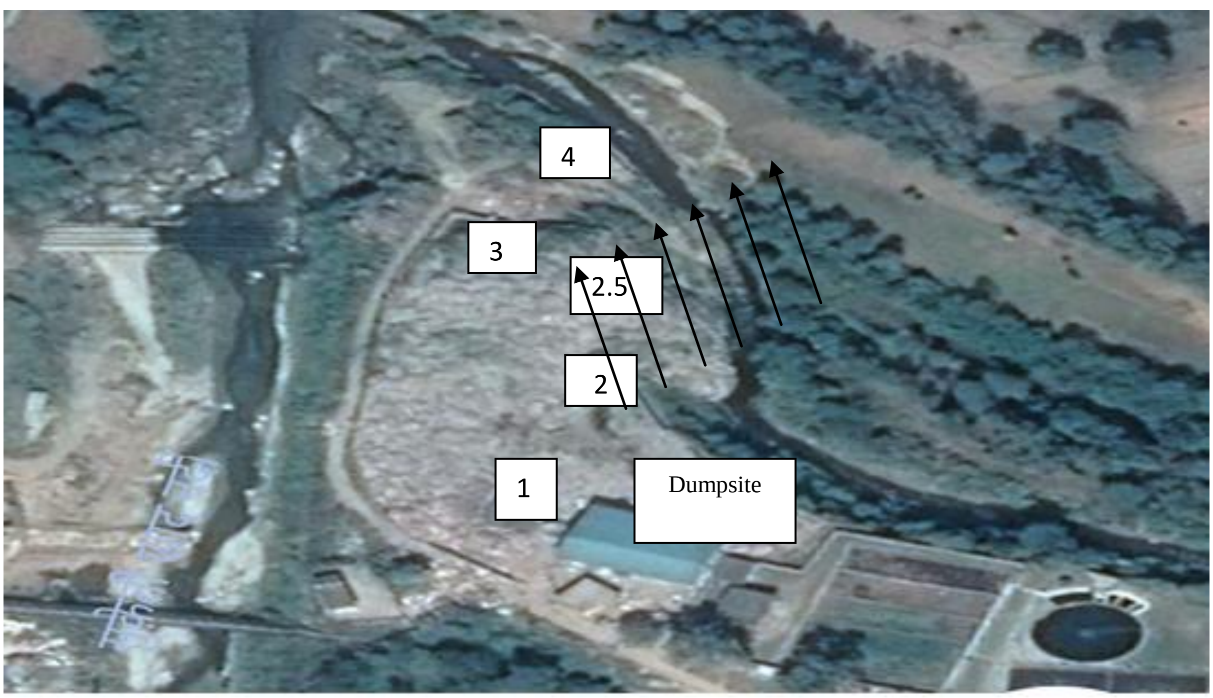


Figure 8.1(c). Location of Sundernagar dumpsite and groundwater sampling points

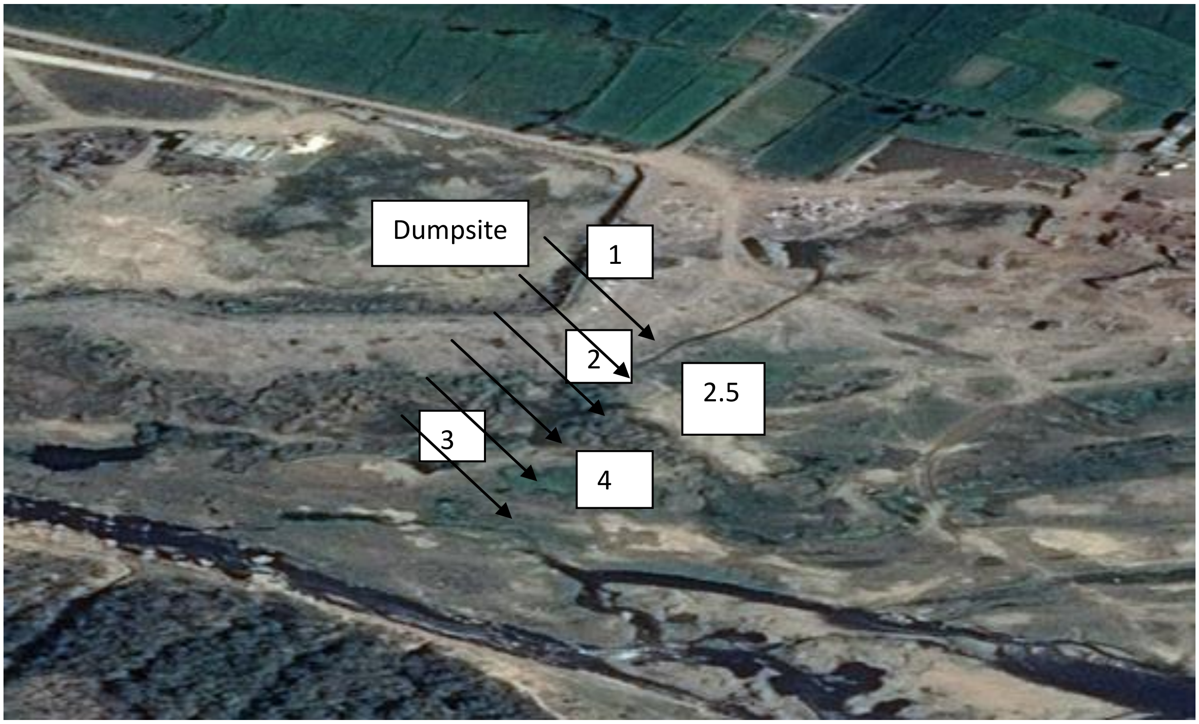


Figure 8.1(d): Location of Baddi dumpsite and groundwater sampling points

Further, similar to the above analysis, the groundwater samples from Solan study location were again collected in the month of April-May 2018 and analysed to check the variations in physico-chemical characterization due to reduction in waste load.

The parameters including calcium, magnesium carbonate, bicarbonate and chloride has been carried out by gravimetric analysis in the laboratory according to APHA 2012 [202, 220]. However, the sulphate, phosphate, and nitrate were examined by means of spectrophotometer instrument (*UV-VIS Spectrophotometer 108).*

8.2.2 Water Quality index

WQI is a tool describing the quality of water using an aggregate indexing approach. It comprises of sub-indices for each parameter and the aggregations of sub-indices in a solitary index value providing the overall water quality index [220-223]. Further, the selection criteria of the parameters for determination of WQI were adopted based on the significance of the considered parameters. The index value thus obtained is the process of identifying the existing water quality in a single value which helps in identifying the best environmental management practices for utilizing the groundwater [221, 214].

There are multiple methods for assessment of WQI including National Sanitation Foundation index (NSFI), Oregon water quality index (OWQI), Bureau of Indian Standard10500, Arithmetic Weight Index and Canadian Council of Ministers of the Environment index method [222]. In this study, we have utilized Oregon water quality index (OWQI), Bureau of Indian Standard (BIS 10500 standards) methods and NSFI technique for the assessment of groundwater quality. The above said three methods has been utilized in the study due to the reason that Oregon water quality index and National sanitation foundation index are most reputed and well prescribed methods utilized internationally and Bureau of Indian Standard (BIS) is the method utilized in India. The details regarding to the determination of WQI using these methods have already been well reported in literature [150, 224] and the same methodology have been used for the classification of groundwater quality. The different categorizations of groundwater quality based on the above three methods have been summarized in Appendix-A (Table 7).

8.2.3 Heavy metal indexing

Heavy metal pollution index (HPI) is an evaluation technique that depicts the impact of heavy metals on the water quality [219]. The weightage assigned in between zero and one, reflecting the virtual importance of water quality and inversely proportional to the standard (Si) for each parameter. In this context, water quality and its appropriateness for drinking purpose can be examined by evaluating its quality index [225]. The detailed description for calculation of HPI has already been discussed in reported literature [225, 226] and the same methodology has been utilized for determining the HPI of groundwater for our study locations. The heavy metal pollution index of groundwater samples has been analysed by means of two methods i.e. IS and WHO method respectively. The heavy metal indexing determined by IS: 10500 method comprised of the Indian standard permissible limits for the drinking of water whereas heavy metal indexing determined by means of WHO comprised of both Indian standard permissible limits and WHO permissible limits for drinking of water.

8.2.4 Multivariate statistical analysis

Multivariate statistical analysis reduces the dimensionality and hence is highly useful in analysing large environmental datasets. Further, utilization of multivariate analysis is a useful technique in analysing parametric characteristics of the groundwater samples as it helps in making correlations between different chemical compositions and ground water samples [126, 150]. The present study uses three multivariate statistical methods includes correlation matrix analysis, Principal component analysis (PCA) and Hierarchical cluster analysis (HCA) using the software SPSS statistics V 22.0. The statistical techniques provide information regarding different physico-chemical analysis of the different measured parameters varying in composition and record their impact on the groundwater quality [204]. The study reported a total of sixteen parameters including pH, TDS, TSS, COD, BOD, turbidity, phosphate, sulphate, calcium, magnesium, chlorides, electrical conductivity, ammonical nitrogen, nitrate, fluoride and total alkalinity. The multivariate statistical analysis including Pearson's correlation coefficient analysis, PCA and HCA are unbiased methods that may provide better correlations amongst the samples and variables [204].

8.2.4.1 Correlation matrix analysis

Pearson's correlation coefficient matrix is produced in order to categorize the rotations among the parameters and sources of groundwater pollution [227]. Correlation matrix shows the agreement of inter-parameter relationship with the results that are produced from Principle component analysis (PCA). It also shows some new associations between the parameters that are not adequately represented. Pearson's correlation is an expressive method used to appraise the degree of interrelation and association between two different variables [227]. A correlation with positive sign specifies the perfect positive correlation between the two variables whereas correlation with negative sign specifies that the variable is inversely related to other variables. However, the correlation of zero signifies there is no relationship between different variables.

8.2.4.2 Principal components analysis (PCA)

Principal component analysis is a technique used for reducing the dimensionality of datasets and increasing the interpretability of the presenting data [228]. Principal component analysis proves advantageous for resolving an Eigen value and Eigen vector problems [229]. Principal component analysis (PCA) uses innovatory unrevealed mathematical principles to alter the number of correlated variables named as principal components [229]. In this context, PCA is the method that reveals the comparison of compositional patterns between the waste systems and helps to identify the factors that may influence each other. It explains the relation of covariance structure of variables and hence used as dimensionally reduction techniques. The principal component analysis (PCA) is a technique that produces 'principal components' to identify the particulars and details of the multivariate analysis in a reduced dimensional space and to identify the variance in the dataset. Apart from this PCA also analyses the dataset that representing observations prescribed by various inter-correlated dependent variables [230].

8.2.4.3 Hierarchical cluster analysis (HCA)

Hierarchical cluster analysis (HCA) is one of important multivariate statistical analysis method that has major role in data analysis in environmental engineering [150]. Cluster analysis or data segmentation is a unique method that is utilized for the related grouping of data and observations into clusters or subsets, wherein within each of the clusters the data have correlations amongst themselves. As such different clusters can represent different interpretations. This indicates the groupings of various datasets by developing a cluster or dendogram. Hierarchical cluster analysis is an algorithm that batching the identical items or objects into groups called clusters based on the chemical composition resemblances. Cluster analysis is a data reduction technique employed for the transformation of observations and different variables into the identical groups thereby helping in grouping the ground water samples based on the similarities in their chemical composition [231]. Hierarchical cluster analysis is the unique technique because it reduces the number of observations by classifying them into identical clusters and groups [232]. Cluster analysis is the class of techniques that classifies cases into groups that are homogeneous within themselves and heterogeneous between each other [233]. HCA utilizes ward method of statistics that prescribed the agglomerative hierarchical clustering procedure where the criteria for opt the set of clusters to integrate each step that is based on the favourable value of an objective function [150].

8.3 Results and Discussions

8.3.1 Groundwater Characterization

The physico-chemical characterization of the groundwater samples analysed from the study locations have been summarized in Table 8.1and again after reduction of waste load from Solan region, the physico-chemical characterization of the groundwater samples has been reported in Appendix-B (Table 8) respectively. The physico-chemical parameters were compared with the standards as prescribed World Health Organization (WHO) and Bureau of Indian Standards (BIS).

The average pH values for all the study locations at different downstream distances can be classified as '*within near -neutral ranges*' and were well within the limits specified by BIS [150]. The results obtained from the study locations were similar to the results conducted in nearby Tricity locations of Chandigarh, Mohali and Panchkula [150]. Increased pH concentrations in groundwater in vicinity of the landfill sites are indicative of percolation of mature leachate contamination. The average total alkalinity for all the study locations for all the downstream distances exceeded the permissible limits of BIS standards and the parameter has the ability to affect the taste and odour of the groundwater making it unpalatable.

The highest TDS concentrations were observed for the dumpsite located in Baddi wherein the average concentrations were greater than 500 mg/l at all the downstream distances and the least concentrations (about 275 mg/l) were observed for dumpsite located in Sundernagar. The concentrations at the other two locations were within intermediate ranges lying between 350 to 500 mg/l. In general, TDS concentrations are representative of salts filtering from soil and other environmental pollutants being contaminated by leachate [220]. The TDS concentrations at the study located were corroborated by electrical conductivity values which ranged between 479.22-523.44µS/cm, 628.98-647.84µS/cm, 458.83-473.64µS/cm and 710.9-745.12µS/cm for dumpsites of Solan, Mandi, Sundernagar and Baddi respectively. Such high values of electrical conductivity are representative of large ionic concentrations in groundwater maybe due to contamination from leachate or from presence of dissolved salts from the [24]. Comparison with reported literature carried out for nearby locations in Chandigarh, Mohali and Panchkula revealed the value of electrical conductivity in the range of 954-1850µS/cm, 460–595µS/cm and 570-720µS/cm

Table 8.1: Physico-chemical characterization of groundwater based on seasonal variations

PARAMETERS	DISTANCE (KM)	SOLAN			MANDI			SUNDERNAGAR			BADDI			STANDARDS	
		S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	WHO	BIS
Ph	1	7.56	7.78	7.9	7.45	7.52	7.58	7.26	7.31	7.34	8.12	8.34	8.87		6.5-8.5
	2	7.49	7.54	7.67	7.41	7.46	7.53	7.25	7.28	7.3	7.88	7.98	8.13		
	2.5	7.43	7.48	7.53	7.38	7.42	7.49	7.22	7.23	7.29	7.52	7.70	7.84		
	3	7.29	7.37	7.4	7.27	7.35	7.31	7.2	7.24	7.25	7.51	7.64	7.77		
	4	7.18	7.26	7.27	7.22	7.29	7.36	7.2	7.2	7.23	7.49	7.57	7.69		
TDS	1	481	492.5	512.6	390.2	398.7	415.4	306.8	312.4	322.42	531.2	542.6	550.9		
	2	476.5	480.3	482.8	381.4	384	392.8	278.4	284.2	285.1	524.8	538.2	544.3		
	2.5	468.2	473.9	476.2	378.2	396.5	399.2	271.2	272.4	281.34	512.5	531.4	535.8		
	3	459.7	467.1	471.6	372.3	375.4	383.6	253.1	261.8	263.9	502.7	522.3	529.9		
	4	389.4	402.1	414.7	357.8	362	378.4	244.6	253.1	260	500.3	519.2	524.7		
TSS	1	10.02	11.34	11.78	6.8	7.22	7.84	5.12	5.29	5.3	16.86	17.5	19.42		500
	2	9.82	9.93	10.81	5.32	6.02	8.84	5.08	5.19	5.27	16.02	16.99	18		
	2.5	6.35	7.84	8.39	5.08	6.83	6.12	5	5.11	5.2	14.82	16.24	17.21		
	3	6.12	6.44	7.14	4.81	5.29	5.74	4.89	4.9	5	14.24	14.82	15.44		
	4	5.09	5.82	5.98	3.36	4.22	5.16	4.72	4.79	4.85	11.09	12.72	13.79		
COD	1	4.4	4.82	5.67	3.8	4.02	4.23	2.8	2.88	2.91	8.09	8.39	8.82		
	2	4.16	4.31	5.02	2.87	2.92	2.98	2.72	2.77	2.84	7.72	8.01	8.45		
	2.5	4.03	4.28	4.66	2.03	2.45	2.66	2.58	2.6	2.61	7.14	7.76	8.12		
	3	2.67	3.18	3.72	2.03	2.45	2.66	2.54	2.59	2.6	5.22	6.61	7.94		
	4	2.32	2.96	4.81	1.9	2.12	2.3	2.39	2.2	3.18	4.04	5.22	6.71		
BOD	1	0.32	0.36	0.41	0.39	0.42	0.43	0.2	0.23	0.27	0.68	0.72	0.73		5
	2	0.26	0.31	0.37	0.21	0.25	0.32	0.17	0.22	0.23	0.62	0.67	0.71		
	2.5	0.19	0.28	0.32	0.22	0.3	0.32	0.12	0.18	0.2	0.51	0.56	0.64		
	3	0.14	0.16	0.17	0.16	0.16	0.17	0.12	0.15	0.16	0.43	0.49	0.54		
	4	0.1	0.12	0.16	0.14	0.15	0.15	0.1	0.11	0.14	0.39	0.42	0.50		

	1	7	8	8	7	8	7	6	6	5	9	10	10		1
	2	6	7	7	5	5	6	5	6	5	9	9	10		
Turbidity	2.5	4	6	5	4	5	5	4	5	5	8	9	9		
	3	3	4	4	3	3	3	2	3	2	8	7	8		
	4	3	3	2	2	3	3	2	2	2	7	7	7		
	1	0.047	0.062	0.069	0.029	0.03	0.033	0.012	0.016	0.017	0.072	0.079	0.083		
	2	0.041	0.047	0.058	0.024	0.025	0.028	0.01	0.014	0.014	0.051	0.064	0.076		
Phosphate	2.5	0.036	0.041	0.052	0.023	0.023	0.026	0.008	0.01	0.012	0.044	0.05	0.061		
	3	0.029	0.033	0.047	0.018	0.02	0.02	0.002	0.0051	0.0058	0.039	0.047	0.052		
	4	0.027	0.028	0.032	0.017	0.018	0.018	0	0	0	0.038	0.04	0.048		
	1	48.24	49.08	52.31	36.02	41.12	42.45	31.25	32.89	35.67	66.42	68.08	72.21		200
	2	42.89	47.63	48.48	34.84	39.33	40.08	30.42	30.74	33.08	65.02	66.82	69		
SULFATE	2.5	37.18	41.02	42.18	29.24	30.12	38.82	30	30.92	32.59	63.29	65.21	68.44		
	3	25.02	269.41	30.49	28.12	30	35.67	27.82	29.22	30.2	63.01	63.99	65.72		
	4	24.87	27.41	29.45	22.08	28.44	29.92	26.04	26.71	28.92	60.74	62.04	63.11		
	1	152.32	136.8	172.01	126.7	131.52	138.2	108.43	113.9	121.62	178.8	183.4	188.2		75
	2	147.84	149.32	163.89	122	130.4	133.3	105.22	111.67	120.08	177.4	180	185.6		
CALCIUM	2.5	139.02	145.67	159.73	1158.8	126.34	129.4	100.9	107.55	115.82	169.2	175.6	181.4		
	3	131.82	142.56	156.09	115.2	121.02	124.2	92.89	101.33	109.22	157.2	161.3	174.8		
	4	118.34	122.43	138.53	108.3	112.34	119.46	32	100	102.45	152.4	159.2	167.1		
	1	86.2	94.6	102.3	66.24	71.02	78.82	57.8	52.41	66.28	84.8	89.2	93.5		30
	2	77	86.2	89.41	59.38	63.48	72.87	49	53.66	60.22	77.4	72.4	89.22		
Magnesium	2.5	72.63	81.81	83.49	52.74	59.92	60.04	47.82	50	56.72	71.6	78.3	81.39		
	3	63	73.04	80	51.35	53.89	54.72	32.55	41.24	51.02	64.9	71.5	78.38		
	4	54	61.47	76.46	50	50.82	51.38	31.48	38.48	44.29	63.7	70.2	73.45		
	1	12.8	15.67	16.08	18.5	20.02	20.98	12.8	14.76	19.31	34.12	38.22	42.41	250	250
Chlorides	2	12.34	13.96	15.82	17.92	18.45	20.12	11.72	14.09	15.84	31.99	31.54	39.8		
	2.5	11.89	13.12	14.49	14.67	15.81	18.37	11.04	11.88	14.72	24.67	30.01	37.44		

	3	11.02	13.08	13.88	14.08	15.12	16.24	9.89	11.21	12.39	22.36	29.67	33.12		
	4	9.74	11.32	12.57	13.48	13.92	14.18	9.22	9.82	10.68	19.67	20.01	28.34		
Electrical Conductivity	1	537.2	582.3	612.6	651.2	662.4	670.3	481.8	492.42	498.33	764.4	789.2	796.2		300
	2	512.4	526.4	576.2	638.4	651.3	664.8	477.02	487.6	472.41	752.1	761.8	789.4		
	2.5	478.3	481.3	492.3	622.8	626.4	642.4	452.14	460.24	472.41	704.8	725.5	766.8		
	3	449.5	462.6	483.9	620.2	621.2	637.5	444.89	459.04	466.24	678.4	681.2	690.7		
	4	418.7	432.3	452.2	612.3	617.8	624.2	438.34	446.42	458.82	655.2	679.4	682.5		
Ammonical Nitrogen	1	1.48	1.73	2.07	2.62	2.87	3.1	2.2	2.26	2.38	3.46	3.82	4.11		0.5
	2	1.46	1.54	1.96	2.38	2.49	2.57	0.007	0.008	0.017	1.82	2.17	2.3		
	2.5	1.19	1.27	1.84	2.05	2.13	2.24	0.012	0.016	0.02	1.26	1.34	1.76		
	3	1.06	1.17	1.23	1.63	1.82	1.89	0.007	0.008	0.017	0.18	0.2	1.43		
	4	1.02	1.11	1.07	1.12	1.24	1.36	0	0.002	0.006	0.06	0.08	0.17		
Nitrate	1	5.6	2.81	3.4	2.39	2.43	2.48	1.73	1.85	2.28	8.8	9.2	9.5	50	45
	2	2.24	2.93	3.16	1.64	1.77	1.89	1.34	1.47	1.69	6.3	6.5	7.2		
	2.5	2.11	2.27	2.48	1.32	1.56	1.61	1.15	1.33	1.52	5.87	6.29	6.8		
	3	1.98	2.03	2.15	1.26	1.38	1.47	1.03	1.24	1.38	3.48	5.53	6.59		
	4	1.34	1.72	1.88	1.08	1.18	1.23	0.062	0.097	1.24	1.78	1.92	2.07		
Fluoride	1	0.003	0.032	0.044	0.058	0.036	0.072	0.02	0.029	0.036	0.08	0.12	0.18	1.5	1
	2	0	0	0	0.031	0.038	0.04	0.0037	0.0042	0.0053	0.06	0.08	0.1		
	2.5	0	0	0	0.007	0.0072	0.0081	0	0	0	0.03	0.05	0.07		
	3	0	0	0	0.002	0.0033	0.0038	0	0	0	0.02	0.03	0.04		
	4	0	0	0	0	0	0	0	0	0	0.006	0.01	0.012		
Alkalinity	1	372	286	419	322	342	359	269	282	293	487	492	512		200
	2	355	363	392	313	327	342	248	263	278	473	484	496		
	2.5	348	352	378	303	321	332	226	234	256	451	466	482		
	3	323	335	359	294	298	308	208	218	232	447	460	473		
	4	281	288	297	228	243	267	196	202	207	425	432	441		

The TSS concentrations are representative of dissolved inorganics and small fraction of organics in the groundwater [234-236]. The parameter is also indicative of generic nature of the water including its salinity. The TSS concentrations were well within the permissible limits for all the study locations at the different downstream distances. However, the turbidity values at all of the study locations at different downstream distances exceeded the permissible limit values prescribed by BIS [236]. In this context, parameters of chloride, nitrate and fluoride concentrations were within the acceptable limits of BIS and WHO standards [235, 236]. The average sulphate concentrations varied from 27 to 108 mg/l, 27 to 40 mg/l, 27 to 33 mg/l and 62 to 69 mg/l over the respective downstream distances for Solan, Mandi, Sundernagar and Baddi respectively. The concentrations were well within the prescribed standards of 200 mg/l by the BIS. High sulphate concentration can lead to dysentery in children and also biological corrosion [237]. Similarly, the average nitrate concentrations were well within the permissible limits for all the study locations for all of the considered downstream distances.

The parameter BOD of the groundwater specifies the amount of organic material present in the groundwater sample [238]. The BOD concentrations present in the groundwater samples varied within the ranges of 0.20-0.28 mg/l for Solan, 0.23-0.28 mg/l for Mandi region, 0.14-0.20 mg/l for Sundernagar and 0.52-0.63 mg/l for Baddi region respectively. The concentrations were well within the permissible limits and indicated fewer fractions of dissolved organics in the groundwater samples. Similarly, the COD value of the groundwater samples in Solan region varied between the range of 3.52 to 4.77 mg/l, for Mandi region within 2.52 to 2.96 mg/l, for Sundernagar within ranges of 2.60 to 2.82 mg/l and for Baddi region varies between 6.44 to 8.01mg/l respectively. The BOD/COD ratio was less than 0.2 which is representative of more non-biodegradable fractions in the groundwater samples. Ammonical nitrogen concentrations were determined to exceed the permissible limits for all study location at all the different downstream distances.

8.3.2 Water Quality Index

8.3.2.1 Water Quality Index

The WQI in the current study was evaluated by using three methodologies viz. the Oregon Water Quality Index, BIS 10500 and National Sanitation Foundation method which has already been discussed in the methodology section. The WQI values determined by OWQI method has been summarized in Tables 8.2.

Table 8.2: Water quality index based on Oregon Water quality index (OWQI)

Oregon Water Quality Index						
Sr. No.	Towns	Summer	Rainy	Winter	Average	Classification (average)
1.	Solan	66	64	64	65	Poor
2.	Mandi	67	66	65	65	Poor
3.	Sundernagar	69	68	67	68	Poor
4.	Baddi	59	59	58	59	Very poor

The OWQI for Solan region was determined to be 66 in summer season, 64 in rainy season and 64 in winter season. Similarly, the WQI for Mandi region were reported to be 67 in summer season, 66 in rainy season, 65 in winter season, and for Sundernagar were reported as 69 in summer season, 68 in rainy season and 67 in winter season. Finally, the WQI for Baddi region were reported as 59 in summer season, 59 in rainy season and 58 in winter season respectively. From the results obtained in Table 8.2, it can be observed that the water quality index varied in the range of 60-70 according to OWQI for three study regions of Solan, Mandi and Sundernagar and was categorized as '*poor quality*'. However, as per OWQI, the groundwater samples from Baddi region was classified as '*very poor*' with the WQI value being less than 60 and this can be attributed to the pharmaceutical and industrial activities imparts in the town. Further, it is important to mention that the WQI value of 59 is borderline value to be classified as '*very poor*' in accordance with the OWQI standards as the range varies between (0-59) for this category.

Apart from this, relative weight of groundwater parameters for evaluation of WQI based on BIS has been summarized in Appendix-A (Table 9) and the calculated WQI and its categorization as poor, fair, good and excellent as per BIS 10500 standards for all the three monitoring seasons.

It is observed that there is significant reduction in WQI (i.e. improvement in water quality) with increase in downstream distance. The highest WQI values obtained using this methodology was observed in monitoring campaign of S3. The *average WQI* considering the seasonal variations at

Table 8.3: Average water quality index based on BIS 10500

WQI	Average WQI (BIS method)				Average (classification)			
Distances	Solan	Mandi	Sundernagar	Baddi	Solan	Mandi	Sundernagar	Baddi
1	131	106	180	131	Fair quality	Fair quality	Fair quality	Fair quality
2	120	60	138	120	Fair quality	Fair quality	Good quality	Fair quality
2.5	109	55	124	109	Fair quality	Fair quality	Good quality	Fair quality
3	100	49	99	100	Good quality	Fair quality	Excellent quality	Fair quality

Table 8.4: Average water quality index based on NSFWQI

WQI	Average WQI (NSF method)				Average (classification)			
Distances	Solan	Mandi	Sundernagar	Baddi	Solan	Mandi	Sundernagar	Baddi
1	79	84	90	70	Good quality	Good quality	Good quality	Fair quality
2	81	87	92	74	Good quality	Good quality	Excellent quality	Good quality
2.5	84	87	92	75	Good quality	Good quality	Excellent quality	Good quality
3	88	89	94	77	Good quality	Good quality	Excellent quality	Good quality
4	89	90	94	78	Good quality	Good quality	Excellent quality	Good quality

different downstream distances utilizing this method and its categorization has been summarized in Table 8.3.

It is observed from the Table 8.3 that as per the WQI methodology using the BIS 10500 standards of water quality assessment methods that the study areas of Solan, Mandi, Sundernagar and Baddi are of fair category within the vicinity of 1Km distance from the dumpsite in summer and rainy season but in winter season wherein Baddi town exhibits the most adverse quality of water. It is perceived that at 2.5 Km distance and thereafter the water quality of Solan, Sundernagar and Mandi shows good quality but Baddi town shows adverse quality of water. However, up to the distance of 4 Km from the domain of the dumpsites, Solan, Mandi and Baddi dumpsites exhibit good quality of water whereas Sundernagar town shows excellent water quality. Apart from this, it is critically observed that the water quality improved with the increase in downstream distances from the dumpsites but continuous dumping of MSW at all the study locations without proper supervision can lead to further deterioration of existing groundwater quality.

Water quality index based on the WQI was developed by the National Sanitation Foundation (NSF) which provides a standard method for comparing the relative quality of various parameters of groundwater samples [224]. The average water quality index based on NSFWQI and its categorization has been illustrated in Table 8.4.

It is observed from Table 8.4 that as per National Sanitation Foundation method for water quality assessment, the study areas including Solan, Mandi and Sundernagar lies under good category range whereas Baddi region lies under fair category within the domain of 1Km distance from the dumpsite due to the involvement of industrial and pharmaceutical activities in the town.

It is noticed that with increment in the distance from the dumping site, the water quality of Solan, Sundernagar, Mandi and Baddi have shown significant improvement in the quality of groundwater.

Further, the effect of reduced loading condition of 8 tons at the Solan dumpsite was also investigated and the WQI was determined using three above said techniques. The WQI obtained from the OWQI was determined to be 67 a slight increase from the overall average value of 65 showing slight improvement in water quality due to reduced MSW loading effects. The WQI index values using all three methods for the revised loading conditions have been summarized in Table 8.5.

Table 8.5: Water quality index of Solan (April 2018) based on BIS 10500, OWQI and NSFWQI

Sr. No.	Distances	BIS (Before load reduction)	BIS (After load reduction)	NSFWQI (Before load reduction)	NSFWQI (After load reduction)	OWQI (Before load reduction	OWQI (After load reduction
1.	1 Km	131	102	79	90	65	67
2.	2Km	120	84	81	91		
3.	2.5 Km	109	78	84	91		
4.	3 Km	100	72	88	93		
5.	4 Km	85	62	89	94		

It is observed from the table that there is significant reduction in concentrations of physico-chemical parameters leading to an improvement in water quality due to reduced MSW loading condition at the Solan dumpsite. The WQI analysis results show that the quality of the groundwater is severely affected by the leaching of ions primarily for those locations which are in closer proximity to the dumpsite (< 2-2.5 km).

8.3.2.2 Heavy Metal Pollution Indexing (HPI)

The heavy metal concentrations based on seasonal variation for the groundwater sources have been summarized in Appendix-A (Table 10) mentioned earlier and average concentration of heavy metal have been summarized in Table 8.6.

Table 8.6: Average concentration of heavy metal analysis of groundwater in study regions (mg/l)

Parameters	Solan	Mandi	Sundernagar	Baddi
Fe	0.26	0.24	0.02	0.89
Zn	0.19	0.12	0.13	0.75
Cu	0.05	0.02	0.04	0.08
Cr	0.34	0.00	0.07	0.07
Ni	0.01	0.00	0.00	0.04
Pb	0.03	0.01	0.00	0.09
Cd	0.02	0.01	0.02	0.03

Over the entire monitoring campaign carried out for different seasons, the average concentrations of zinc were well below the permissible limits (5 mg/l) as per the BIS standards. In contrast, all the study locations exceeded the cadmium concentrations (0.003mg/l) as per BIS standards. Iron and copper concentrations exceeded the standards (0.3 mg/l for Fe; 0.05 mg/l for Cu) at the Baddi open landfill site whereas chromium was exceeded at all the study locations except Mandi where it was not detected.

Heavy metal pollution indexing (HPI) of groundwater was evaluated for all the four study regions seasonally as discussed earlier in the methodology section. The heavy metal indexing of groundwater samples was assessed and was compared to two sets of standards, viz., BIS1:0500 standards and WHO standards. The HPI values determined have been summarized in Table 8.7.

Table 8.7: Heavy metal index of the groundwater in study regions of Himachal Pradesh

Solan	164	193	224	184	217	255	193	218
Mandi	57	79	94	62	96	117	76	91
Sundernagar	94	127	156	115	150	208	125	157
Baddi	188	221	232	214	259	275	213	249

The HPI is a standard parameter for comparing the groundwater characteristics in the context of heavy metal contamination [225]. The average range of heavy metal pollution indexing by using IS: 10500 standards of the four study regions including Solan, Mandi, Sundernagar and Baddi exhibits the value i.e. 193, 76, 125 and 213 and heavy metal pollution indexing by using WHO standards exhibits the values i.e. 218, 91, 157 and 249 respectively. The results obtained from the analysis were clearly indicated that HPI of the groundwater samples from Solan, Sundernagar and Baddi was above the critical index value of 100 by using both the standards, whereas the HPI of Mandi region showed comparatively lesser value of pollution index in heavy metals i.e. below critical value (100). However, with the increase in time and seasons, significant increment has been observed in HPI value for all three seasons including summer, rainy and winter season. The higher HPI values were due to the migration of landfill leachate generated from the municipal solid waste dumpsite into the deep aquifers [219].

To summarize, the context of groundwater pollution in the dumpsites of the study location pertains to contamination by leachate which percolate through the soil. However, as reported in literature, the rate of percolation is dependent on multifarious factors including pollution potential of leachate, precipitation, zone of influence to cause pollution and downstream distances considered from the actual polluted site location [239]. Further, it has been observed that the samples analysed for representing downstream distances closer to dumpsite are more contaminated in general than those further away from them i.e. more than the distance of 2.5 Km. This is also due to loss of viscosity by the leachate encountering surrounding soil thereby reducing its downstream velocity [239].

8.3.3 Multivariate statistical analysis

8.3.3.1 Correlation matrix analysis

Pearson's correlation matrix is the measure of linear association between the two variables and the values of the correlation coefficients are always lies between -1 and +1 [227]. The correlation between the different physico-chemical characterization of groundwater samples of all four study regions including Solan, Mandi, Sundernagar and Baddi has been shown in Appendix-A (Table 11-14).

The results obtained from the Pearson's correlation matrix of Solan region indicated that the parameters including TDS, TSS and pH are having significant correlation with almost all the parameters named as BOD, turbidity, EC, calcium, magnesium, phosphate etc. TDS showed the positive significant correlation with TSS ($r = 0.80$), BOD ($r = 0.81$), turbidity ($r = 0.81$), EC ($r = 0.82$), pH ($r = 0.85$) and Calcium ($r = 0.80$) whereas in Sundernagar region, the parameters including TDS, TSS, BOD, EC, TA and nitrate are having maximum positive correlation among different parameters explained earlier. Among all, TDS has maximum and strong correlation with parameters named as TSS ($r = 0.87$), BOD ($r = 0.90$), Turbidity ($r = 0.82$), Phosphate ($r =0.90$), Sulphate ($r = 0.89$), magnesium ($r = 0.85$), chloride ($r = 0.85$), EC ($r = 0.92$), ammonical nitrogen ($r = 0.85$), nitrate ($r =0.85$), fluoride ($r = 0.89$), total alkalinity ($r = 0.94$) and pH ($r = 0.88$). The strong correlation of TDS among different variables indicated that the presence of TDS in the leachate generated in the MSW dumpsites affect strongly the above said parameters. However, in case of Mandi and Baddi region, most of the parameters are having statistically substantial correlation with each other hence describes the influence of leachate on the groundwater quality.

8.3.3.2 Principal component analysis (PCA)

The analysis of principal component is based on the Kaiser Normalization which states that the Eigen values only greater than unity are considered [150]. *Three* components were obtained for *Sundernagar* and *Solan* region having Eigen value greater than one and the total variance revealed 90.382% and 87.806% respectively. *Two* principal component analyses were obtained for the *Mandi* region with Eigen value greater than unity revealed 90.091% of total variance in the groundwater samples datasets. However, *only* one component was extracted for *Baddi* region having Eigen value greater than unity and the total variance of the groundwater samples dataset revealed 90.076% of total component matrix.

Component 1

The first component in the groundwater samples dataset of study regions including Solan, Mandi and Sundernagar is influenced by the high positive loading in phosphate, pH, electrical conductivity, turbidity, chloride, ammonical nitrogen, BOD and magnesium. The moderate positive loading is exhibited by total solids and COD whereas poor positive loading is exhibited by calcium and alkalinity. The negative loading of the calcium is influenced by phosphorus ions. The calcium and phosphorus have negative correlation with each other whereas alkalinity and pH are positively correlated. As the alkalinity of water increases, pH value of water samples also tends to increase. These parameters are indicative of presence of hardness (due calcium and magnesium ions), high electrical conductivity and TDS.

However, in Baddi region, the high positive loading has been illustrated by pH, total solids, BOD, COD, turbidity, sulphate, calcium, magnesium, chlorides, electrical conductivity, ammonical nitrogen, nitrate, fluoride and total alkalinity. In this context, the principal component analysis revealed the results that Baddi region had only one component matrix and hence no rotated component matrix can be extracted. The high positive influence of phosphate in water is due to the urban and agricultural settings and excess of it may cause eutrophication in water. The sulphate content is basically due to the agricultural activities and sewage practices whereas electrical conductivity is due to the concentration of salts in water. Alkalinity is due to the leaching of minerals in the groundwater aquifers.

Component 2

The second component in the groundwater datasets of Solan, Mandi and Sundernagar has been illustrated by the high positive loading in the variables including total alkalinity, calcium, ammonical nitrogen and fluorides whereas variables including electrical conductivity, pH, turbidity, magnesium, chlorides, ammonical nitrogen and fluorides exhibits moderate positive loading in the component matrix. For example, a higher pH tends to produce fluoride concentration in groundwater. In this context, the higher concentration of the fluoride in groundwater is generally attributed to the alkaline behaviour of water.

Sometimes weathering of fluoride bearing rocks may cause the existence of fluoride content in water.

Component 3

The third component in the groundwater datasets of Solan and Sundernagar has been influenced by the high positive loading in the variables including calcium and sulphate. The plots for rotated component matrix with variance for the respective study regions have been presented in Appendix-A (15-25).

8.3.3.3. Hierarchical cluster analysis (HCA)

The principle of HCA is applied to four study regions of Himachal Pradesh. The ground water samples dataset is divided into different clusters and the visual observation of the cluster is defined by dendogram illustrated in Appendix-B (Figure 29-31) for Solan, Mandi, Sundernagar and Baddi region of Himachal Pradesh respectively. A dendogram is commonly employed to represent the arrangement of clusters acquired by the hierarchical clustering technique.

Solan

In case of Solan region, three cluster are formed (cluster 1, 2 and 3) exhibiting low, medium and high pollution regions. The cluster 1 exhibits different variables numbered as 6, 14, 4, 12, 13, 3, 5, 2, 16, 10 and cluster 2 exhibits variables numbered as 7, 9, 8 and the cluster 3 represents the variables numbered as 1, 11 and 15. The above represented variables of the individual cluster exhibits the pollution-based classification of the pollutant variables of various groundwater samples for different dumping sites. For the dumpsite in Solan, cluster 1 included the variables named as phosphate, fluoride, BOD, ammonical nitrogen, nitrate, COD, turbidity, total suspended solids, pH and chlorides. The water samples revealed the less pollution in cluster 1 due to the above said variables present in the groundwater samples dataset.

Cluster 2 exhibits three variables including sulfate, magnesium and calcium revealed moderate pollution region. The total hardness is due to the leaching of minerals in the groundwater and the presence of calcium and magnesium ions. The cluster 3 of the groundwater samples in Solan region exhibits three more variables named as total dissolved solids, electrical conductivity and total alkalinity and due to the presence of these ions, it exhibited the high pollution region in the groundwater dataset. Total dissolved solids are the salts, heavy metals and traces of organics dissolved in water which become the cause of sediments and turbidity in the water and other anthropogenic sources. Cluster diagrams have been shown as follows for Solan location. For the remaining study locations, the cluster diagrams have been presented in Appendix-B (Figure

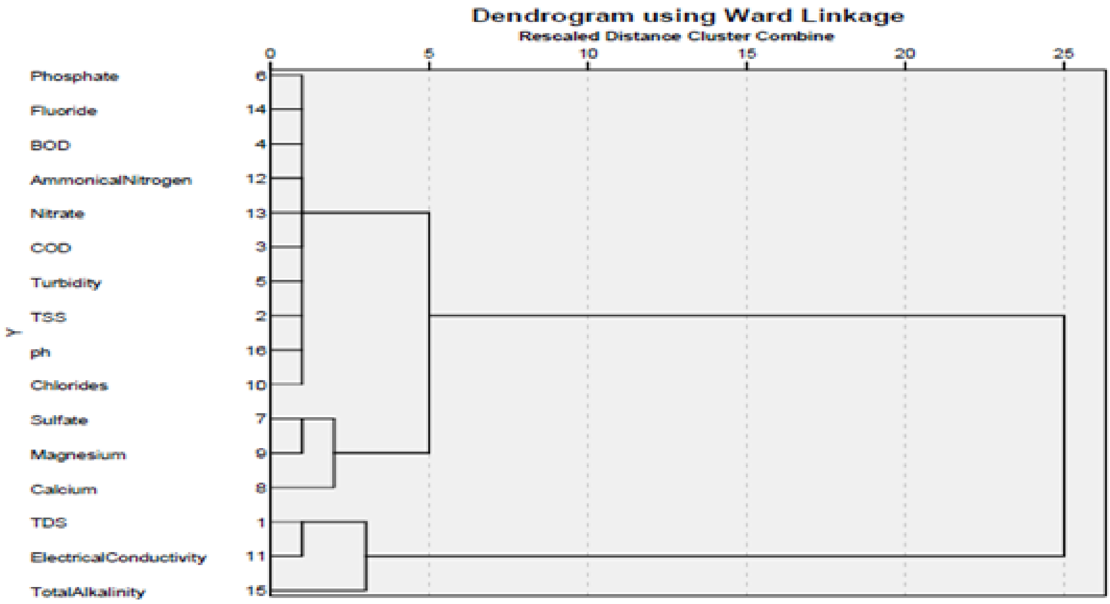


Figure 8.2: Hierarchical dendogram for ground water samples in Solan region

Mandi

The groundwater samples dataset of Mandi region revealed the formation of three clusters (cluster 1, 2 and 3) exhibiting low, medium and high pollution regions. The cluster 1 exhibits the variables numbered as 6, 14, 4, 12, 13, 3, 2, 5, 16 while cluster 2 exhibits variables numbered as 7, 10, 9 and the cluster 3 represents the variables numbered as 1, 15, 11 and 8. However, in case of Mandi region, cluster 1 included the variables named as phosphate, fluoride, BOD, ammonical nitrogen, nitrate, COD, total suspended solids, pH and turbidity. The water samples revealed that lower pollution occurred in cluster 1 due to the above said different variables present in less proportion in the groundwater samples dataset. The cluster 2 exhibits three variables including sulfate, chloride and magnesium and revealed moderate pollution region whereas cluster 3 of the groundwater samples dataset in Mandi region exhibits four different parameters named as total dissolved solids, total alkalinity, electrical conductivity and calcium cause high pollution in the region. The high pollution region indicates the calcium content due to the agricultural activities basically by the application of excessive amount of lime to the soil.

Sundernagar

The groundwater samples dataset of Sundernagar region revealed three clusters formations (cluster 1, 2 and 3) exhibits low pollution region, medium pollution region and high pollution region. The cluster 1 exhibits the variables numbered as 6, 14, 4, 12, 13, 2, 5, 3, 16, 10 whereas cluster 2 exhibits variables numbered as 7, 9, 8 and the cluster 3 represents the variables numbered as 1, 11, 15. However, cluster 1 represents the variables named as phosphate, fluoride, BOD, ammonical nitrogen, nitrate, total suspended solids, turbidity, COD, pH and chlorides. The water samples revealed the less pollution in cluster 1 due to the above present variables in the groundwater dataset. The cluster 2 exhibits three variables including sulfate, magnesium and calcium which revealed moderate pollution region whereas cluster 3 of the groundwater samples dataset in Sundernagar region exhibits three parameters named as total dissolved solids, total alkalinity and electrical conductivity that becomes the cause of high pollution in the region. In this context, the higher concentration of these above said parameters has been observed during physico-chemical analysis of groundwater. So, it clearly indicated that the results are having good correlation with statistical analysis.

Baddi

The groundwater samples dataset of Baddi region revealed three clusters formations (cluster 1, 2 and 3) exhibits low pollution region, medium pollution region and high pollution region. The cluster 1 exhibits the variables numbered as 7, 15, 5, 13, 1, 6, 4, 14, 3, 11 (Phosphate, fluoride, BOD, ammonical nitrogen, pH, turbidity, COD, nitrate, total suspended solids and chlorides revealed less pollution region whereas cluster 2 exhibits variables numbered as 8, 9, 10 (sulfate, magnesium and calcium) revealed moderate pollution region and the cluster 3 represents the variables numbered as 2, 16, 12 (total dissolved solids, total alkalinity and electrical conductivity exhibits high pollution region due to the saline water and moreover the leaching of minerals in the groundwater. Electrical conductivity of water is its ability to conduct an electric current and electrical conductivity is directly related to the concentration of dissolved ionized solids in the water.

Summary

The current study compiles the physical and chemical characterization of groundwater, heavy metal analysis, water quality index and heavy metal pollution index for the samples collected from four study regions of Himachal Pradesh. The groundwater quality of the study regions in Himachal Pradesh exhibited moderate to poor quality of water through as determined using OWQI. The water quality assessment by means of BIS 10500 standards and NSFWQI analyses showed that groundwater samples extracted from sources closer to the immediate proximity of dumpsites were of moderate and fair quality, but the quality of groundwater improved with increasing distances from the dumpsites. In general, the contamination levels reduced with increasing downstream distances and after 4 Km distance from the dumpsites, the water quality of Solan, Sundernagar and Baddi were categorized as good quality whereas for Sundernagar it was excellent quality. However, based on the seasonal variation analysis, the results revealed that the concentrations of different parameters of groundwater going to increase with time period. Out of four study regions, the water quality of Baddi region degraded quickly due to the industrial activities running in the town. Similar results were obtained using the HPI analysis wherein the highest value of HPI were observed for Baddi location and the lowest for Mandi study area. It is recommended that the illegal dumping should be constrained and proper sanitary engineered landfill system along with the liner system, leachate collection and transfer mechanism, energy monitoring system and final cover mechanism should be made to prevent the environmental pollution and to preserve the groundwater reserves. Considering all of the summaries of the previous chapters presented in the thesis, the following chapter presents the combination of best treatment alternatives using an LCA approach.

CHAPTER 9

LIFE CYCLE ASSESSMENT OF MSW IN HIMACHAL PRADESH

9.1 Introduction

The outcomes from the results of the previous chapters suggest a need for a combination of suitable treatment systems for effectively handling of the wastes generated at the study locations. This has been achieved through a LCA assessment has been discussed in details in this chapter. Life Cycle Assessment (LCA) is the important tool to reduce environmental influences by identifying the substantial effects of such ineffective waste management system. LCA is the process of collection and valuation of inputs, outputs and ultimately assess the environmental effects of a product system through its life cycle [240]. LCA is an important environmental organizational tool that helps in predicting the ecological issues and its probable influences throughout the entire lifespan of the waste (i.e. cradle to grave) within a defined system boundary [241]. The LCA starts from raw material acquisition through production, use and final disposal. LCA is an analysis tool recognized during the 1990's with various guidelines of Indian Standard Organization (ISO). LCA is the compilation of inputs and outputs of a product, evaluating the potential impacts of those inputs and outputs and interpreting the results in relation to the objectives of the study [242-244]. The main applications of LCA include product comparison, product improvement, design and development, strategy and policy development etc. The general description of system boundary has been illustrated in Figure 9.1 and the systematic approach of LCA has been illustrated in Figure 9.2.

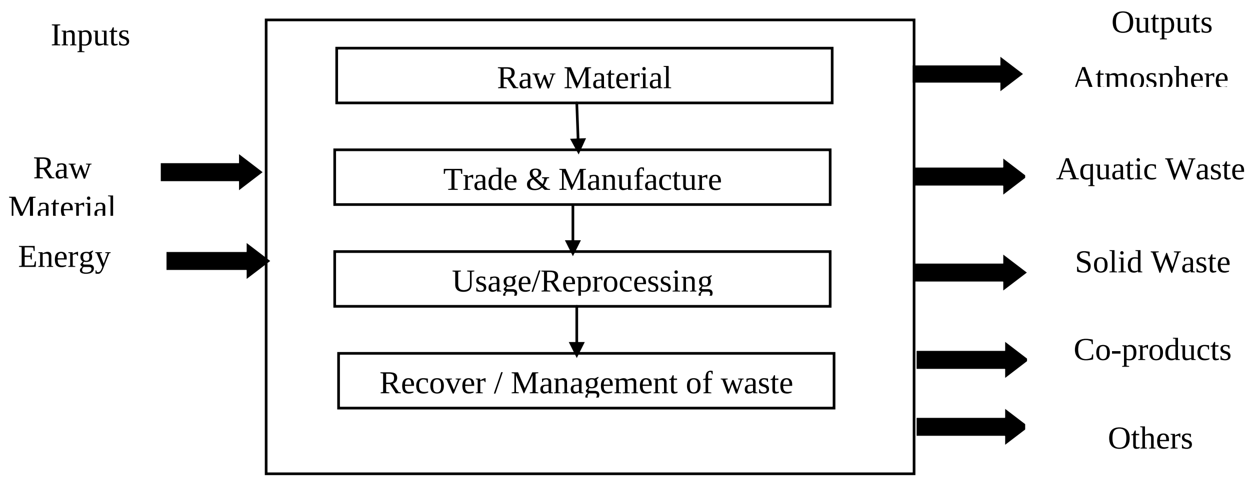


Figure 9.1: Description of the system boundary

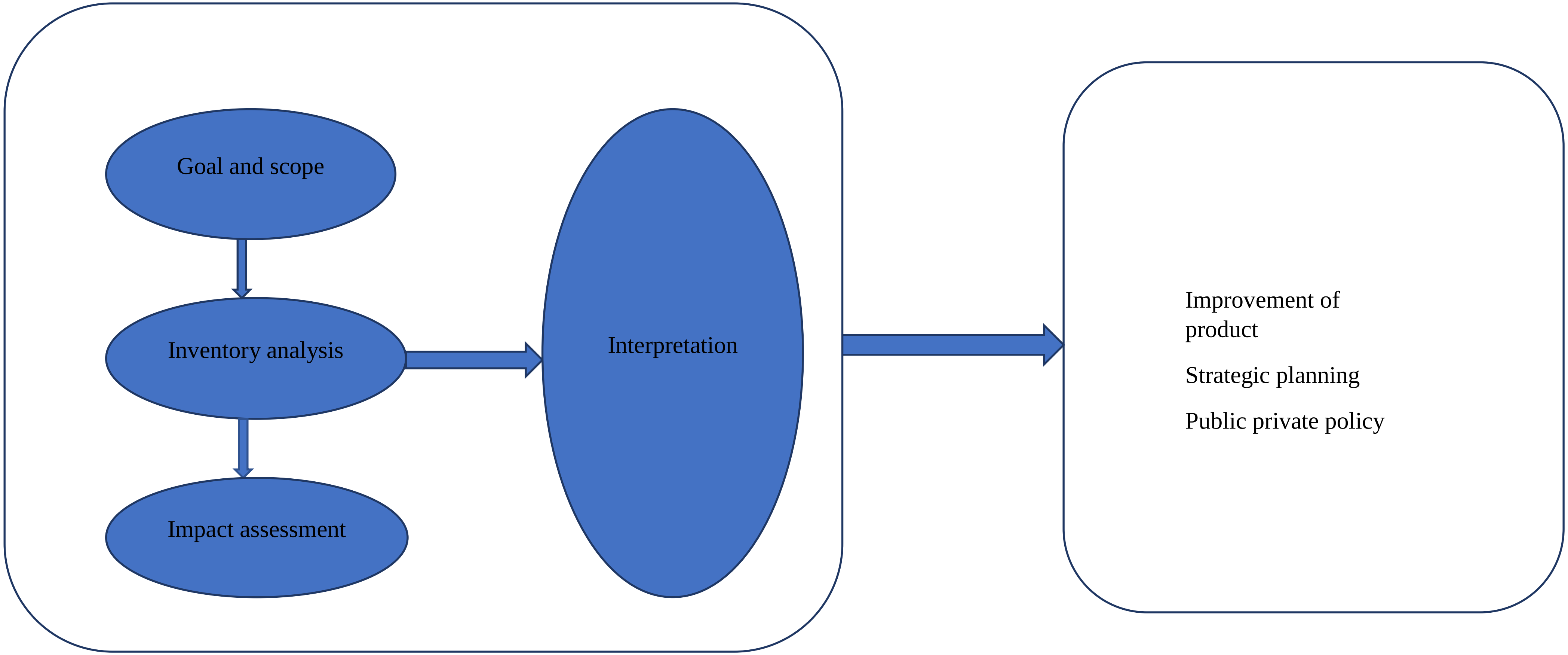


Figure 9.2 Systematic approach of LCA

LCA comprised of four components including: (a) goal and scope that describe the product and activities (b) life cycle inventory analysis (c) life cycle impact assessment (d) interpretation of results.

The goal and scope of LCA includes the objective of the study, the intended use of the results, time-dependent analysis, technology analysis, system boundaries, environmental involvements and effects, mode of analysis and thecomplexity level.

The second phase of LCA includes inventory analysis that is the elementary flows accompanying with the life cycleof the product. Generally, this stage comprised of the inputs in terms of material and energy and outputs in terms of waste and outputs of all the processes which are within the system boundaries.

The third stage of LCA is life cycle impact assessment is in which results are first classified into impact categories that are relatable to the first phase i.e. goal and scope of the LCA study. The main aim is focused on environmental concerns and energy usage, global warming potential, acidification potential, eutrophication potential and human toxicity potential. Thereby, these environmental impacts are assessed in terms of the pollution to ground and water, gas emission to the atmosphere and the impact on the human health.

The last phase of the LCA is the important phase in which the consequences of the analysis and the assumptions made during its entire process are evaluated in terms of soundness and overall conclusions and commendations are made.

The design and employment of sustainable waste management is extremely challenging because it must fully cover all the scopes including financial, technical, legal and mainly environmental viewpoints [245].

The chapter includes the LCA study comprised of inventory of the inputs and outputs related to the four different study regions of Himachal Pradesh based on their municipal solid waste management strategies. The physical composition of municipal solid waste, energy in terms of fuel are the inputs and emissions to the air, water and soil are considered as outputs in LCA study for four selected regions in Himachal Pradesh. In the life cycle assessment of waste, four scenarios are being proposed and the boundaries of each system are defined.

SimaPro 8.2.3 software has been applied to model the various waste management scenarios. The data needed for the life cycle inventory were collected gathered from the literature, the database of the software and the municipalities of different study regions in Himachal

Pradesh.The research results can assistance the decision makers to set different policies for the effective waste processing techniques.

9.2 Methodology

Life cycle assessment has been broadly utilized for the evaluation of solid waste management systems. LCA approach has been utilized to carry out an environmental comparison of the substitute scenarios to the present waste management system. In the present study, the framework has been designed by the assistance of International Organization for Standardization (ISO) 14040:2006 methodology for life cycle assessment. Generally, LCA comprises of four stages including aim of the study that describes the aim of the study, life cycle inventory that emphasise the evaluation of input and output, Life cycle impact assessment emphases on the environmental impacts of the entire system, and the analysis of results that help to explain the outcomes [246].

9.2.1 Goal and Scope Definition

The goal of the study is to evaluate the environmental impacts of the municipal solid waste management strategy in Solan, Mandi, Sundernagar and Baddi region by adopting LCA approach. In this context, four scenarios of municipal solid waste management have been designed to select an optimum waste management system that comprises of waste treatment, processing and disposal facilities and then compared with respect to the global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP) for each of the four study regions of Himachal Pradesh.

9.2.1.1 Functional Unit

The functional unit is taken as 1 ton of MSW in each of the four study regions of Himachal Pradesh for the comparison of municipal solid waste management system. Functional unit is described as the amount of given quantity of municipal solid waste that will be managed under a specific waste management strategy. The functional unit is the base of all calculations and for the evaluation of each alternative.

9.2.1.2 System Boundary

System boundary consists of collection of unit processes that performs the distinct functions. The description of the system boundary for the study regions in Himachal Pradesh has been demonstrated in Figure 9.3.

The system boundary of the current study starts with the collection of MSW, waste transportation, material recovery, sorting of waste, processing and ultimate disposal of municipal solid waste. Apart from this, vehicles hired for collection of waste and equipment used for waste processing, fuel and energy consumption are also encompassed in life cycle assessment analysis

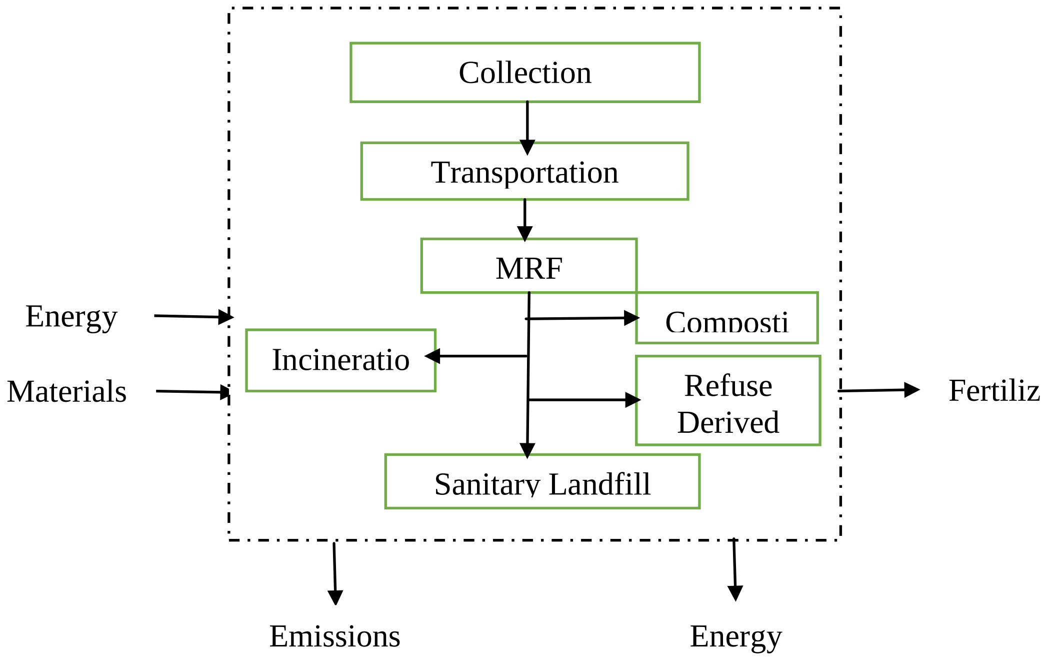


Figure 9.3: System boundary for study regions in Himachal Pradesh

The input data utilized in the system boundary are municipal solid waste composition, energy and mass whereas the outputs considered are air emission, water emissions, and emissions to soil from all the processes. The system boundaries comprised of direct emissions i.e. emissions associated from material recovery facility recycling, landfilling, composting process, reduced derived fuel, incineration and the indirect emissions includes fuel electricity.

9.2.2 Life Cycle Inventory Analysis (LCI)

Life cycle inventory analysis quantifies the elementary flows associated with the life cycle of the product system that generates the reference flow that proves helpful in the prediction of environmental performance. The input data utilized in the current study were gathered from on-site surveys, data from the municipal councils of the specified towns (waste generation, waste processing, transportation of waste, processing of waste), values from literature and the database Eco invent 2.2 of the SimaPro software [246]. However, for the selected four study regions, the data for life cycle inventory was gathered from literature and the database of the

SimaPro 8.3.2 version. The database of the software was adjusted to the conditions similar to the conditions in Himachal Pradesh. The inventories of resource use and by-products for various processes are as represented in Table 9.1.

Table 9.1: Life-cycle inventories for Himachal Pradesh

Inputs	Values	Units
1. Landfill		
(a)Diesel	2	L^{-1}
(b) Net electrical efficiency	10	%
2. Material recovery facility		
(a) Diesel	3.20	
(b) Electricity	3.1	L^{-1}
		kWh t^{-1}
3. Composting		
(a) Diesel	0.53	
By-product		L^{-1}
(a) Compost	140	
		kg t^{-1}
4. Incineration	22	%
(a) Net electrical efficiency	140.8	Kgt^{-1}
By- product		
Ash		
5. Reduced derived fuel		
(a) Net electrical		%
efficiency	15	
By-product		Kgt^{-1}
Ash	90.76	

9.2.3 Life cycle impact assessment (LCIA)

Life-cycle impact assessment is the third stage of LCA that aims at associating all the inputs and outputs with the environmental issues. The results of life cycle inventory analysis are classified into impact categories that are pertinent for the scope and goal of the life cycle assessment study [246-248]. In the current study, the emissions released in the inventory stages have been assigned four impact categories including global warming, acidification, eutrophication and human toxicity by the CML 2000 method (CML 2 baseline 2000 method).

9.2.4 Life cycle interpretation

The last phase of life cycle assessment is the interpretation of results that reviews all of the stages during LCA. In this stage, all the input and output data were analysed and the outcomes were checked against the distinct goals and scopes of the study [246, 249-253]

.

9.3 Description of the Scenarios

Scenario 1:(***Baseline scenario):*** Business as usual (BAU) defines the present municipal solid waste management strategy of selected study regions including Solan, Mandi, Sundernagar and Baddi in Himachal Pradesh.

The waste generation in Solan region is approximately 22 tons on the daily basis. Out of the total waste generation in the city, 10% of the waste is recycled in the recycling plant, 40% of the waste is directed to the compost plant and the rest of 50% is dumped illegally in the open dump site. The waste generation in Mandi region is approximately 21 tons on the daily basis. Out of the total waste generation in the city, 20% of the waste is recycled in the recycling plant, 40% of the waste is directed to the compost plant and the rest of 40% is dumped illegally in the open dump site. The waste generation in Sundernagar region is approximately 20 tons on the daily basis. Out of the total waste generation in the city, 10% of the waste is recycled in the recycling plant, and rest of the waste is dumped in the open dump site. The waste generation in Baddi region is approximately 18 tons on the daily basis. Out of the total waste generation in the city, 10% of the waste is recycled in the recycling plant and rest of the waste (90%) is dumped in the open dump site in an ill-mannered way. The depiction of scenarios utilized in life cycle assessment of MSW in Himachal Pradesh in Table 9.2.

Table 9.2: Depiction of scenarios utilized in modelling of LCA in study regions

Sr. No.	Scenarios	Description
1.	Scenario 1: Baseline scenario (BAU)	Business as usual signifies the current MSW management practice in study regions of Himachal Pradesh.
2.	Scenario 2: Material recovery facility _Composting, Incineration (MRF_COM_INC)	20% recycling+40% composting+30%incineration
3.	Scenario 3: Reduced derived fuel Material recovery facility Composting, Sanitary landfilling (RDF_MRF_COM_SLF)	30% reduced derived fuel + 20% material recovery facility + 30% composted + 20% sanitary landfilling.
4.	Composting Material recovery facility Sanitary landfilling (COM_MRF_SLF)	50% composting + 30% material recovery facility + 20% landfilling
5.	Reduced derived fuel Sanitary landfilling (RDF_SLF)	60% reduced derived fuel + 40% sanitary landfilling.

Scenario 2 (MRF_COM_INC):

The scenario describes the combination of Material recovery facility, composting and incineration and is one of the simple approaches in near future for the conversion of open disposal of waste into engineered landfill systems. The scenario assumes that 20% fraction of the waste materials are recycled, 40% of MSW is composted whereas rest of 30% fraction of the waste is dumped in the engineered landfill system.

Scenario 3 (RDF_COM_MRF_SLF): This scenario depicts the potential to diminish the environmental influences of municipal solid waste by presuming that 30% of the material is directed to refused derived fuel (RDF) plant for the generation of electricity, 30% of the biodegradable is composted (COM), 20% waste is recycled and the remaining fraction i.e. 20% is sent for disposal into sanitary landfill.

Scenario 4 (MRF_COM_SLF): Due to presence of high moisture content in the total waste, this scenario introduced the composting along with MRF and rest of the waste is directly transported to the proper engineered sanitary landfill sites. In this scenario 30% fraction of waste materials are recycled and 50% of the biodegradable waste is processed through composting whereas rest of the waste 20% is transported to sanitary landfills.

Scenario 5 (RDF_SLF): This scenario introduced the waste processing technique including refused derived fuel whereas rest of the waste is directly transported to the proper engineered sanitary landfill site. In this scenario 60% of the waste is utilized in reduced derived fuel plant and 40% of the waste sent to sanitary engineered landfills.

9.4 Results and Discussion

SimaPro version 8.3.2 was run for four different scenarios along with the baseline scenario for respective study regions of Himachal Pradesh. The environmental emissions i.e. air emission, water emission, emissions to soil under different scenarios for Solan, Mandi, Sundernagar and Baddi has been presented in Table 9.3 to 9.6 respectively.

There are three main types of emissions covered under four scenarios i.e. airborne emissions, waterborne emissions and emissions to soil for all the selected study regions including Solan, Mandi, Sundernagar and Baddi. The airborne emissions consist of the emission under four categories i.e. global warming potential (GHG's), human toxicity potential, acidification potential and eutrophication potential. The second type of emission is waterborne emission and the categories covered under this emission are eutrophication and human toxicity potential. The third type of emission is soil emission and the categories covered under this emission are eutrophication and human toxicity potential. The emissions covered under global warming includes CO_2, methane, particulate matter etc. The emissions covered under human toxicity includes cadmium, copper, Dioxins, Hydroxide fluoride and chromium. The emissions under acidification potential include nitrogen oxides, nitrogen dioxide, sulphur dioxide and phosphorus and the emissions covered under eutrophication potential include phosphorus, ammonia, nitrate etc.

Table 9.3: Emissions under each scenario for Solan

Airborne emission						
		BAU	COM_MRF_INC	RDF_MRF_COM_SLF	COM_MRF_SLF	RDF_SLF
Green House emission	carbon dioxide, biogenic	22.45	19.59	18.55	4.72	5.04
	Carbon dioxide, fossil	1.35	1.94	1.06	0.45	2.08
	Methane, fossil	2.92	3.99	2.64	2.32	2.79
	PM	0.52	0.74	0.33	0.012	0.22
Human toxicity	Cadmium	0.64	-4.45	-5.25	-7.89	-6.78
	Copper	2.44	1.75	1.55	1.22	1.67
	Dioxin	0.46	0.39	0.18	-1.11	-1.98
	Hydrogen fluoride	-16.85	-24.55	-29.77	-32.78	-25.52
	Chromium	1.08	0.47	0.53	0.34	0.49
Acidification	Ammonia	7.58	6.32	3.84	2.89	3.72
	Nitrogen dioxide	6.60E-05	7.82E-05	8.23E-05	8.11E-05	6.39E-05
	Nitrogen oxides	1.39	-0.53	-0.62	-0.82	-0.77
	Sulphur dioxide	-6.45	-10.60	-13.67	-16.44	-9.55
Eutrophication	Phosphorus	0.012	0.01	0.02	-0.002	0.003
	Ammonia	1.65	1.38	0.84	0.68	0.53
	Nitrogen dioxide	0.36	-0.13	-0.39	-0.58	-0.24
	Nitrogen oxides	3.85E-05	5.95E-05	6.98E-05	8.83E-05	7.38E-05
Waterborne emission						
Eutrophication	Remaining waterborne emission	0.06	0.05	0.03	0.24	0.35
	Nitrate	0.002	0.0002	0.0001	0.0001	0.0002
	Phosphate	-4.93	-8.48	-8.79	-9.88	-7.61
Human toxicity	Copper	11.53	9.83	8.52	6.33	8.79
	Lead	4.77	3.47	2.77	1.52	3.89

	Nickel	6.69	5.02	5.12	4.77	5.00
	Zinc	3.66	2.98	2.66	2.11	3.24
	Cadmium	0.08	0.07	0.05	0.02	0.04
Emission to soil						
Eutrophication	Phosphorus	0.04	0.03	0.02	0.01	0.02
	Nitrate	6.12E-05	7.42E-05	7.88E-05	9.42E-05	7.74E-05
Human toxicity	Cadmium	0.35	0.34	0.25	0.19	0.22
	Lead	0.30	0.30	0.21	0.16	0.20
	Nickel	0.22	0.21	0.16	0.14	0.22
	Zinc	0.13	0.13	0.96	0.74	0.84
	Cobalt	0.06	0.05	0.42	0.03	0.04
	Mercury	0.002	0.002	0.0018	0.0003	0.024

Table 9.4: Emissions under each scenario for Mandi

Airborne emission						
		BAU	COM_MRF_INC	RDF_MRF_COM_SLF	COM_MRF_SLF	RDF_SLF
Green House emission	Carbon dioxide	21.24	17.92	11.45	5.23	23.98
	Carbon dioxide, fossil	3.44	3.08	1.87	0.67	2.78
	Methane, fossil	2.45	3.32	1.98	1.22	2.43
	PM	0.21	0.34	0.16	0.007	0.86
Human toxicity	Cadmium	1.68	0.69	0.45	0.22	0.54
	Copper	1.45	1.26	1.34	1.13	1.16
	Dioxin	0.40	0.36	0.11	-1.45	0.11
	Hydrogen fluoride	-28.53	-43.35	-48.65	-61.20	-52.45

	Chromium VI	1.98	1.65	1.67	0.02	1.23
Acidification	Ammonia	5.65	4.89	3.28	2.28	6.13
	Nitrogen dioxide	-1.85	-1.56	-2.52	-7.20	-1.39
	Nitrogen oxides	1.73	-3.48	-1.78	-6.30	-3.43
	Sulphur dioxide	0.88	-9.95	-16.23	-31.87	-9.98
Eutrophication	Phosphorus	-0.013	-0.021	-0.011	-0.053	-0.03
	Ammonia	1.34	1.07	0.72	0.19	0.26
	Nitrogen dioxide	-0.36	-0.40	-0.65	-0.85	0.72
	Nitrogen oxides	-0.89	-0.90	-0.46	-0.98	-0.32
Waterborne emission						
Eutrophication	Remaining waterborne emission	-0.06	-0.36	-0.41	-0.80	-0.76
	Nitrate	-0.15	-0.24	-0.45	-0.03	-0.15
	Phosphate	-0.23	-0.45	-0.5446	-0.87	-0.68
Human toxicity	Benzene	1.06	-11.11	0.55	0.34	-9.04
	Arsenic	1.48	-12.34	-16.77	-23.76	-15.96
	Barium	10.38	-59.97	-105.27	-108.98	-48.98
	Nickel	7.18	-12.56	-18.76	-24.44	-19.99
Emission to soil						
Eutrophication	Remaining emission to soil	0.066	0.03	-0.13	0.002	0.03
	Ammonia	-0.56	-0.89	-1.93	-3.59	-2.23
	Phosphate	-1.12	-1.56	-2.20	-5.08	-3.89
Human toxicity	Total of emission to soil	0.12	-0.39	-1.06	-5.54	-3.87
	Remaining emission to soil	0.12	-0.39	-1.06	-5.54	-2.65

Table 9.5: Emissions under each scenario for Sundernagar

Airborne emission						
		BAU	COM_MRF_INC	RDF_MRF_COM_SLF	COM_MRF_SLF	RDF_SLF
Green House emission	Carbon dioxide	15.87	12.92	10.45	4.23	13.44
	Carbon dioxide, fossil	4.34	2.27	1.23	0.42	1.55
	Methane, fossil	4.13	2.07	1.54	1.00	1.54
	PM,	0.82	0.20	0.12	0.004	0.66
Human toxicity	Nitrogen oxides	-10.37	-40.67	-45.98	-52.12	-43.76
	Cadmium	0.09	0.06	0.05	0.03	0.06
	Copper	1.87	0.94	0.66	0.32	0.41
	Dioxin	-21.04	-46.56	-56.87	-56.21	-45.98
	Chromium VI	-38.66	-51.45	-43.88	-59.13	-42.99
Acidification	Ammonia	5.55	1.50	2.51	1.23	2.99
	Nitrogen dioxide	-1.23	-1.49	-0.99	-2.46	-1.11
	Nitrogen oxides	-4.32	-16.94	-40.48	-54.98	-34.12
	Sulphur dioxide	-11.39	-12.76	-14.87	-21.65	-18.45
Eutrophication	Phosphorus	-0.018	-0.013	-0.005	-0.003	-0.43
	Ammonia	1.21	0.33	0.54	0.22	0.33
	Nitrogen dioxide	-0.32	-0.38	-0.44	-0.21	-0.36
	Nitrogen oxides	-1.12	-4.40	-10.52	-18.78	-8.93
Waterborne emission						
Eutrophication	Remaining waterborne emission	-0.04	-0.29	-0.3	-0.99	-0.87
	Nitrate	-0.18	-2.15	-5.95	-6.22	-5.23
	Phosphate	-9.39	-12.46	-16.77	-19.55	-15.00
Human toxicity	Benzene	2.87	-9.88	-2.63	-12.60	-5.9
	Arsenic	1.87	-85.94	-23.88	-14.03	-56.87

	Barium	11.87	-53.11	-58.76	-68.94	-51.09
	Nickel	4.00	-12.44	-11.94	-23.78	-34.67
Emission to soil						
Eutrophication	Remaining emission to soil	0.005	0.003	-0.002	-1.119	0.001
	Phosphate	0.006	0.005	0.003	-1.95	0.004
	Phosphorus	1.83	0.56	0.34	0.022	0.07
Human toxicity	Total of emission to soil	0.22	-15.60	-44.23	-59.87	-31.26
	Remaining emission to soil	0.22	-15.60	-44.23	-59.87	-31.26

Table 9.6: Emissions under each scenario for Baddi

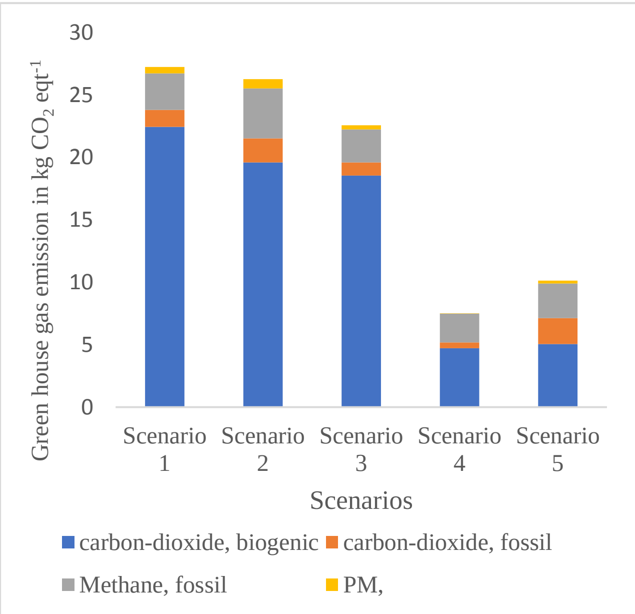
Airborne emission						
		BAU	COM_MRF_INC	RDF_MRF_COM_SLF	COM_MRF_SLF	RDF_SLF
Green House emission	Carbon dioxide	42.76	34.32	22.45	8.96	25.87
	Carbon dioxide, fossil	5.86	6.98	3.26	1.24	3.56
	Methane, fossil	3.44	2.45	2.00	1.14	2.87
	PM	0.43	0.32	0.12	0.014	0.45
Human toxicity	Cadmium	2.45	1.32	0.45	0.22	0.43
	Copper	6.43	4.32	2.57	1.99	2.46
	Dioxin	0.56	0.24	0.33	0.22	0.35
	Hydrogen fluoride	-12.56	-19.56	-32.56	-45.65	-52.44
	Chromium	4.67	3.11	2.44	1.45	2.09
Acidification	Ammonia	9.54	3.56	2.87	3.34	0.54
	Nitrogen dioxide	-1.33	-1.49	-1.54	-1.59	-1.23

	Nitrogen oxides	-2.13	-2.16	-12.07	-23.94	-19.85
	Sulphur dioxide	-6.57	-6.45	-16.89	-19.56	-12.46
Eutrophication	Phosphorus	-0.01	-0.02	-0.01	-0.006	-0.03
	Ammonia	1.34	1.07	0.72	-0.43	0.26
	Nitrogen dioxide	0.36	-0.40	-0.65	-0.85	0.72
	Nitrogen oxides	0.89	-0.90	-0.46	-0.98	-0.32
Waterborne emission						
Eutrophication	Remaining waterborne emission	-0.08	-0.04	-0.09	-0.15	-0.12
	Nitrate	-0.10	-0.87	-1.62	-3.57	-2.33
	Phosphate	-5.48	-7.89	-5.45	-8.56	-7.98
Human toxicity	Benzene	2.35	-7.35	-9.45	-13.56	-10.09
	Arsenic	1.79	-8.06	-18.56	-27.56	-21.11
	Barium	3.72	-38.80	-40.67	-47.98	-43.67
	Nickel	2.56	-23.46	-26.56	-31.56	-37.87
Emission to soil						
Eutrophication	Remaining emission	0.08	0.06	0.01	0.01	0.02
	Ammonia	-2.54	-5.92	-8.93	-11.23	-6.54
	Phosphate	-1.03	-2.5	-2.98	-5.834	-4.62
Human toxicity	Total of emission to soil	-1.03	-0.42	-12.67	-28.10	-15.65
	Remaining emission to soil	-1.03	-0.42	-12.67	-28.10	-15.65

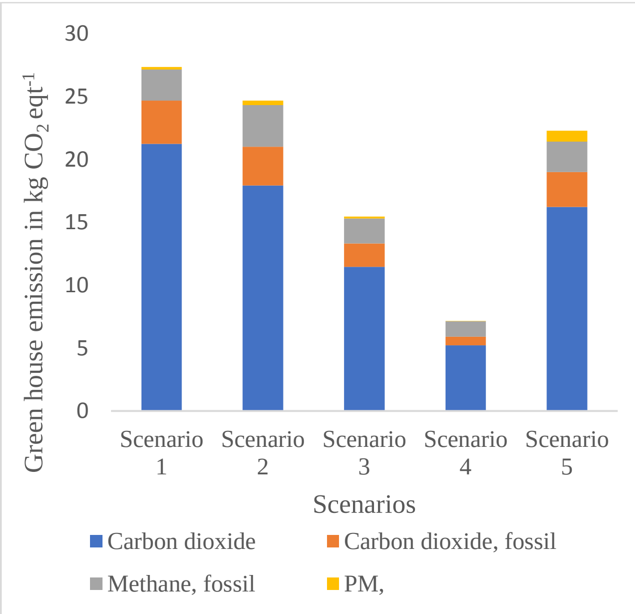
The analysis of global warming potential, acidification potential, eutrophication potential and human toxicity potential under airborne emission for Solan, Mandi, Sundernagar and Baddi respectively has been shown in Figures 9.4 to 9.7.

Global warming Potential

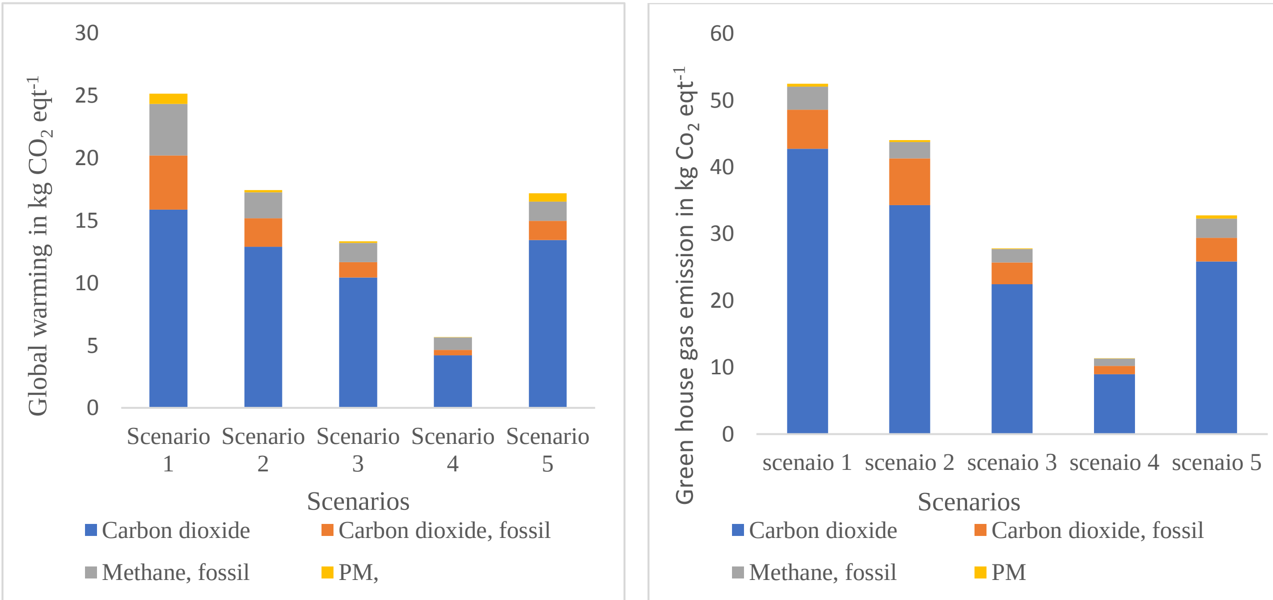
Figure 9.4 revealed the greenhouse emissions under four scenarios along with baseline scenario. Scenario 1 (BAU) showed the emission of maximum greenhouse gas at 27.24kg CO_2eq t^{-1} (Solan), 27.34 kg CO_2 eq t^{-1} (Mandi), 25.16kg CO_2eq t^{-1} (Sundernagar), 52.51kg CO_2eq t^{-1} (Baddi) due to the emissions of methane, carbon-dioxide (fossil), carbon-dioxide (biogenic) and particulate matter. Generally, burning of MSW generates biogenic and fossil CO_2, wherein the biogenic CO_2 is produced by the burning of organic waste and the fossil CO_2 is produced by the burning of non-biodegradable materials including plastic, leather, textile, wood etc. The generation of fossil CO_2 and CH_4 are produced comparatively in lesser amount in incineration process than in open dumps. If the waste is not burned, then it is likely to end up in the uncontrolled dumpsites which are considered least environmentally friendly options. However, burning of waste can also pollute public as well as environment because it emits dioxins, mercury, carbon-dioxide and many more pollutants but rather more safe than open dumping process. However, it has been observed that the least greenhouse gas emissions occur for scenario 4 (MRF_COM_SLF) i.e. 7.51 kg CO2 eq t^{-1} (Solan), 7.13kg CO2 eq t^{-1}(Mandi),5.65 kg CO2 eq t^{-1} (Sundernagar), 11.36 kg CO2 eq t^{-1} (Baddi).



(a)



(b)



(c) (d)

Figure 9.4: Global warming potential under different scenarios for (a) Solan, (b) Mandi (c) Sundernagar (d) Baddi

Acidification Potential

Acidification Potential refers to the impact of gases like SO_2, SO_3, NOx, HCl and hydrogen fluoride that are released into the air and subsequently falling like "acid rain". The pH of the precipitation increases due to acid gases and the rainwater are absorbed by plants, soil and surface waters that lead to degradation of soil, air and water quality. However, acidification also proves harmful for the health of human being as it directly affects the respiratory system of human beings.

The maximum acidification potential has been observed in Baseline scenario i.e.8.979 kg SO_2eq t^{-1} (Solan), 8.26 kg SO_2eq t^{-1} (Mandi), 5.558 kg SO_2eq t^{-1} (Sundernagar), 9.546 kg SO_2eq t^{-1} (Baddi) because during the combustion process most of the sulphur and nitrogen compounds are converted into the SO_x and NO_x. Further, BAU consists of open and uncontrolled dumping of municipal solid waste with very less amount of material recovery facility. The least acidification potential has been noticed in scenario 4 due to environmental benefits by a combination of composting and material recovery. Hence, the overall impacts of this scenario have the lesser impact among the alternative scenarios i.e. 2.89 kg SO_2eq t^{-1} (Solan), 2.28 kg SO_2eq t^{-1} (Mandi), 1.24 kg SO_2eq t^{-1} (Sundernagar),3.345 kg SO_2eq t^{-1} (Baddi).

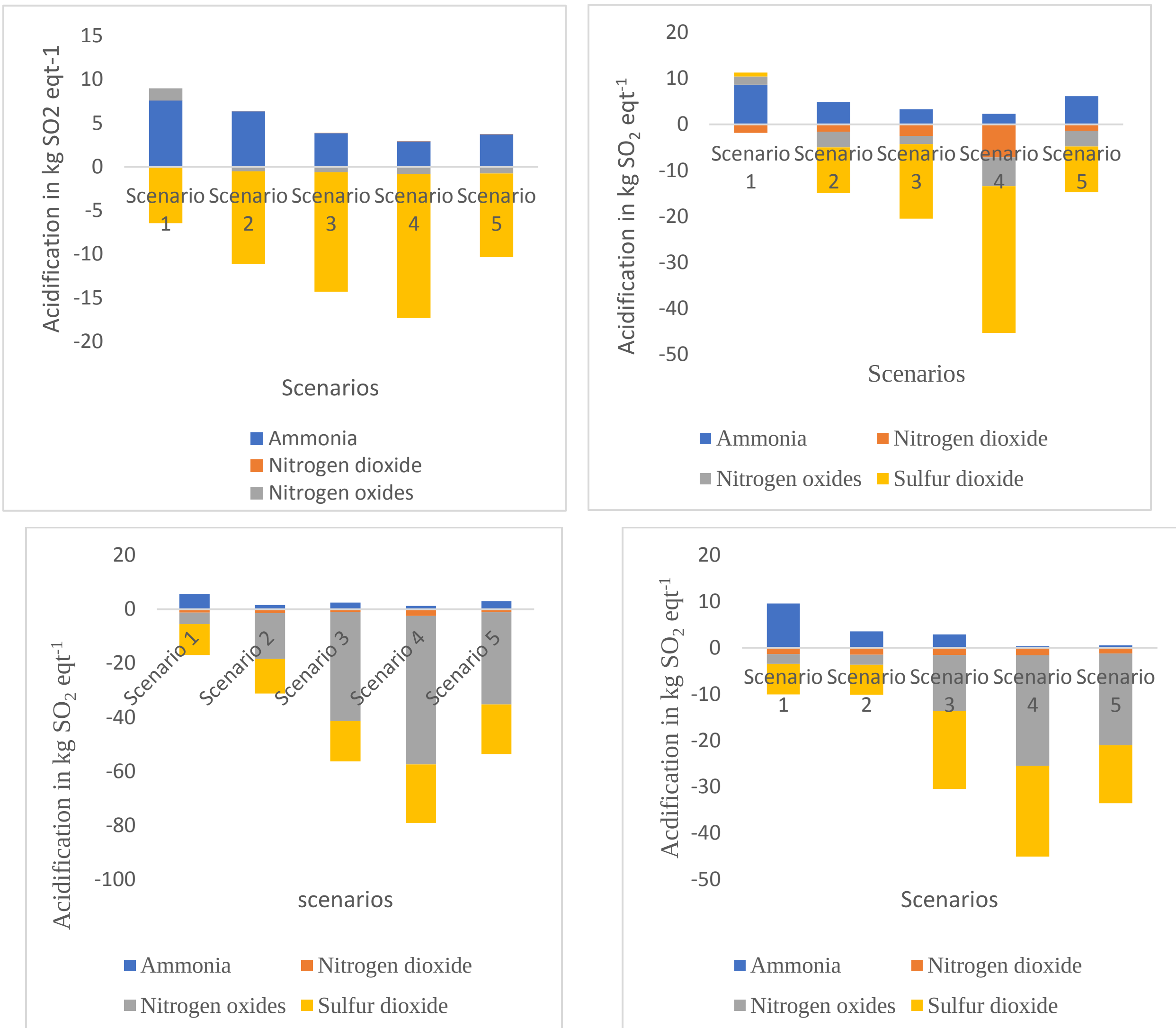
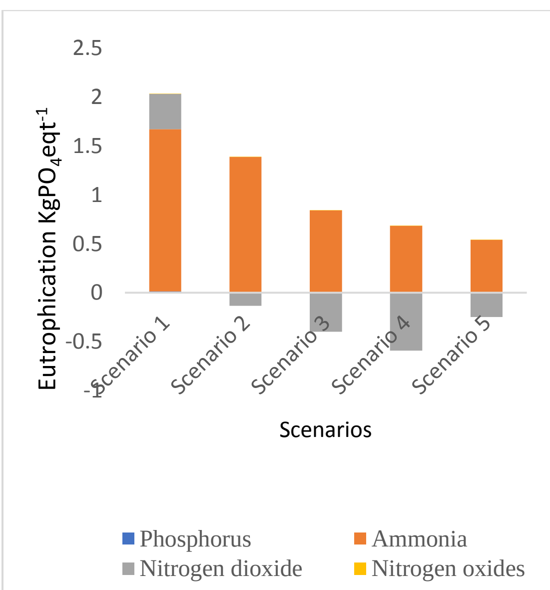


Figure 9.5: Acidification potential under different scenarios for (a)Solan, (b) Mandi (c) Sundernagar (d) Baddi

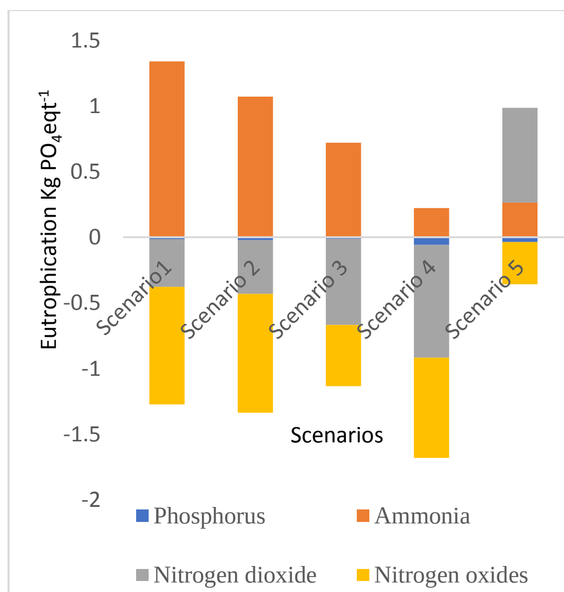
Eutrophication Potential

Eutrophication is the process in which the water bodies are enriched with minerals and nutrients that may cause the excessive growth of algae. In ecosystems, the increased growth of algae may cause less sunlight reaches deep into the layers, lesser amount of photosynthesis and reduction in oxygen concentration. The lower concentration of oxygen is inadequate for fishes and other aquatic animals to survive. The main substances in municipal solid waste are phosphorus and ammonium that contributes eutrophication potential expressed in Kg PO_4eq t^{-1}. However, the increment in the activities of ammonia and phosphorus may cause the activity of microorganism those results in the consumption of more oxygen.

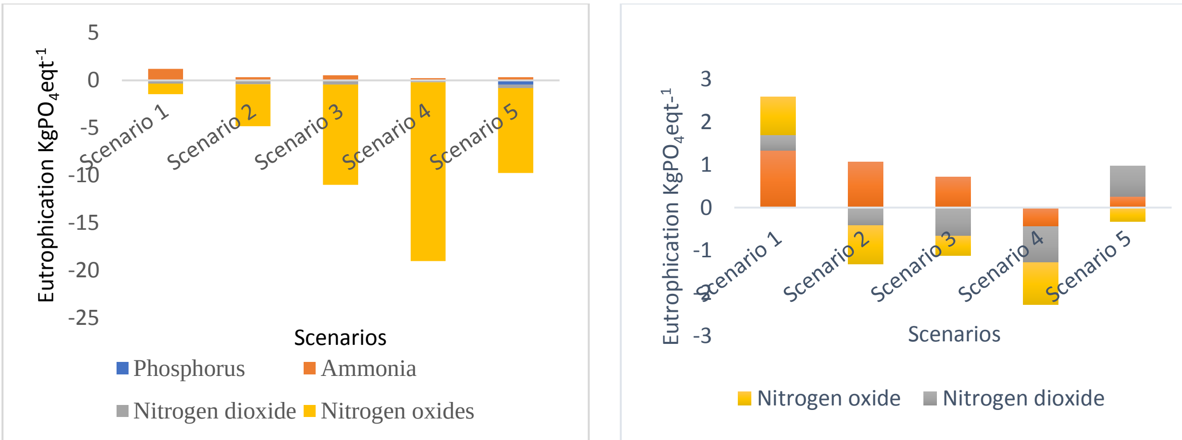
However, the presence of extreme nitrogen makes ground water unfit for drinking purpose. It was observed that maximum eutrophication potential was observed in scenario 1 (BAU) due to the absence of liner system i.e. Solan - 2.03 kg PO_4^- eq t^{-1}; Mandi - 1.341 kg PO_4^- eq t^{-1}, Sundernagar - 215 kg PO_4^- eq t^{-1} and Baddi - 2.59 kg PO_4^{3-}eq t^{-1}. The main cause of eutrophication potential is the absence of impermeable liner system for safe disposal of municipal solid waste. The harmful emissions caused by total nitrogen and phosphorous during the combustion process because of biological activities occurring in open dump sites. These compounds dissolve along with the leachate and cause more environmental impacts. However, the least eutrophication potential was observed in scenario 4 (MRF_COM_SLF) i.e. Solan - 0.68 kg PO_4^{3-}eq t^{-1}, Mandi - 0.19 kg PO_4^{3-}eq t^{-1}, Sundernagar- 0.23 kg PO_4^{3-}eq t^{-1} and Baddi - 0.98 kg PO_4^{3-}eq t^{-1}.



(a)



(b)



(c) (d)

Figure 9.6: Eutrophication potential under different scenarios for (a) Solan, (b) Mandi (c) Sundernagar (d) Baddi

Human toxicity potential

The main contributor to human toxicity potential is heavy metals that are released into soil, water and air. The toxicity of a substance is dependent on various parameters including chemical composition, physical properties and main source of emission. Human toxicity potential (HTP) is one of the emissions of airborne expressed as kg 1, 4-DB eq t^{-1}. It is an index which evaluates the potential of a unit chemical released in environment. Human toxicity is mainly caused by pollutants like dioxins, copper, chromium, cadmium and hydrogen fluoride. Maximum human toxicity impact was observed in Scenario 1 (BAU) Solan – 4.62 kg 1,4-DB eq t^{-1}; Mandi –5.51 kg1, 4-DB eq t^{-1}, Sundernagar - 1.96 kg 1,4-DB eq t^{-1} and Baddi – 14.11 kg 1,4-DB eq t^{-1}. However, scenario 4: MRF_COM_SLF has the least impact Solan –1.56 kg 1,4-DB eq t^{-1}, Mandi – 1.37 kg 1,4-DB eq t^{-1}, Sundernagar – 0.35 kg 1,4-DB eq t^{-1} and Baddi – 4.22 kg 1,4-DB eq t^{-1} among the alternative scenarios. Further, emissions under other alternative scenarios are having the values ranged between Baseline scenario and scenario 4 i.e. COM_MRF_SLF. Apart from this, it has been perceived that Baddi region has maximum pollution potential of all the emissions including global warming potential, acidification potential, eutrophication potential and human toxicity potential because Baddi town is the hub of industries and pharmaceutical activities. Further, the reason of pollution due to open duping is due to the unsegregated municipal solid waste and lack of provision of collection and treatment facility for leachate and absence of proper impermeable liner systems so that the leachate cannot seep into the aquifer. In this aspect, the leachate produced from these non-engineered landfill sites tends to permeate into ground water and hence leads to huge amount of human toxicity potential.

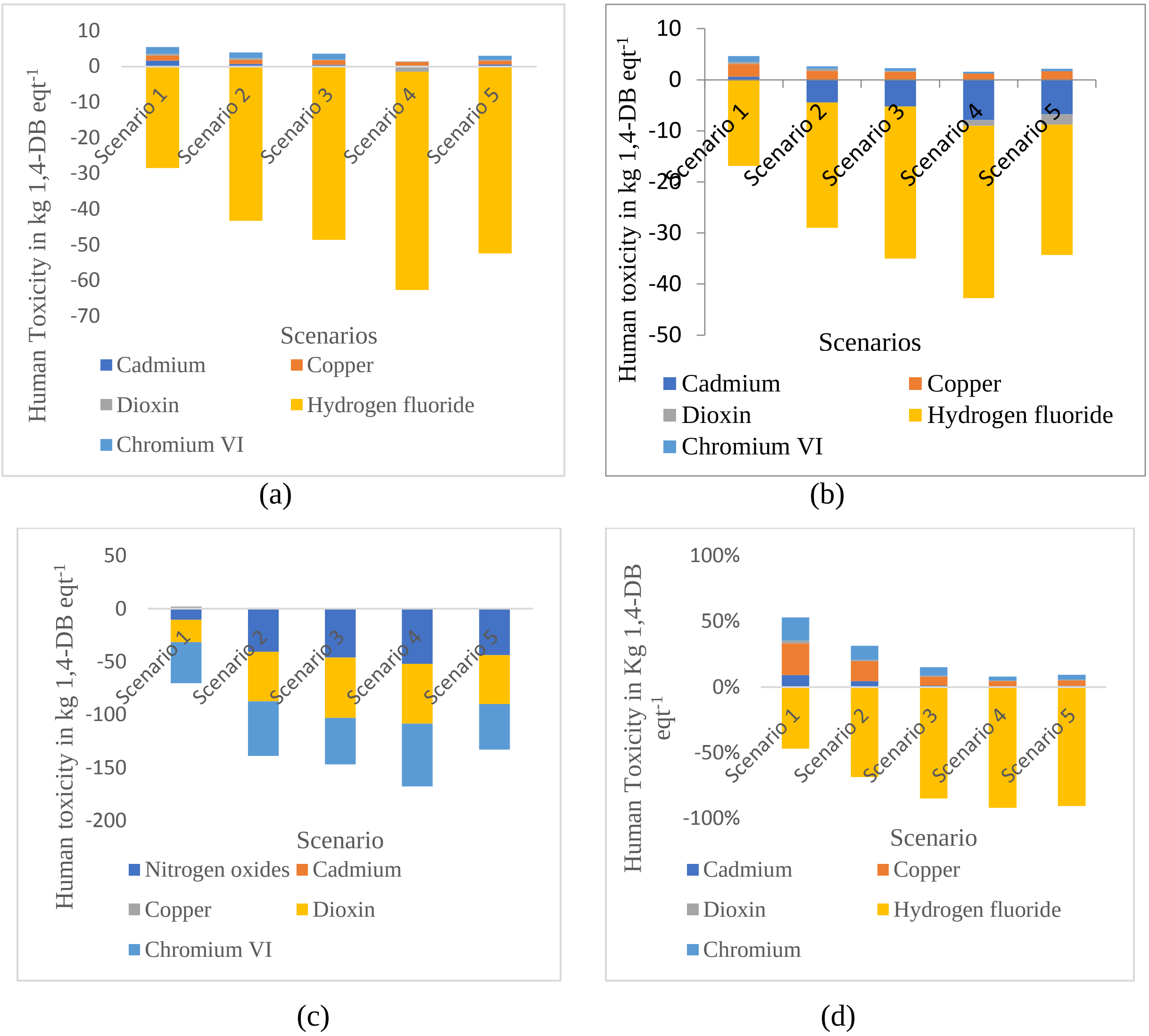


Figure 9.7: Human toxicity potential under different scenarios for (a)Solan, (b) Mandi (c) Sundernagar (d) Baddi

Sensitivity Analysis

The effect of varying recycling rates on the life cycle emissions were analyzed for the current waste management scenario i.e. BAU. In the current study the sensitivity analysis means for recycling of the materials including paper, plastic, textile etc. The impact of the various recycling rates in the fraction of 10%, 40% and 90% has been analyzed in the study. The analysis results revealed that recycling rate will significantly decrease the emissions released from the MSW management systems in the selected study regions. The results of global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP) for Solan, Mandi, Sundernagar and Baddi has been demonstrated in Figure 9.8 to 9.11.

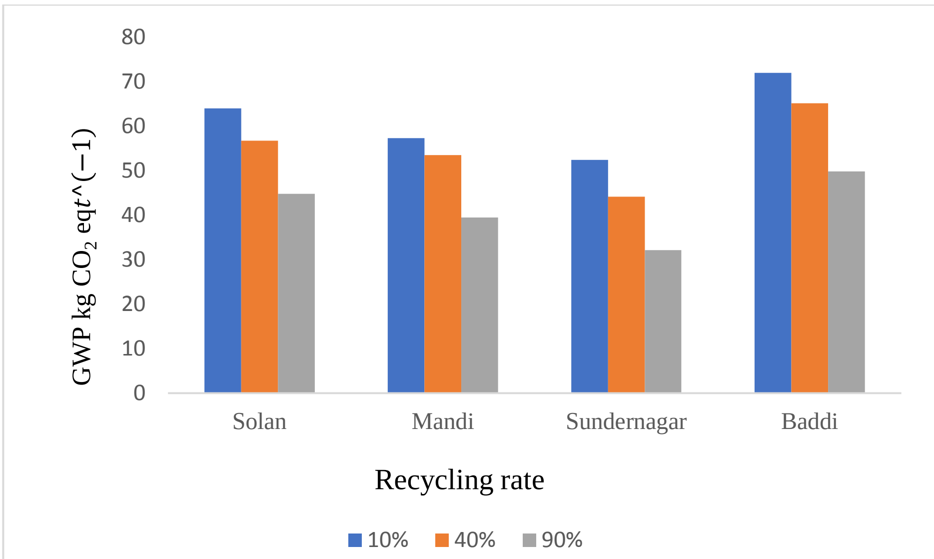


Figure 9.8: Effect of recycling rate on GWP under BAU scenario

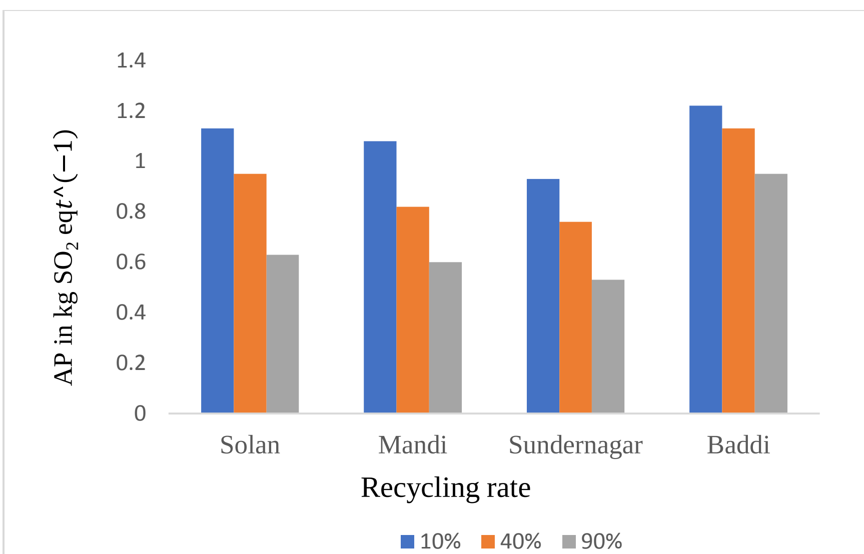


Figure 9.9: Effect of recycling rate on AP under BAU scenario

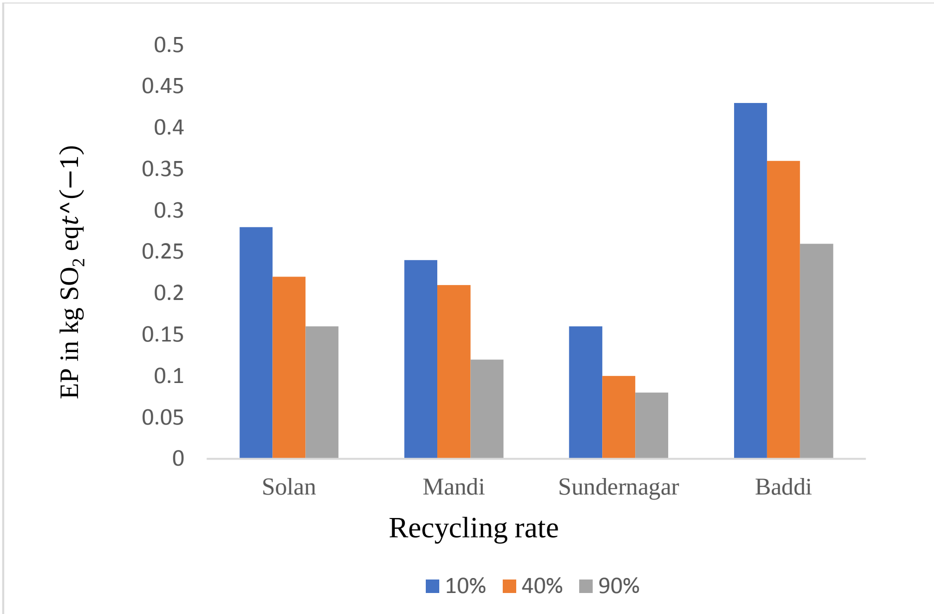


Figure 9.10: Effect of recycling rate on EP under BAU scenario

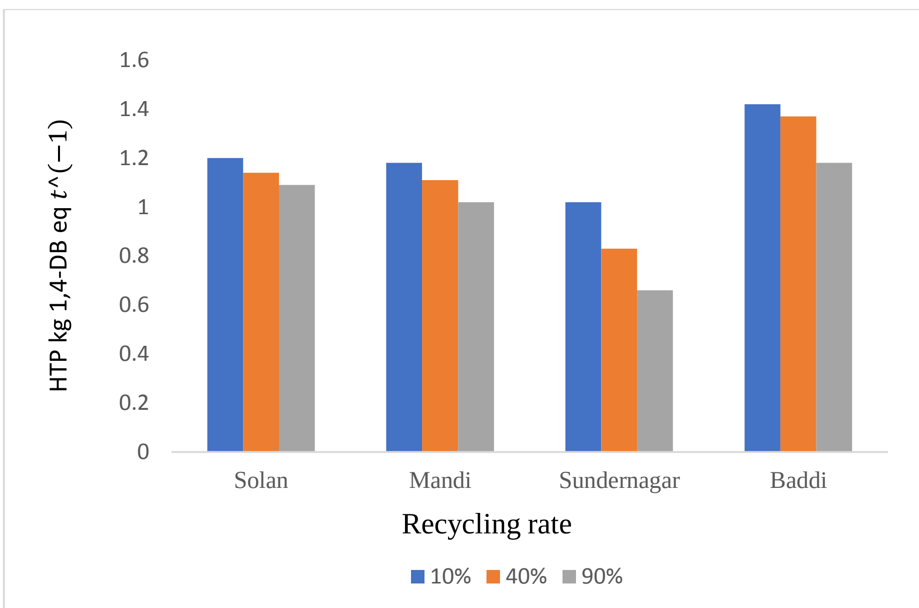


Figure 9.11: Effect of recycling rate on HTP under BAU scenario

It is illustrated from the analysis that the environmental remunerations would intensify as the recycling rate increases. If the recycling phenomena may increase from 10% to 90%, the environmental impacts will reduce in comparison to the prevailing condition. The environmental impacts in the BAU scenario for sensitivity analysis have been illustrated in Table 9.7.

Table 9.7: Environmental Impacts in the BAU for sensitivity analysis at10% (a) and 90%(b)

	GWP	AP	EP	HTP
Solan	63.98 kg CO_2eqt^{-1} To 44.80 kg CO_2eqt^{-1}	1.13 kg SO_2eqt^{-1} To 0.63 kg SO_2eqt^{-1}	0.28 kg PO_4eqt^{-1} To 0.16 kg PO_4eqt^{-1}	1.2 kg 1,4-DBeqt^{-1} To 1.09 kg 1,4-DBeqt^{-1}
Mandi	57.32 kg CO_2eqt^{-1} To 39.44 kg CO_2eqt^{-1}	1.08 kg SO_2eqt^{-1} To 0.6 kg SO_2eqt^{-1}	0.24kg PO_4eqt^{-1} To 0.12kg PO_4eqt^{-1}	1.18 kg 1,4-DBeqt^{-1} To 1.02 kg 1,4-DBeqt^{-1}
Sundernagar	52.38 kg CO_2eqt^{-1} To 32.11 kg CO_2eqt^{-1}	0.93 kg SO_2eqt^{-1} To 0.53kg SO_2eqt^{-1}	0.16kg PO_4eqt^{-1} To 0.08kg PO_4eqt^{-1}	1.02 kg 1,4-DBeqt^{-1} To 0.66 kg 1,4-DBeqt^{-1}
Baddi	72.00 kg CO_2eqt^{-1} To 49.81 kg CO_2eqt^{-1}	1.22 kg SO_2eqt^{-1} To 0.95 kg SO_2eqt^{-1}	0.43kg PO_4eqt^{-1} To 0.26kg PO_4eqt^{-1}	1.42 kg 1,4-DBeqt^{-1} To 1.18 kg 1,4-DBeqt^{-1}

(First values depict at 10%; Second value depicts 90%)

Summary

LCA is a tool that is utilized to compare the various waste management processes and to assess the most feasible option for the selected study locations in HP. However, the feasible option is the alternative that has insignificant effect on the environment. The current study results revealed that scenario 4 i.e. MRF_COM_SLF has the minimum impact on environment. Further, the results clearly depict that the waste management techniques can be easily attained with the recycling and reprocessing of the waste materials including paper, paperboard, plastics etc. and by composting technique. Further, the prevailing scenarios (i.e. BAU) in selected study regions of Himachal Pradesh are mainly comprised of open dumps and prove unfavourable and detrimental for the well-being of environment. This is predominantly because of the prevailing dumping sites are un-scientific, non-engineered without any provision of liner facility, leachate collection facility as well as lack of segregation processes. Additionally, life cycle analysis assessed for Himachal Pradesh has some shortcoming in the availability of appropriate data for the study regions. Generally, the data that were utilized in the study includes waste production rate, number of vehicles used for waste transportation, as well as physico-chemical characterization of waste. As there exists no literature studies on life cycle assessment for Himachal Pradesh, hence the study uses comprehensive LCA for examining the various management techniques, hence make it potential for the municipalities of the selected study locations towards the enhancement in the current waste management strategies. Finally, the next chapter presents a detailed design of an engineering landfill site.

CHAPTER – 10

DESIGNING OF LANDFILL IN HIMACHAL PRADESH

10.1 Introduction

The drastic growth in urbanization and industrialization results in increment in the waste generation hence the management of MSW has become one of the biggest challenges in today's world. Consequently, due to enormously growing MSW, the open dumps are also increasing day by day. The leachate produced in the open dumpsites consists of organic pollutants [24, 254, 255] which are harmful and has the potential to cause contamination of soil air and water as observed from the results of the previous chapters and hence a design of detailed landfill has been discussed in this chapter for effective control of the MSW generated at the study locations. The schematic diagram showing the effect of opens dumping in environment and has been demonstrated in Figure 10.1 (a & b).

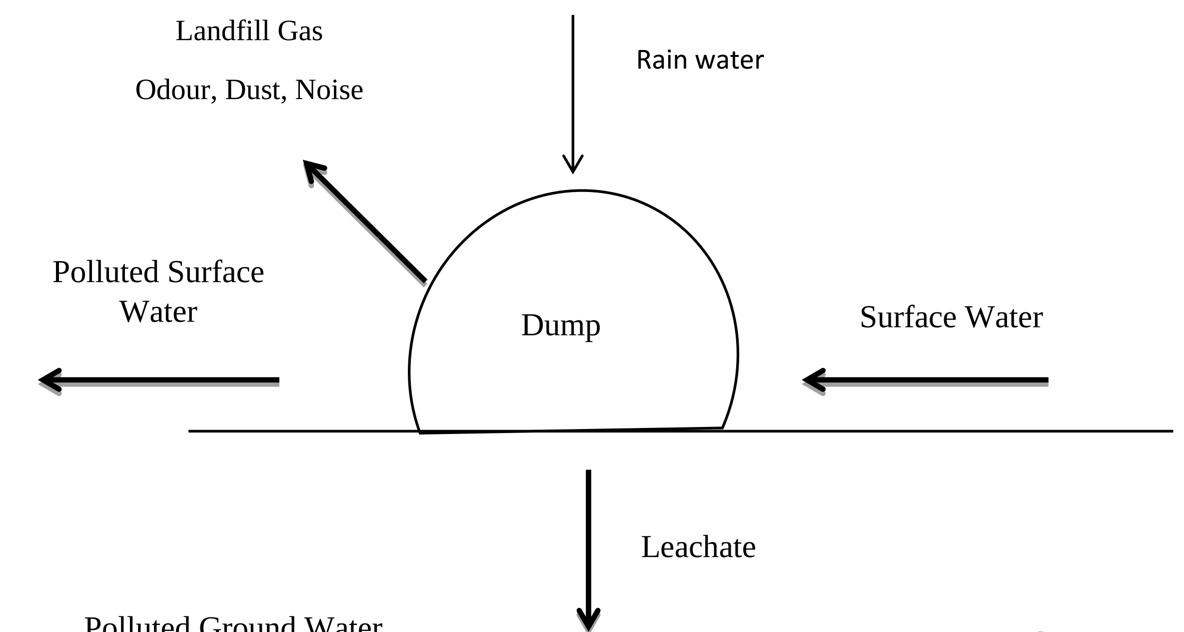


Figure 10.1 (a): Effect of open environment

In order to minimize the harmful effects of open dumping of waste, properly designed engineered landfill is required for the disposal of municipal solid waste.

A landfill is the well-developed strategy which is designed for the disposal of municipal solid waste generated from areas any municipal corporation. The basic step in the designing of landfill is that the waste is dumped in landfill daily and covered during the end of each day. Landfill's construction includes planning, design and implementation of different components such as use of liners, leachate collection systems to prevent the migration of contaminants into groundwater and soil.

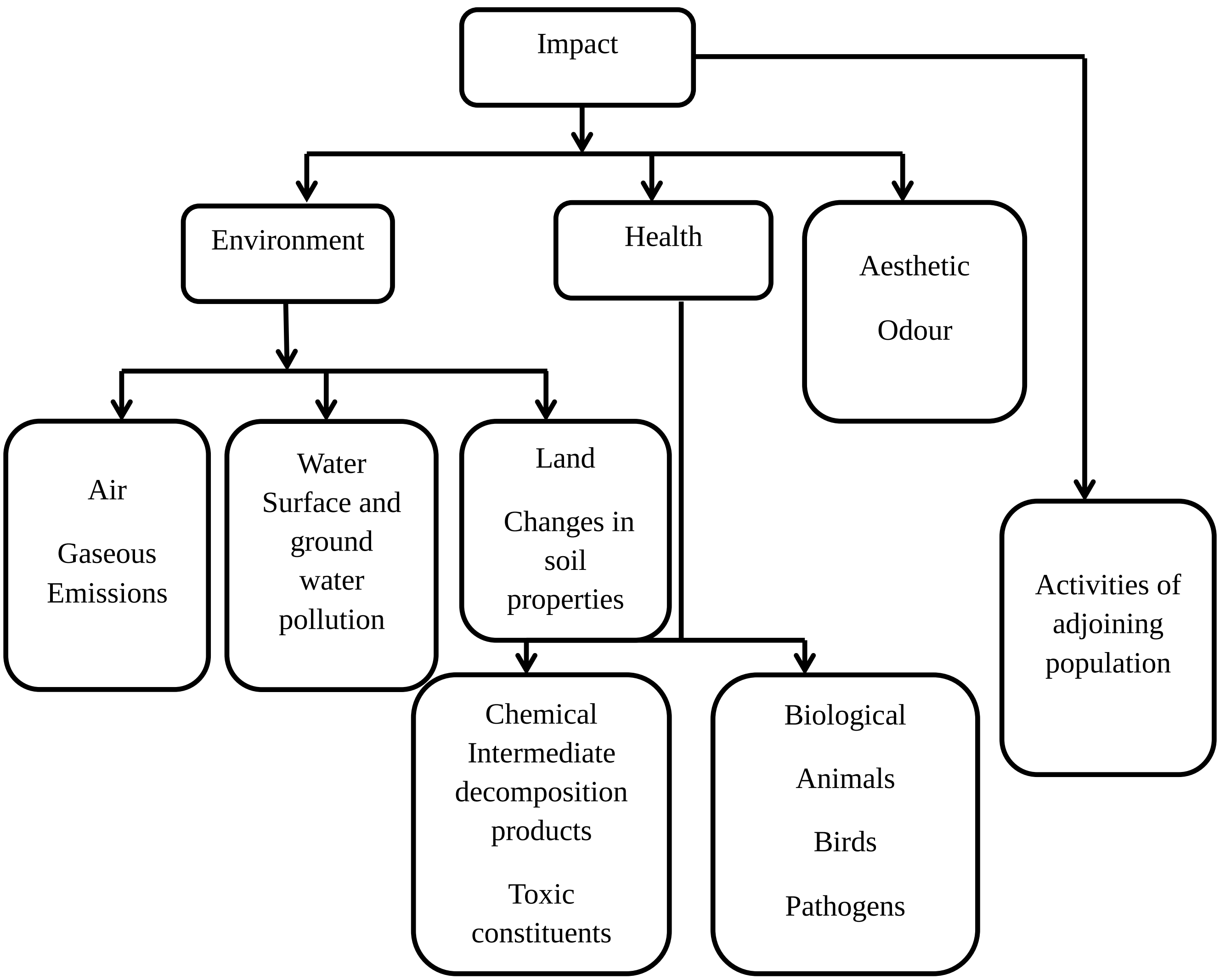


Figure 10.1 (b): Effect of open dumping on environment

Non-engineered landfills are often responsible for causing serious environmental damages, especially groundwater pollution affecting the surrounding communities. Therefore, every landfill needs an appropriate design and operation to reduce negative impacts on the environment. The conceptual sketch of an engineered landfill system has been illustrated in Figure 10.2 and the waste containment system has been demonstrated in Figure 10.3 respectively.

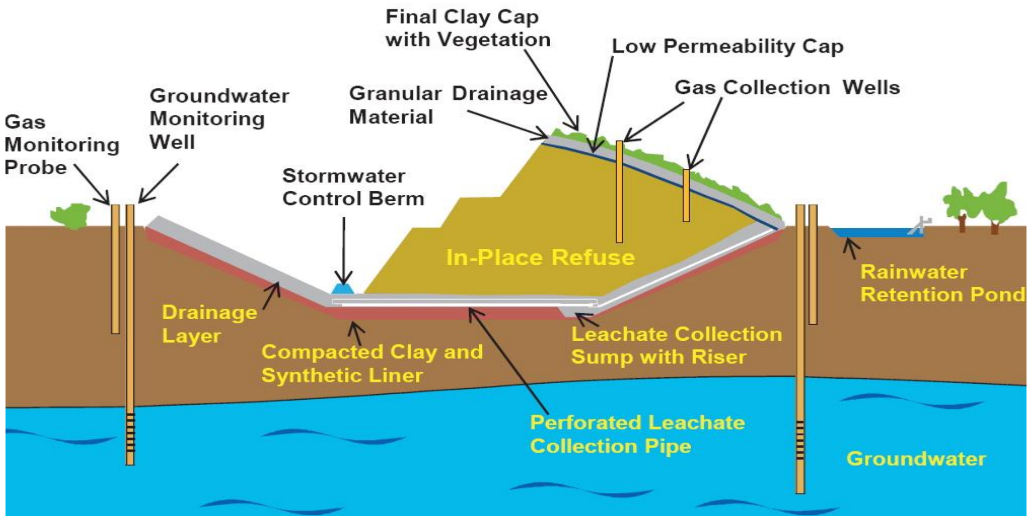


Figure 10.2: Conceptual sketch of an engineered landfill system

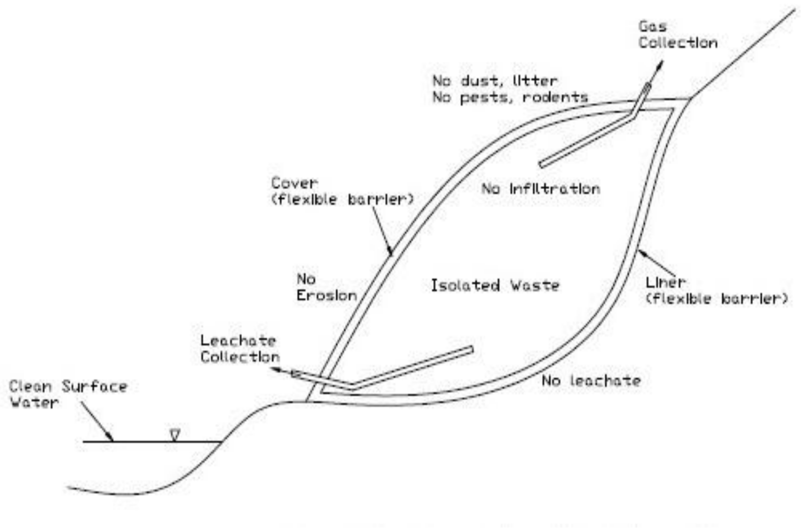


Figure 10.3: Waste containment system of an engineered landfill

10.2 Components of landfill system

Liner system is one of the most important components in the designing of any landfill. Liner system is a low permeable barrier which is laid under engineered landfill sites to protect the percolation of leachate contaminants into aquifers. A solid waste landfill must have two or more liners and properly constructed along with a leachate collection system placed above these liner systems to prevent its percolation through the soil. The leachate collection system is constructed to accumulate the leachate produced in the landfill and to drain leachate to leachate treatment plant through the leachate storage tank or sump. Apart from this, well monitoring system, gas collection facilities are also the major components in landfill system and play vital role in the regulation of the landfills. Ultimately the final and top most component of landfill is the final cover system in which the waste should be dumped throughout the end of each day by means of local soil.

10.3 Purpose of landfilling in Himachal Pradesh

Presently, landfill is operated as a non-engineered sanitary landfilling systemin Himachal Pradesh without any provision for the treatment and processing of leachate and gases. There is a dire need of replacement of open dumping system by proper sanitary engineered landfill facility whereby environment control measures can be put in place preventing pollution in the nearby vicinity. However, one of the most persistent problems facing the towns of Himachal Pradesh is the efficient and long-term disposal of municipal solid waste. There are deficiencies in the present system of MSW management including no waste segregation leading to uncontrolled dumping of waste in the selected study locations of Himachal Pradesh. The proper disposal and treatment of MSW is essential for the public health and is also a potential for resource recovery. In this context, the design of sanitary landfill is required.

For designing the sanitary engineered landfill system, the foremost and the most important step is the site selection criteria. The selection criteria for land to be used for landfill design should adhere to the conditions as specified in Table 10.1.

Apart from this, the layout of a landfill in plan is generally governed by the shape of the area available for land filling. About 80% of the total area is used for placement of the waste whereas the balance 20% of the area is utilized for making built-up-area-office, laboratory, workshop, equipment shelters, and treatment facilities for leachate [19].

Table 10.1: Selection criteria for the land used for landfill design [256-258]

Sources	Distance
Lake/pond	>200 m
River	>100 m
Highway	> 500 m
Habitation	> 500 m
Public Park	> 500 m
Critical habitat	No
Airport	> 20 km
Water supply well	> 500 m

10.4 Description of selected site for landfill design

The proposed sanitary landfill area is located at Bhariyal, along Taradevi-Totu bypass road, Maujja. Shimla city lies in the coordinates of 31^{o} 05’06” N and 77^{o}7’44” E. The annual average rain is 1420 mm and average daily evaporation is approximately 4 mm. The landfill site is a natural valley of a depth of approx. 80 m below the bypass road. The nearest residential area is more than 500 m away from the downstream end of the site. Due to the steep slopes, the design should be carried out under consideration of the **“Valley method”.** The construction works for the valley landfill will start from the lowest point with the construction of a retaining wall so as to contain the waste in the designed cell. The base will be constructed in form of steps depending on the natural slope of the valley. Cover material for the deposited waste can be obtained from the excavation works from the slopes of the valley itself. The length of the initial section will be determined in a way that settlements can take place over one year before the next section is placed. Succeeding sections must be constructed by hauling solid waste over the first section to the head of the valley.

The aerial view of the proposed site has been generated using software MXV8i and has been shown in Figure 10.4.

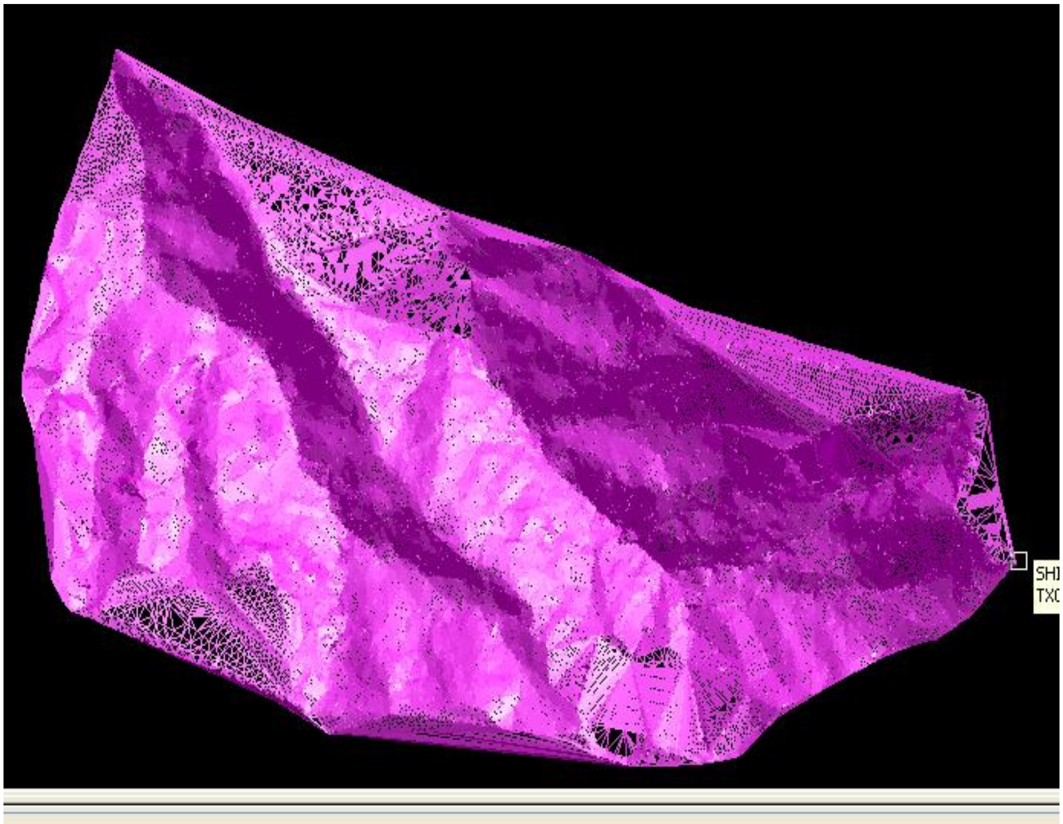


Figure 10.4: Arial view of proposed site in Shimla (H.P.)

10.4.1 Landfill Capacity, Sections, Elevations and Plans

The required landfill capacity is significantly greater than the waste volume it accommodates. The actual capacity will depend upon the volume occupied by the liner system and the cover material (daily, intermediate and final cover) as well as compacted density of waste. In addition, the amount of settlement a waste will undergo due to overburden stress and due to bio degradation too will be taken into account. Thus, landfill facility design calculations cover estimation of the area, height and capacity required for land fill site.

10.4.2 Estimation of Landfill Capacity

The section of landfill showing phases of landfill has been worked out using AutoCAD 7.0 and the volume of IV phases of landfill has been calculated.

The section of landfill has been illustrated in Figure 10.5

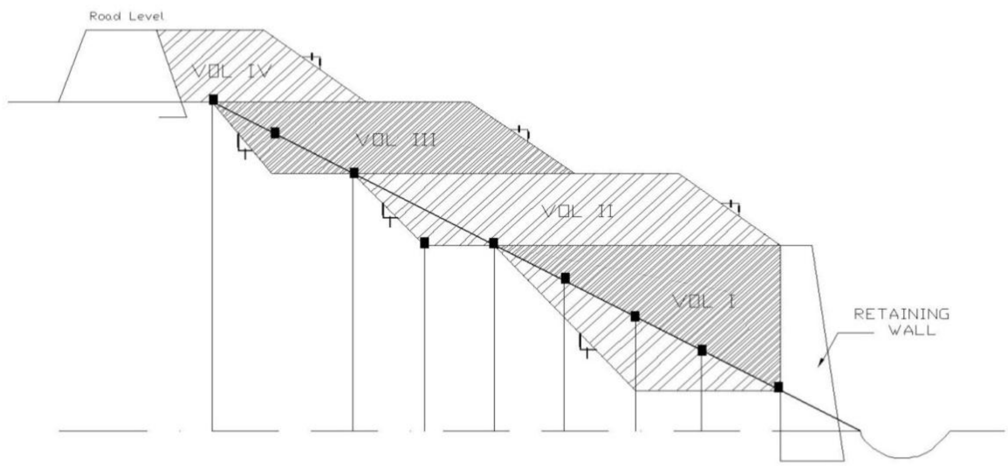


Figure 10.5: Section of a landfill for estimation of landfill capacity

10.5 Preliminary design of landfill

The preliminary design of the landfill includes:

Location - Shimla, Himachal Pradesh

Waste generation - 500 tons per day (current)

Design Life - Active life = 20 years

Closure and post closure period = 20 years

Topography – Hilly or mountainous terrain

Subsoil – Sedimentary brownish grey soil (Sandy loam to silty clay)

Water table – 5 m (min) to 30 (max) (Requirement – 10 m below ground surface)

Average total precipitation – 830 mm (year)

Monthly precipitation – 25.4 mm

Landfill capacity, landfill height, and landfill area

$Waste\ generation/day = 500 tons/day$

$Waste\ genertation/year = 500 \times 365/year$

$Estimated\ waste\ generation\ after\ 20\ years\ (per\ day) = 500\left(1 + \frac{1.33}{100}\right)^{20}$

$= 700\ tons/day$

$Estimated\ waste\ generation\ after\ 20\ years\ (per\ year) = 700 \times 365$

$Estimated\ rate\ of\ increase\ or\ decrease\ in\ waste\ generation\ per\ year$
$= 1.33\%/\ annum$

$Total\ waste\ generation\ in\ n\ (20) years = \frac{1}{2}(500 + 700) \times 365 \times 20$

$= 438000 tons/year$

$Total\ waste\ volume = assumed\ density\ (0.85\ t/cu.m)$ [19]

$$V_w = \frac{438000}{.85} cu.m = 152941.17 cu.m$$

$Volume\ of\ daily\ cover$

$= \ (in\ years) on\ basis\ of\ 15cm\ soil\ cover\ on\ top\ and\ sides\ for\ lift\ \square eig\square t\ 1.5\ to\ 2m$

$V_d \ = .1 \times V_w = .1 \times 515294 cu.m$

$Volume\ of\ liners\ and\ cover\ system \quad V_c = K \times V_w$

$On\ the\ assumption$

- $1.5m\ thick\ liner (including\ lechate\ collection\ system)$
- $m\ cover\ system\ (including\ gas\ collection\ system)$

$Hence, V_c = K \times V_w cu.m$

Also

$K = 0.25\ for\ 10m\ high\ landfill\ (CPCB\ 2000)$

$= 0.125\ for\ 20m\ high\ landfill$

$= 008\ for\ 30m\ high\ landfill$

$Therefore, \quad K = 0.25 \times 5152941.17$

$= 1288235.29\ cu.m$

Volume likely to become available within 10 years due to settlement and biodegradation of waste

$$Therefore, \quad V_s = m \times V_w$$

$Also, \quad m = .010\ for\ biodegradable\ waste\ (EPA\ 2000)$

$= will\ be\ less\ than\ 0.05\ for\ incineration/inert\ waste$

$Therefore, \quad V_s = 0.10 \times 515294.117 cu.m$

First estimate of landfill volume

$$C_i = (V_w + V_d + V_c - V_s) cu.m \quad (CPCB\ 2000; EPA\ 2000)$$

$$C_i = 515294.17 + 515294.117 + 128825.29 - 515294.117$$

$$C_i = 6441176.46\ cu.m$$

$Possible\ maximum\ landfill\ height = 10m$

$$Hence, area\ required\ for\ seperation = \left(\frac{6441176.46}{10}\right)\ sqm$$

$$= 644117.646\ sqm$$

$$Total\ area\ required\ including\ infrastructure\ facilities = 1.15\ A_i$$

$$= 1.15 \times 644117.646\ sqm$$

$$= 7407353.136\ sqm$$

Landfill Phases

$Active\ life\ of\ landfill = 20\ years$

$Duration\ of\ one\ phase = 1 year$

$Number\ of\ phases = 20$

$$Volume\ of\ one\ phase = \frac{Landfill\ capacity}{20}$$

$$= \frac{6441176.46}{20}\ cu.m = 322058\ cu.m$$

10.6 Gas collection facility

Waste disposal with the recovery of gases is one of the most important aspects in the designing of landfill system. Due to the fact that MSW in India consist more organic waste and also high moisture content along with prevailing tropical climate, LFG generates even in open dumps and escapes into the atmosphere. In addition to this, improper dumping consumes more area. In the light of the newly formulated legislation for properly designed landfills, MSW from Himachal Pradesh with its rich organic and moisture content would result in more gas generation, which also needs to be handled. Further, due to the fact that methane is a major constituent of LFG and has considerable energy value, its energy potential needs to be evaluated.

The release of methane and other gases (mainly carbon dioxide) from landfill is also one of the major problems linked to landfills. It is highly flammable gas which causes fires and explosions in landfills if present in high concentrations [256].

Landfill gas can migrate laterally and potentially cause explosions. Landfills are therefore provided with gas collection and processing facilities. The rate and quantity of gas generation with time, is difficult to predict. The typical constituents of MSW gas are illustrated here in Table 10.2.

Table 10.2: Typical constituents of MSW gas

MSW gases	Constituents
Methane	30-60%
Nitrogen	1-21%
Carbon dioxide	25%
Carbon monoxide	0-0.2%
Hydrogen	0-0.2%
Ammonia	0.1-1%
Oxygen	0.1-2%

The total energy generation can be calculated as shown below:

Total carbon available in one year $(t) = W_a \times f_{lf} \times f_{a-doc}$ [125]

where,

W_a = annual waste generated (tons)

f_{lf} =fraction land filled

f_{a-doc} =fraction of organic carbon in the degradable waste

Total gas generated from one year of waste = $\left[(W_a \times f_{lf} \times f_{a-doc})(r_{lfg} \times f_{methane})\right]$

$f_{methane}$= the fraction of methane in LFG

r_{lfg}= the methane generation rate (m3/t)

Total energy generated from one year of waste using LFSGR

$$(E_r) = [W_a \times f_{lf} \times f_{a-doc})(r_{lfg} \times f_{methane})\varphi \times \omega]$$

where,

φ =gas collection efficiency

ω = the calorific value of Methane (Kcal/m^3)

The total energy generation can be calculated as shown below:

Total carbon available in one year $(t) = W_a \times f_{lf} \times f_{a-doc}$

where,

W_a = annual waste generated (tons) = 182500 t/year

f_{lf} =fraction land filled = 0.65

f_{a-doc} =fraction of organic carbon in the degradable waste = 0.60

Total gas generated from one year of waste = $[(W_a \times f_{lf} \times f_{a-doc})(r_{lfg} \times f_{methane})]$

Total energy generated from one year of waste using LFSGR

$$(E_r) = [W_a \times f_{lf} \times f_{a-doc})(r_{lfg} \times f_{methane})\varphi \times \omega]$$

= 9.86 × 10^{-19} Kcal per year.

10.7 Recommended Bottom liners for leachate migration reduction

Liner system is placed on the bottom and side slopes of landfill. Liner system is used to separates the dumped solid waste and soil-water mainly to intercept the contamination of soil and groundwater underneath. Liner system minimizes the migration of leachate into the groundwater reserves and hence prevents the pollution of groundwater (aquifers). A liner system should have low permeability, should be durable and should be resistant to chemical attack. Geosynthetic clay liner (GCL) or 2 mm high density polyethylene (HDPE) geomembrane liner is suggested as a bottom-liner system for MSW landfill site at Shimla, Himachal Pradesh.Over the limit of excavation, a layer of cushion, 300 mm thick, will be laid and compacted, which will become the sub-grade to the overlying HDPE Liner. The cushion material should be clean sands, clear of any sharp rocks that may puncture, tear, or damage the HDPE Liner.

Geosynthetic clay liner: Geosynthetic clay liner (GCL) is a woven fabric material used for lining of landfills. Geosynthetic clay liner consist of two layers of geotextiles of low permeability and sodium bentonite that are needle punched together to increase internal shear resistance. The geotextiles offer a long-lasting resistance to physical or chemical breakdown in harsh elements. The high swelling capacity and low permeability provides an effective hydraulic seal. The permeability of geosynthetic clay liner varies in between 10^{-10} to 10^{-12}m/sec which is low and sufficient for the reduction of leachate contaminants migration into the subsoil. The lower permeability of geosynthetic clay liner proves more effective for retaining seepage inside of the landfill.

Geomembrane liner: Geo membrane is the low permeability synthetic membrane liner constructed from various plastic materials including polyvinyl chloride (PVC) and high-density polyethylene (HDPE).

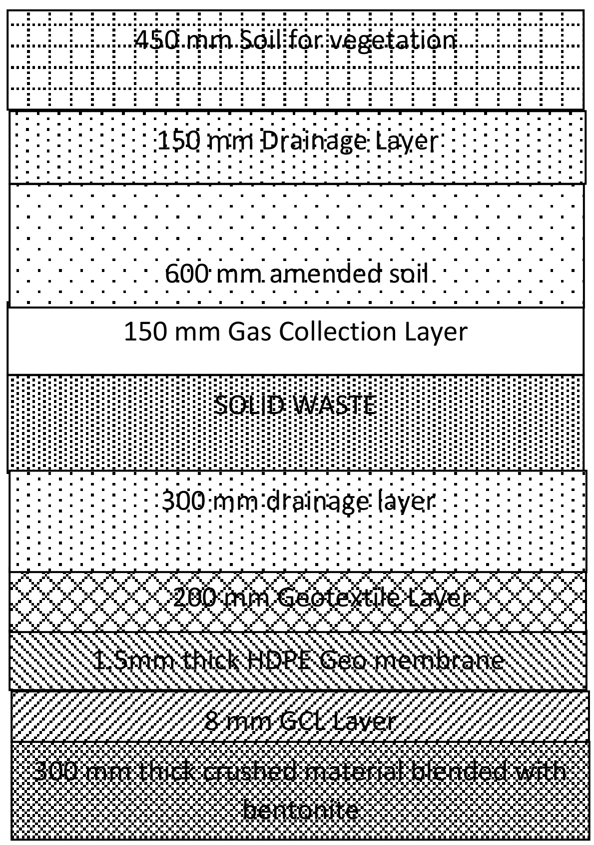


Figure 10.6: Sections of Top Cover and Bottom Liner System of landfill

Geomembrane liner retards the migration of leachate into the underground reserves that may cause the spoliation of water. High density polyethylene is the most preferred material for use in

MSW and secure landfill. The various thickness of geomembrane may be used as the bottom lining system in MSW landfill are 1 mm, 1.50 mm, 2 mm and 2.54 mm. The HDPE geomembrane liner possesses very low permeability of 10^{-12}m/sec which prevents the migration of pollutants into the aquifers. The sections of Top Cover and Bottom Liner System of landfill have been demonstrated in Figure 10.6.

Base Liners

The bottom portion of the landfill directly rests on stable compacted specially prepared soil bed. The various layers of liners from bottom to top which are required as per the SWM CPHEEO Manual are:

- 300 mm thick crushed material blended with bentonite ($k \leq 10^{-7}$ cm/sec.)
- 8 mm GCL Layer
- 1.5 mm thick high-density polyethylene (HDPE) Geomembrane
- 200 mm Geotextile Layer
- 300 mm thick granular soil drainage layer (Leachate Collection Layer)

Top Cover Design

The top cover of the landfill directly rests on compacted specially shaped waste surface. The bed shall be laid to 3 to 5 % slope (after allowing for pre-grade settlements of the waste) for providing good natural drainage.

The various layers of liners from bottom to top have been shown in Table 10.3.

Table 10.3: Various layers of liner system

Vegetation Soil	150 mm
Top Soil	450 mm
HDPE Layer	1.5 mm
GCL	8 mm
Soil Cover	150 mm

10.8 Leachate collection system

Typically, leachate collection and removal system of MSW landfills consist of perforated pipes, sump and drainage materials. The material used in drainage layer of leachate collection system should essentially satisfy two requirements such that it should be permeable enough to collect and transport liquid. The material should be compatible with the waste. The material should not damage the liner systems. Sometimes geotextile is used between geomembrane and the drainage layer. Materials that can be used in the drainage layer of leachate collection system areas and gravel. The leachate pipe is covered longitudinally with well-compacted filter material of pebbles (grain size: 50 – 150 mm). The conceptual sketch of leachate collection system has been illustrated in Figure 10.7.

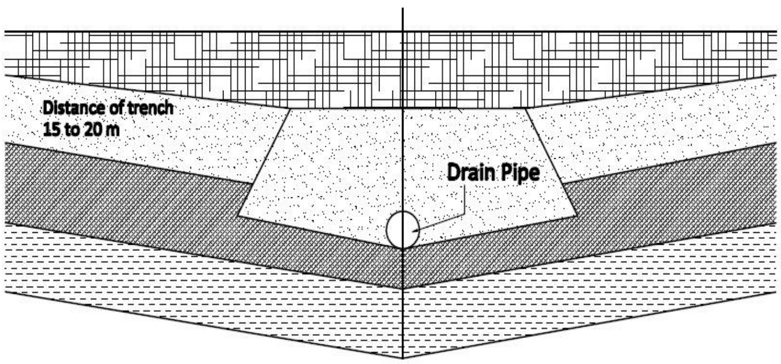


Figure 10.7: Leachate collection system

The pipe spacing will be governed by the requirement that the leachate head shall not be greater than the drainage layer thickness. For collection and conveyance of leachate to sump, a perforated HDPE pipe must be installed in the channel. At the end of the channel, the perforated HDPE pipe will connect to the RCC sump.

10.8.1 Leachate Generation Rate

$$I = P - R_o - ET \pm \Delta S \text{……………….}(1)$$

Where

$I = Infiltration\ rate$

$R_o = Run\ off$

$ET = Evapotranspiration$

$\Delta S = Change\ in\ storage$

$$P = Precipitation$$

Also

$$R_o = C.P$$

Where

$$C = Run\ off\ cofficient$$

Also

$$C = a.b_i$$

where

$$a = depends\ upon\ the\ slopes, types\ of\ material\ used.$$

$$b_i = depends\ upon\ soil\ moisture\ in\ average\ month.$$

For loamy/ clayey soil if the slope is between 5% to 10%

$$a = 0.18\ to\ 0.22$$

$$a = 0.20\ mm$$

$$b_i = 1.50\ mm$$

Therefore

$$Runoff = (0.2\ mm \times 1.50\ mm) \times 1420\ mm/year$$

$$Runoff = 444\ mm^3/year$$

We know that

$$Actual\ ET = ET_p(DT/360)\ \ mm/month$$ …………..(2)

Where

$ET_P =$ Potential evapotranspiration

$$D = number\ of\ days\ in\ a\ month.$$

$$T = average\ number\ of\ sunshine.$$

$$ET_p = 16(10T_i/I_T)^a$$ …………………………………..(3)

Where,

$T_i = average\ monthly\ temperature$ ($\approx$ 24℃)

$$I_T = annual\ thermal\ index$$

The annual thermal index has been summarized in equation below:

$$I_T = \Sigma\left(\frac{T_i}{5}\right) \times 1.514 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$I_T = \frac{24}{5} \times 1.514$$

$$I_T = 7.26$$

Therefore

$$ET_p = 16\left(10 \times \frac{24}{72}\right)^{.02}$$

$$ET_p = 32.20\ mm/month$$

Now actual evapotranspiration is

$$ET = ET_p(DT/360)$$

$$ET = 32.20\left(30 \times \frac{5}{360}\right)$$

$$ET = 13.42 mm/month$$

$$ET = 189\ mm/year$$

Leachate Quantity Generation

$$I = P - R_o - ET \pm \Delta S$$

$$\Delta S = Rainfall - (Run\ off + ET)$$

$$\Delta S = 1420 - (\ 444 + 200)$$

$$\Delta S = 776$$

Therefore

$$I = 1420 - 444 - 486 + 776$$

$$I = 1266\ mm^3/year$$

$$I = 3.46 \times\ 10^{-9} m^3/day$$

10.8.2 Design of leachate collection system

10.8.2.1 Determination of Pipe size

Assumed data

Total length of the leachate collection pipe = 50m

Leachate collection pipe is adjacent to (3H:1V) side slope with the height of 15m.

Peak generation rate at the side slope area = 3.12×10^{-7}

Peak generation rate at the bottom of the floor area = 2.08×10^{-7}

$$Area\ of\ upgradient\ portion\ of\ landfill\ cell\ (A_u) = 50(3 \times 15)$$

$$= 2250m^2$$

$$Maximum\ leachate\ flow\ for\ upgradient\ portion\ of\ the\ cell\ is\ (Q_u)_{max}$$

$$(Q_u)_{max} = (q_u)_{max} \times A_u$$

$$= 3.12 \times 10^{-7} \times 2250$$

$$= 7.02 \times 10^{-4} m^3/sec$$

$$Area\ of\ down\ gradient\ portion\ of\ landfill\ cell\ (A_d) = 50 \times 20$$

$$= 1000m^2$$

$$(Q_d)_{max} = (q_d)_{max} \times A_d$$

$$= 2.08 \times 10^{-7} \times 1000$$

$$= 2.08 \times 10^{-6} m^3/sec$$

$therefore$

$$(Q_u)_{max} + (Q_d)_{max} = 7.02 \times 10^{-4} m^3/sec + 2.08 \times 10^{-4} m^3/day$$

$$= 9.1 \times 10^{-4} m^3/sec$$

Selection of Pipe size

(i) The size of the pipe can be calculated by Manning's formula.
(ii) First of all, assume the pipe size, and then calculate the flow rate of the pipe based on the assumed pipe size using Manning's equation.
(iii) The calculated flow rate from Manning's equation must be greater than the required leachate flow rate.
(iv) If not, another pipe size must be tried and hence the process repeated.

$$Select\ 6(inch) HDPE\ pipe\ SDR = 11$$

$$SDR = \frac{Outer\ diameter\ of\ pipe}{Inner\ Thickness\ of\ pipe}$$

$$SDR = \frac{D_o}{t}$$

$$t = \frac{D_o}{SDR}$$

$$t = \frac{6}{11} = 0.55\ inch = .014m$$

Also

$$D_i = D_o - \ 2t$$

$$D_i = .15 - \ 2 \times .014$$

$$D_i = 0.122$$

Also

$$r_n = hydraulic\ radius = \frac{D_i}{4}$$

$$r_n = \frac{0.122}{4}$$

$$r_n = .0305m$$

Also

$$Area = \frac{\pi}{4}(D_i)^2$$

$$Area = \frac{\pi}{4}(.122)^2$$

$$Area = .0116m^2$$

$For\ HDPE\ pipe\ Manning's\ roughness\ cofficient\ n = .011$

$$Q_{\ req} = \frac{1}{n}A.(r_n)^{2/3}.S^{1/2}$$

$$Q_{\ req} = \frac{1}{0.011} \times 116 \times (.0305)^{2/3} \times (.01)^{1/2}$$

$$Q_{\ req} = 0.0104m^3/\sec > 9.1 \times 10^{-4}m^3/sec$$

Hence okay.

10.8.2.2 Pipe Perforations

Maximum leachate inflow per unit length of the pipe

$$Q_{(inflow)} = (q_u)_{max} \times A_u + (q_d)_{max} \times (A_d)_{unit}$$

$Total\ Lechate\ generation/m^2 = \ 5.26 \times 10^{-7} m^3/sec/m^2$

$= 0.00000052 \times .40$

$= .0000002 \times 50$

$= .00001$

$= .00000052 \times .060$

$= .000000.3 \times 10 = .000003$

Therefore, Total inflow rate i.e. $Q_{(inflow)}$ = 0.00001+0.000003

$= .000013 m^2/sec/m$

$Assume\ that\ the\ diameter\ of\ perforation\ hole\ d$=.25 inches

$d = 6mm = .006m$

$$Area = \frac{\pi}{4}(.006)^2$$

$$Area = .000028m^2$$

Now,

$C = 0.62$

$Limiting\ leachate\ enterance\ velocity\ \ V_{ent} = \ .003\ (standard)$

$Now\ by\ Bernaulli's\ equation$

$$Q_b = C.A_b.V_{ent} m^3/sec$$

$$Q_b = 0.62 \times .000028 \times .03\ m^3/sec$$

$$Q_b = .00000052\ m^3/sec$$

$Therefore\ number\ of\ perforated\ pipes$ $\qquad N = \dfrac{Q_{inflow}}{Q_L}$

$N = 19.23 \approx 20\ holes$

$i.e. 10\ holes\ per\ m\ on\ each\ side\ of\ the\ pipe$

The perforation in HDPE collection pipe has been shown in Figure 10.8. The schematic of landfill with all its components has been illustrated in Figure 10.9& the summary of designing outcomes has been illustrated in Table 10.4.

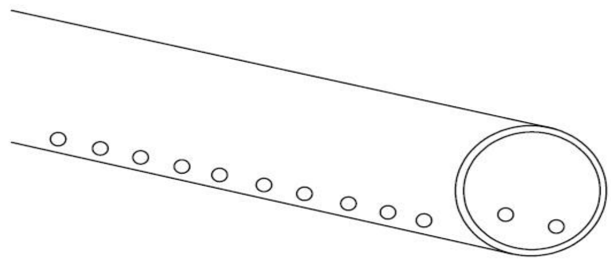


Figure 10.8: Perforations in HDPE leachate collection pipe

The summary of designing outcomes has been summarized in Table 10.4.

Table 10.4: Summary of designing outcomes

Designing Parameters	**Outcomes**
Waste generation per day	500 TPD
Total waste generation in 20 years	4380000 tons
Volume of waste	5152941.17 cu.m
Volume of daily cover	515294.117 cu.m
Volume of liner system	1288235.29 cu.m
Estimation of landfill capacity	6441176.46 cu.m
Height of landfill	10 m
Area required for landfill separation	644117.646 sq. m
Total area required	740735.293 sq. m
Active life of landfill	20 years
Liner system	HDPE geomembrane liner
Leachate generation rate	3.46×10-9 m3/day
Pipe perforations	10 holes per m on each side of the pipe

10.9 Surface Water Drainage

To minimise the generation of leachate and prevent the pollution of surface water sources at the site, each phase of the landfill shall be provided with adequate drainage system. The drainage has been designed to the maximum rainfall intensity. Further to avoid the entry of leachate into the stream flowing across the landfill site, RCC box culvert of adequate size is provided for the entire length of stream stretch that is passing through the site. At the upstream end of the stream, a silt trap and a bar screen are provided to the culvert, so that the silt deposition in the stream is minimised.

10.10 Water Quality Monitoring

Before establishing any landfill site, baseline data of ground water quality in the area shall be collected and kept in record for future reference. The ground water quality within 50 meters of the periphery of landfill site shall be periodically monitored to ensure that the ground water is not contaminated beyond acceptable limit as decided by the Ground Water Board or the State Board or the Committee. Such monitoring shall be carried out to cover different seasons in a year that is, summer, monsoon and post-monsoon period.

10.11 Plantation at Landfill Site

A vegetative cover shall be provided over the completed site in accordance with the following specifications -

1. Selection of locally adopted non-edible perennial plants that are resistant to drought and extreme temperatures shall be allowed to grow
2. The plants grown are such that their roots do not penetrate more than 30 cm. This condition shall apply till the landfill is stabilized
3. Selected plants shall have ability to thrive on low-nutrient soil with minimum nutrient addition. Plantation to be made in enough density to minimize soil erosion.

10.12 Closure of Landfill Site and Post-care

The post-closure care of landfill site shall be conducted for at least fifteen years and long-term monitoring or care plan shall consist of the following-

1. Maintaining the integrity and effectiveness of final cover, making repairs and preventing run-on and run-off from eroding or otherwise damaging the final cover
2. Monitoring leachate collection system in accordance with the requirement

3. Monitoring of ground water in accordance with requirements and maintaining ground water quality.

Summary

Open dumping of wastes has much detrimental and unfavorable impact on the environment. Hence, an engineered landfill system proves important measure for the waste disposal. The present chapter covers the planning and design considerations of a proposed sanitary engineered landfill system in Shimla, capital of Himachal Pradesh by adopting the guidelines of Environmental protection agency (EPA). The detailed design of the landfill system includes liner system, leachate collection system, gas monitoring system and final cover system. The study proposes the use of HDPE geomembrane as bottom line system to isolate the waste from the environment. This is due to the reason that it is made of high-density polyethylene having very less permeability and lesser leakage rate as compared to other liner systems. Further, in addition to the liner system, leachate collection system and landfill gas collection system has also been analyzed for landfill designing in the study and has been found that a large volume of gas is generated which can be further reused for energy applications. In the nutshell, it can be concluded that landfill design for Himachal Pradesh will promote effectiveness and efficacy of municipal solid waste management, thereby reducing the environmental impacts and hence ensuring public health and environment. This is in accordance with the GOI mission of Swachh Bharat Mission (Smart city) and the design also serves as an important treatment component for the waste generated for the Shimla to be considered as a smart city.

CHAPTER 11

CONCLUSIONS

11.1 General

This chapter embraces the summary of conclusions derived from all the investigations made throughout the study.

11.2 Conclusions

- It was concluded that the total waste generation in Himachal Pradesh is about 350 TPD and the waste generation rates in the study locations vary between 18 to 22 TPD with a collective efficiency of 60%. This indicates low collection efficiency and the hence the inadequate measures for existing waste management.
- The research utilized 'Wasteaware' benchmark parameters and the 'Matrix' system for examination of the existing MSW management practices for the respective selected locations in HP. The results obtained from the 'Wasteaware' benchmark analysis led to conclude that the existing waste management practices had *Low/Medium* efficiency. Quantification results obtained from matrix method showed that efficiency of the existing MSW practices at the study locations varied between *32 to 36%* and hence were deemed inadequate.
- It was further concluded from the study using 'Wasteaware' benchmark indicators that the recycling provisions were almost negligible in the study regions of Himachal Pradesh.
- Physical characterization of municipal solid waste determined at all the study locations varied between 50.40 to 55.35% leading to conclude that a high fraction of organics present in the sample. Further, the highest proportions were determined for Solan and Mandi since the dump sites in these two locations are adjacent to the fruit and vegetable markets of city and the rotten and degraded food products are directly dumped in the dumpsite leading to increased fraction.
- The seasonal variation in the biodegradable waste fraction were determined to be higher in summer and least in winter season because of high temperature and

consumption of more goods, fruits and vegetables in summer season at all the study locations.

- Other important conclusions obtained from the physical characterization were that paper was the second highest fraction varying between 10.60 to 19.74% at the study locations. The highest values were reported from Sundernagar because maximum number of schools, institutions, offices has been found in this region and least in Baddi due to industrial activities.
- It was further concluded from the physical characterization study that the average proportion of plastics varied between 5 to 15% in the study locations. The highest fraction of plastic waste was for Baddi region as it lies in between the boundary of Himachal Pradesh and Haryana state and the use of plastic is not banned in Haryana state thereby leading to 'spill-over effect'.
- It was concluded from chemical characterization study the presence of high values of moisture content varying between 42 to 51% at all the study locations due to high proportions of organic waste.
- Other important conclusions obtained from chemical characterization were that the overall ash content varied between 23 to 29% at the study locations. Its significance lies in its seasonal analysis wherein it was observed to be highest for winter season due to wood burning.
- It was further concluded from the chemical characterization that the average calorific value of the fuel of the MSW generated at the study locations varied between 2327-2667 kcal/kg and hence was suitable for generating energy.
- It was further concluded from the study that the potential for methane generation from the waste were about 15.78 of waste for Solan, 14.37 for Mandi, 13.87 for Sundernagar and 14.37 ppm methane /gm for Baddi.
- It was concluded from heavy metal analysis that presently they were within permissible limits with the exception of chromium at Baddi site due to increased industrial and pharmaceutical activities in the particular town.
- It was concluded from the study that the C: N ratio varied from 23.92 to 33.03 in the study locations and that the waste was amenable for composting.

- It was concluded from compost analysis at the two locations of Solan and Mandi that the classification of compost as per the FCO standards were under Class D and Class A respectively which suggested that compost generated from MSW of Solan region can be used for non-food crops etc. while the compost from Mandi could be used for high value crops.
- It was concluded from the geotechnical properties of contaminated soil due to leaching behaviour at all the study locations that some of proportion of contamination had taken place at the upper strata of soil but had not yet reached the lower layers of the soil. In particular the permeability of the contaminated soil was higher than the natural soil surrounding the dumpsite at all the study locations.
- It was concluded from the physico-chemical analysis of the leachate samples at all the study locations that the pH varied between 8.17 and 9.44 which were indicative of the methanogenic phase of the landfill.
- It was concluded from the LPI analysis that it varied between 14 and 22 at all of the study locations which exceeded the permissible values and indicated high toxicity levels of the leachate.
- It was concluded from the LPI analysis that there was a slight reduction in values from 17 to 15 due to transfer of 8 TPD of MSW from Solan dumpsite to Shimla dumpsite showing slight improvement but still exceeding the permissible limits.
- It was concluded from the WQI analysis that the groundwater was classified as '*poor quality*' and *good category* for the study regions of Solan, Mandi and Sundernagar and '*very poor*' and *fair* for Baddi region using the **OWQI methodology and NSF methodology respectively** within the *domain of 1Km* distance from the dumpsite (NSF).
- It was concluded from the WQI results using **BIS 10500** methodology that the study regions including Solan, Mandi, Sundernagar and Baddi are of *fair quality* within the vicinity of *1Km* distance from the dumpsite. However, it is perceived that at 2.5 Km downstream distance and thereafter the water quality of Solan, and Mandi shows good quality, Sundernagar shows excellent quality whereas Baddi town shows fair quality water up-to 3 km distance from the dumpsite. It is noticed that with increment in the distance from the dumping site, the water quality of Solan,

Sundernagar, Mandi and Baddi have shown significant improvement in the quality of groundwater.

- It was concluded likewise from the WQI analysis that there was a slight improvement in WQI values using all the three methods of analysis due to transfer of 8 TPD of MSW from Solan dumpsite to Shimla dumpsite.
- It was concluded from the HMPI study that the groundwater samples from Solan, Sundernagar and Baddi were above the critical index values for both WHO and BIS 10500 standards, whereas the HMPI of Mandi region showed comparatively lesser values than critical index values for both the standards.
- Multivariate statistical technique (PCA and HCA) suggests that the components of the PCA accounts for 87.81%, 90.08% 90.09% and 90.38% of the total variance in the dataset for Solan, Baddi, Mandi and Sundernagar study locations respectively. The Cluster analysis assist for the grouping of 16 parameters into three clusters i.e. Cluster 1 (low pollution region), cluster 2 (moderate pollution region) and cluster 3 (high pollution region) for each of the four sites including Solan, Mandi, Sundernagar and Baddi of Himachal Pradesh.
- It was concluded from the Life Cycle Assessment (LCA) study that scenario 1 (BAU condition) had the maximum potential environmental impacts whereas the proposed scenario 4 which is a combination of composting, material recovery facility and sanitary landfilling had the least environmental impacts. Scenario 1 and Scenario 4 had the highest and the lowest emission rates respectively when considered in terms of acidification potential, eutrophication potential, human toxicity potential and global warming potential.
- It was concluded from the sensitivity analysis that a small change in an input parameter would induce a large change in the impact category. It was determined that recycling proportions of 10, 50 and 90% induced in BAU conditions will considerably lower the life cycle emissions from the existing MSW management systems in all the study locations.
- Finally, a detailed landfill design was carried out for the study locations with a design life of 20 years and design waste of 500 TPD using the *valley method* of landfill design.

11.3 Future scope of the work

1. The characterization of municipal solid waste, leachate and groundwater assessment for rest of the regions in Himachal Pradesh.
2. The assessment of compost and its characterization analysis in various regions of Himachal Pradesh.
3. Field implementation of the best fit scenario for waste management in Himachal Pradesh i.e. Composting_ Material recovery facility Sanitary landfilling system.
4. Environmental impact assessment studies on open dumping of MSW in Himachal Pradesh.

REFERENCES

1. Hazra T., Goel S., "*Solid waste management in Kolkata, India: Practices and challenges*" Waste management, 29: 470-478, 2009.

2. Ahsan A., Alamgir M., El-Sergany M.M., Shams S., M., Rowshon M.K., Nik Daud N.N., *"Assessment of municipal solid waste management system in a Developing Country*", Chinese Journal of Engineering, 561935, 11. Http://Dx.Doi.Org/ 10.1155/2014/561935, 2014.

3. Joshi R., Ahmed S., "*Status and Challenges of Municipal Solid Waste Management in India: A Review",* Cogent Environmental Sciences, 2, 1139434, 2016.

4. Sharma A., Ganguly R., Gupta A.K., "Matrix method for evaluation of existing solid waste management system in Himachal Pradesh, India", J Mater Cycle Waste Management Article in Press, 2018 https://doi.org/10.1007/s10163-018-0703-z

5. Jha A., Sharma C., Singh N., Gupta P.K., "*Greenhouse gas emissions from municipal solid waste management in Indian mega-cities: A case study of Chennai landfill sites*". Chemosphere*, 71 (4), 750-758, 2008*.

6. Shekdar AV., "*Sustainable solid waste management: an integrated approach for Asian countries"*, Waste Management, 29(4):1438e48, 2009.

7. Sharholy M., Ahmad K., Mahmood G., Trivedi R.C., "*Municipal solid waste management in Indian cities – A review*", Waste Management, *28, 459-467, 2008*.

8. Ramachandra T.V., "*Municipal Solid Waste Management",* Teri Press, New Delhi, India, 2009.

9. World Bank "*What A Waste: Solid Waste Management in Asia*‖ Urban Development Sector Unit East Asia and Pacific Region, 1999, 2014.

10. World Bank "*What A Waste: Solid Waste Management in Asia*‖ Urban Development Sector Unit East Asia and Pacific Region, 2016.

11. Tchobanoglous G., Theisen H., Vigil S., "*Integrated Solid Waste Management*." Mcgraw-Hill Inc., New York, 2002.

12. TERI, "Urban Waste Management in Himachal Pradesh". Available online at http://www.teriin.org/projects/green/pdf/HP-Waste-management.pdf (Accessed on 02 May 2017 at 3.28 PM)

13. Talyan V., Dahiya R.P., Sreekrishna T.K., "*State of Municipal Solid Waste Management in Delhi, The Capital of India*" Waste Management, 28 (7):1276-1287, 2008.

14. Akhtar M.N., "*Prospective Assessment for Long Term Impact of Excessive Solid Waste Generation on the Environment*, International Journal of Advancement in Earth and Environmental Sciences, 2(2), Issn 2321 – 9149, 2014.

15. Rana R., Ganguly R., Gupta A.K., "*An assessment of Solid Waste Management in Chandigarh City, India,*" Electronic Journal of Geotechnical Engineering*, 20(6), 1547-1572, 2015*.

16. Kumar S., Bhattacharyya J.K., Vaidya A.N., Chakrabarti T., Devotta S., Akolkar A.B., "*Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: An insight*". Waste management*, 29, 883-895, 2009*.

17. Pappu A., Saxena M., Asolekar SR., "*Solid wastes generation in India and their recycling potential in building material*", Building and Environment, 42(6):2311e20, 2007.

18. Goel S., "*Municipal Solid Waste Management (MSWM) in India - A critical Review*. Journal of Environmental Science and Engineering*, 50(4), 319-328, 2008*.

19. Central Pollution Control Board (CPCB), "*Status of municipal solid waste generation, collection, treatment and disposal in class 1 cities".* New Delhi, India: CPCB; 2000.

20. Central Pollution Control Board (CPCB), Delhi "*Status of solid waste generation, collection, treatment and disposal in metro cities*" 2011, 2012, 2016.

21. NEERI, "*Assessment of status of municipal solid waste management in metro cities, state capitals, Class I Cities And Class Ii Towns - Annual Report*, 2010.

22. NEERI, "*Assessment Of Status Of Municipal Solid Waste Management In Metro Cities, State Capitals, Class I Cities And Class Ii Towns - Annual Report*, 2015.

23. Pokhrel D., Viraraghwan T., "*Municipal Solid Waste Management In Nepal: Practices And Challenges‖,* Waste Management, 25 (5): 555-562, 2005.

24. Mor S., Khaiwal R., Dahiya R.P., Chandra A., "*Leachate Characterization and Assessment of Groundwater Pollution near Municipal Solid Waste Landfill Site.*" Environmental Monitoring and Assessment, 435-456, 2006.

25. Alabi A., Mutiu Dowu Gboahan., Oyefuga H., Olalekan Sunday., M Rita., Olowokere Temitope., Osanaiye G., Folake Odiaka Stella., "*Assessing The Ground Water Quality In Sagamu Town, Ogun State, South West Nigeria.*" Iosr Journal of Environmental Science, Toxicology and Food Technology (Iosr-Jestft) E-Issn: 2319-2402, -ISSN: 2319-2399, Volume 6, Issue 3, 57-63, 2013.

26. Mufeed S., Kafeel A., Gauhar M., Trivedi R.C., "*Municipal Solid Waste Management In Indian Cities- A Review*." Waste Management 28, 459–467, 2008.

27. Ogoueleka T.C., "*Municipal solid waste characterization and management in Nigeria*". Iran Journal of environmental Health Science Engineering, 6: 173-180, 2009.

28. Olukanni D.O., Mnenga, M.U., "*Municipal solid waste generation and characterization: A Case Study of Ota, Nigeria*". International Journal of Environmental Science and Toxicology Research, 3, 1-8, 2015.

29. Sharma A., Ganguly R., Gupta A.K., "*Characterization of municipal solid waste in Sundernagar, Himachal Pradesh, India*. Research Journal of Pharmaceutical Biological and Chemical Sciences, 8(3):276e81, 2017.

30. Lebersorger S., P Beigl "*Forecasting Municipal Solid Waste Generation For Urban And Rural Regions‖,* Proceedings Of Xii International Waste Management And Landfill Symposium, Sardinia, Italy, 2009.

31. Rawat M., Ramanathan A.L., Kuriakose T., "*Characterization of municipal solid waste compost from selected from selected Indian cities - A case study for its sustainable utilization".* Journal of Environmental Protection, 4, 163-171. DOI: 10.4236/jep.2013.42019, 2013.

32. Talalaj I.A., "*Assessment Of Groundwater Quality Near The Landfill Site Using The Modified Water Quality Index*, Environmental Monitoring And Assessment 186(6):3673–3683, 2014.

33. Kalra N., Kumar R., Yadav S.S., Singh R.T., "*Water Quality Index Assessment of Ground Water in Koilwar Block of Bhojpur (Bihar),* Journal of Chemical and Pharmaceutical Research, 4(3), 1782-1786, 2012.

34. Cumar S.K.M., Nagaraja B., "*Environmental Impact of Leachate Characteristics on Water Quality",* Environmental Monitoring And Assessment, 178, 1, 499-505, 2011.

35. Tan S.T., Lee C.T., Hashim H., Ho Wo., Jeng J.S., "*Optimal Process Network for Municipal Solid Waste Management In Iskandar Malaysia*." Journal of Cleaner Production", 71:48–58, 2014.

36. Nash H.N., "*The Revised Directive on Waste: Resolving Legislative Tensions in Waste Management",* Journal of Environmental Law. 21.10.1093/Jel/Eqp001, 2009.

37. Olukanni D. O., Akinyinka M.O., Ede A.N., Akinwumi II, Ajanaku K.O., "*Appraisal of Municipal Solid Waste Management, Its Effect and Resource Potential in a Semi-Urban City: a Case Study"*. Journal of South African Business Research, 2014.

38. Olukanni D.O., "*Analysis of Municipal Solid Waste Management in Ota, Ogun State, Nigeria: Potential for Wealth Generation*". Proceeding of the 28thInternational Conference on Solid Waste Technology, 2013.

39. Khazaei E., Mackay R., Warner J.W., "*Investigation of Groundwater Quality Near A Municipal Landfill Site"*, International Journal of Chemical Engineering and Applications 3, 1- 6, 2012.

40. Nandan A., Yadav B.P., Baksi S., Bose D., "*Recent Scenario of Solid Waste Management in India"*, World Scientific News, 66, 56-54, 2017.

41. Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., Giusti, A., Yi, L., "*Municipal solid waste management in Pudong New Area, China"*, Journal of Waste Management, 29, 1227-1233. Doi:10.1016/j.wasman.2008.07.016.

42. Sethi, S., Kothiyal, N.C., Nema, K.A., Kaushik, M.K., *"Characterization of Municipal Solid Waste in Jalandhar City, Punjab, India"*, Journal of Hazardous, Toxic and Radioactive waste, 17(2), 97-106, 2013.

43. Manaf L.A., Samah M.A., A Zukki., N.I.M., "*Municipal Solid Waste Management in Malaysia: Practices and Challenges",* Journal of Waste Management 29, 2902–2906, 2009.

44. Kumar, S., Bhattacharyya, J.K., Vaidya, A.N., Chakrabarti, T., Devotta, S., Akolkar, A. B (2009), " *Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: An insight*". Waste Management, 29 (2), 883–895.

45. Pappu A., Saxena M., Asokar S.R., "*Solid Waste Generation in India and Their Recycling Potential in Building Material*, Journal of Buildings and Environment, 42 (6): 2311-2324, 2007.

46. Annepu, R.K., "*Sustainable solid waste management in India,* Waste-to-Energy Research and Technology Council (WTERT). City of New York: Columbia University" 2012, Retrieved from http://www.seas.columbia.edu/earth/wtert/sofos/.

47. Srivastava A., Jain V.K., "*Study To Characterize The Suspended Particulate Matter In An Indoor Environment In Delhi, India",* Building And Environment, 42, 2046-2052, 2007.

48. Srivastava R., Krishna V., Sonkar I., "*Characterization And Management Of Municipal Solid Waste: A Case Study Of Varanasi City, India."* Int Journal of Current Academic Review, 2(8):10–16, 2014.

49. Zerbock O., "*Urban Solid Waste Management: Waste Reduction In Developing Nations*." Www.Cee.Mtu,Edu, 2003.

50. Shivasharanappa, S. P., Huggi M.S., "*Assessment of Ground Water Quality Characteristics And Water Quality Index (Wqi) of Bidar City And Its Industrial Area, Karnataka State, India*", International Journal Of Environmental Science 2(2):965–976, 2011.

51. Wilson D.C., Rodic L., Cowing M.J., Velis C.A., Whiteman A.D., Scheinberg A., Vilches R., Masterson D., Stretz J.Z., Oelz B., "*Benchmark Indicators for Integrated & Sustainable Waste Management (ISWM)*" in Proceedings of ISWA World Congress, International Solid Waste Association, Vienna, Austria, October, 2013.

52. Wilson D.C., Rodic L., Cowing M.J., Velis C.A., Whiteman A.D., Scheinberg A., Vilches R., Masterson D., Stretz J.Z., Oelz B., "*Wasteaware benchmark indicators for integrated sustainable waste management in cities*" , Waste Management, 35, 329-342, 2015.

53. Yelda S., Kansal S., "*Economic Insight into Mswm In Mumbai: A Critical Analysis",* Environmental Pollution 19 (5), 516–527, 2003.

54. Yang Y., Campbell C.D., Clark L., Cameron C.M., Paterson E., "*Microbial Indicators of Heavy Metal Contamination in Urban And Rural Soils",* Chemosphere 63, 1942-195, 2006.

55. Olukanni D.O., "*Analysis of Municipal Solid Waste Management in Ota, Ogun State, Nigeria: Potential for Wealth Generation*". Proceeding of the 28th International Conference on Solid Waste Technology, 2013.

56. Olukanni D.O., Akinyinka M.O., Ede A.N.,.Akinwumi II, Ajanaku K.O., "*Appraisal of Municipal Solid Waste Management, Its Effect and Resource Potential in a Semi-Urban City: a Case Study"*. Journal of South African Business Research, 2014.

57. Khatib I.A., "*Municipal Solid Waste Management in Developing Countries: Future Challenges and Possible Opportunities",* Integrated Waste Management Volume 2, 2011.

58. Couth B., Trois C., "*Carbon Emissions Reduction Strategies In Africa From Improved Waste Management- A Review",* Waste Management, 30, 2347-2353, 2010.

59. Katiyar R.B., Suresh S., Sharma A.K., "*Characterisation of Municipal Solid Waste Generated by The City of Bhopal, India*", International Journal of Chem Tech Research 5 (2): 623-628, 2013.

60. Katherine, Z., Greyson, G., Cameron, M., Caitlin, S., Lauren, T., Dori, C., "*Plastic film recycling initiative*". UNC institute for the environment. ENST 698 Environmental Capstone. Spring, 2009.

61. Akhtar M.N., "*Prospective Assessment for Long Term Impact of Excessive Solid Waste Generation on The Environment",* International Journal of Advancement in Earth And Environmental Sciences, Vol.2, No. 2, Issn 2321 – 9149, 2014.

62. Mazumdar, N.B., "Composting municipal solid waste: The Indian scenario". International Journal of Environment Technology and Management, 7, 326-350, 2007.

63. Manohara B., Belagali S.L., "*Evaluation of Energy Dispersive Scanning Electron Microscopy and X-Ray Fluorescence Techniques for Analysis of Compost Quality*". Royal Society of Chem. DOI: 101039/c6ay02586b, 2016.

64. Manohara B., Belagali S.L., Ragothama S., "*Study of decomposition pattern during aerobic composting of municipal solid waste by physico-chemical and spectroscopic method*. International Journal of ChemTech Res. 10, 27-34, 2017.

65. Code A., Gonzenbach B., "Solid Waste, Health and Millennium Development Goals", A Report of Cwg International Workshop, Kolkata, India, 2006.

66. Kiran B.M., Srikantaswamy S., "*Heavy metals assessment in municipal solid waste dumpiste, Mysore, Karnataka, India*. International Journal of Ad Res in Engg and Tech. 5, 88-93, 2014.

67. Saha J.K., Panwar N., Singh M.V., "An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices". *Waste Management*, 30(2), 192–201, 2010.

68. Rawat M., Ramanathan A.L., Kuriakose T., "Characterization of municipal solid waste compost from selected from selected Indian cities - A case study for its sustainable utilization". *Journal of Environmental Protection, 4, 163-171. DOI: 10.4236/jep.2013.4201*9, 2013.

69. Mautairi S.O., Ghoneium A.M., Modaihsh A.S., Mohjoub M.O., Abdul-Aziz R.A., "*The characterization and composting of the municipal solid waste of Riyadh city, Saudi Arabia*". Ecology and the Environment, 180, Doi: 10.2495/WM140241, 2014.

70. Vuai S.A., "*Characterization of MSW and related waste derived compost in Zanzibar municipality*. Journal of Waste Management Resources, 28(2):177-184. Doi: 10.1177/07342x09335699, 2010.

71. Epelde L, Jauragi L., Urra J., Ibarratxa L., Romo J., Goikoetxea I., Garbisu C., "*Characterization of composted organic amendments for agricultural use,* Journal of Frontier Sustainable Food System, 2018. http://doi.org/10.3389/fsufs.2018.00044

72. Ambade B., Sharma S., Sharma Y., Sharma Y., "*Characterization and open windrow composting of MSW in Jodhpur city, Rajasthan, India*", Journal of Environment Science and Engineering, 55 (3): 351-358, 2013.

73. Goswami U., Sarma H.P., "*Study of the impact of municipal solid waste dumping on soil quality in Guwahati city*, Journal of Pollution Research, 27(2):327-330, 2008.

74. Raman N., Sathiya Narayanan D., "*Impact of solid waste effect on groundwater and soil quality nearer to Pallavaram solid waste landfill site in Chennai, Rasayan* J. Chem, 1(4): 828-836, 2008.

75. Pillai S., Peter A.E., "*Soil Pollution near a Municipal Solid Waste Disposal Site in India*", International Conference on Biological, Civil and Environmental Engineering (BCEE-2014) March 17-18, Dubai (UAE), 2014.

76. Roseta E., Kelechi L., "*Heavy metal content and physicochemical properties of municipal solid waste dump soils in Owerri Imo stat*e". International Journal of Modern Engineering Research, 2(5), 3795-3799, 2012.

77. Salami L., Fadayini M.O., Madu. C "*Assessment of a Closed Dumpsite and its Impact on Surface and Groundwater Integrity: A Case of Oke Afa Dumpsite, Lagos, Nigeria*" International Journal of Research and Review in Applied Science, 18(318), 2014.

78. Zainol N.A., Aziz H.A., Yusoff M.S., "*Characterization Of Leachate From Kuala Sepetang And Kulim Landfills: A Comparative Study",* School of Civil Engineering, University Sains Malaysia", Energy And Environment Research, 2(2), 45-52, 2012.

79. Sujatha E.R., Gurucharan R., Ramprasad C.S., Sornakumar V., "*Impact of municipal solid waste dumping on the geotechnical properties of soil and groundwater in Ariyamangalam, Trichy, India*". Electronic Journal of Geotechnical Engineering, 18:2119e32, 2013.

80. Khaiwal R., Kaur K., Mor S., "*System Analysis Of Municipal Solid Waste Management In Chandigarh And Minimization Practices For Cleaner Emissions.*" Journal of Cleaner Production Doi: 10.1016/J.Jclepro.2014.10.036, 2014.

81. Jayakrishnan T., Jeeja Mc., Bhaskar R., ―*Occupational Health Problems Of Municipal Solid Waste Management Workers In India",* International Journal of Environment Health Engineering, 2:42, Downloaded Free From Http://Www. Ijehe.Org On 21 Sept 2016 (Ip: 117.220.104.196), 2013.

82. Nanda H.S., Shivaraju R., Ramakrishnegowda C., "*Impact of municipal solid waste disposal on geotechnical properties of soil*". In: Proceedings of Indian geotechnical conference. Indian Geotechnical Society, 715e6, 2011.

83. Kanmani S., Gandhimethi R., "*Investigation of physicochemical characteristics and heavy metal distribution profile in groundwater system around the open dumpsite*". Journal of Applied Water Science, 3:387-399, 2013.

84. Akinbile O., Christopher Yusoff S., Mohd., "*Environmental Impact of Leachate Pollution on Groundwater Supplies In Akure, Nigeria",* International Journal of Environmental Science And Development, 2(1), Issn: 2010-0264, 2011.

85. Akinbile C.O., Yusoff M.S., Shian L.M., "*Leachate Characterization And Phytoremediation Using Water Hyacinth(Eichorrnia Crassipes) In Pulau Burung, Malaysia*", Bioremediation Journal, 16, 1,9-18, 2012.

86. Lone I.H., Kumar A., Khan F., Saxena S., Dar A.I., "*Evaluating the effect of landfill leachate on groundwater quality in relation to physicochemical and bacteriological characteristics*", Journal of Chemical and Pharmaceutical Research, 4 (12): 5202-5214, 2012.

87. Rana R., Ganguly R., " *Solid Waste Management in Chandigarh – A Case Study,* Journal of civil Engineering and Environmental Technology, 1(4): 67-70, 2015.

88. Longe, E.O. and L.O. Enekwechi , "*Investigation on potential groundwater impacts and influence of local hydrogeology on natural attenuation of leachate at a municipal landfill"*. Int. J. Environ. Sci. Tech., 4(1):133-140, 2007.

89. Jhamnani B., Singh S.K. (2009), "Groundwater contamination due to Bhalaswa landfill site in New Delhi". *International Journal of Environmental Science Engineering*, 1(3): 121-125.

90. Renou S., Givaudan G.J., Poulain S., Dirassouyan F., Moulin P., "Landfill Leachate Treatment: Review and Opportunity". Journal of Hazardous Materials, 150: 468–493, 2008.

91. Pandey Bk., Vyas S., Pandey M., Gaur A., "*Municipal Solid Waste To Energy Conversion Methodology As Physical, Thermal, And Biological Methods",,* Current Science Perspective 2(2) 39–44 (Issn: 2410-8790), 2015.

92. Kumar D., Alappat B.J., "*Evaluating Leachate Contamination Potential Of Landfill Sites Using Leachate Pollution Index*", Clean Technologies And Environmental Policy, 7, 3, 190–197, 2005.

93. Kumar D., Alappat B.J., "*Selection of the Appropriate Aggregation Functions for Calculating Leachate Pollution Index.* Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 8, 4, 253–264, 2004.

94. De S., Maiti S.K., Hazra T., Debsarkar A., Dutta A., "*Leachate characterization and identification of dominant pollutant index for an uncontrolled landfill site*". Journal of Environmental Science Management, 2(2): 177-186, 2016.

95. Yusoff N., Haraguchi A., Hassan M.A., Othman M.R., Wakisaka M., Shirai Y., "*Measuring organic carbon, nutrients and heavy metals in rivers receiving leachate from controlled and uncontrolled municipal solid waste (MSW) landfills*". Waste Management, 29: 2666–2680, 2009.

96. Fang J.J., Yang N., Cen D. Y., Shao L. M., He P. J., "*Odour compounds from different sources of landfill: characterization and source identification*". Waste Management, 32(7): 1401–1410, 2012.

97. Nguyen T.A.H., Ngo H.H., Guo W.S., Zhang J., Liang S., Yue Q.Y., Li Q., Nguyen T.V., "*Applicability of agricultural waste and by-products for adsorptive removal of heavy metals from wastewater*", Bioresource Tech., 148: 574–585, 2013.

98. Awaz B.M. (2015), "*Leachate and groundwater assessment at Kirkuk sanitary landfill site in Zindana Village, Iraq*". International Journal of Environment Resources, 9(2): 457-466.

99. Raman N. , Sathiya Narayanan D., "*Impact of solid waste effect on groundwater and soil quality nearer to Pallavaram solid waste landfill site in Chennai, Rasayan* Journal of Chem, 1(4): 828-836, 2008.

100. Kalra N., Kumar R., Yadav S.S., Singh R.T., "*Water Quality Index Assessment of Ground Water in Koilwar Block of Bhojpur (Bihar)",* Journal of Chemical and Pharmaceutical Research, 4(3), 1782-1786, 2012.

101. Swamee P.K, Tyagi A., "*Improved method for aggregation of water quality sub-indices*", Journal of Environmental Engineering, 133(2):220-225, 2007.

102. Singh A., Chandra S., Kumar Gupta S., Chauhan L.K., Kumar Rath S., "*Mutagenicity of leachate from industrial solid waste using salmonella reverse mutation assay*". Ecotoxical Environment Safety, 66 (2): 210-6, 2007.

103. Parameswari K., Mudgul B.V., Nelliyat P., "*Evaluation of groundwater contamination and its impact: an interdisciplinary approach*," Journal of Environmental Engineering, 14(2): 725-744, 2012.

104. Bogale D., Kumie A., Tefera W., "*Assessment of Occupational Injuries Among Addis Ababa City Municipal Solid Waste Collectors: A Cross-Sectional Study*", Bmc Public Health. 14:169. Doi: 10.1186/1471-2458-14-169, 2014.

105. Bundela S.P., Sharma B.A., Pandeyc k.A., Pandeya P., "*Physico chemical analysis of ground water near municipal solid waste dumping sites in Jabalpur*" International Journal of Plant, Animal and Environmental Sciences 2(1): 217-222, 2012.

106. Rathod M., Mishra H., Karmakar S., "*Leachate Characterization and Assessment of Water Pollution Near Municipal Solid Waste Landfill Site*", International Journal of Chemical and Physical Science, 2,186-189, 2013.

107. Bhalla G., Swamee P.K., Kumar A., Bansal A., "*Assessment of ground water quality near municipal solid waste landfill by an Aggregate Index Method*", *International Journal of Environmental Sciences*, 2(2): 1492-1503, 2012.

108. Nawaf Al., Asman A., Ali El-B., "*Application of Water Quality Index to Assess the Environmental Quality of Kuwait Bay",* International Conference on Advances in Agricultural, Biological & Environmental Sciences (Aabes-2014), Dubai (Uae), 2016.

109. Zhao Y., Christensen T., Lu W., Wu H., Wang H., "*Environmental Impact Assessment of Solid Waste Management in Beijing, China"*, Waste Management, 31 (4), 793-799, 2011.

110. Sharma B.K., Chandel M.K., "*Life Cycle Assessment of Potential Municipal Solid Waste Management Strategies for Mumbai, India",* Waste Management and Research, 1-13, Doi: 10.1177/0734242x16675683, 2016.

111. Mendes M.R., Aramaki T., Hanaki K., "*Comparison of Environmental Impact Of Incineration And Landfilling In Sao Paolo City As Determined By LCA",* Resource, Conservation And Recycling, 41, 47-63, 2004.

112. Mc Dougall F., White P., Franke M., Hindle P., "*Integrated Solid Waste Management: A Life Cycle Inventory",* 2nd Edition, Blackwell Science, 2001.

113. Aljaradin M., Persson K.M., "*Comparison of Different Waste Management Technologies and Climate Change Effect - Jordan",* American Journal of Climate Change, 1, 57-63, Http://Www.Scirp.Org/Journal/Ajcc, 2012.

114. Song Q., Wang Z., Jinhui Li., "*Environmental Problems of Municipal Solid Waste Strategies Based on LCA Method: A Case Study of Macau",* Journal of Cleaner Production 57, 92- 100, 2013.

115. Babu G.L.S., Lakshmikanthan P., Santhosh L.G., "*Life Cycle Analysis of Municipal Solid Waste (Msw) Land Disposal Options in Bangalore City",* Icsi 2014: Creating Infrastructure For A Sustainable World © Asce, 2014.

116. Yadav P., Samadder S.R., "*Life Cycle Assessment of Solid Waste Management Options: Review",* Recent Research in Science and Technology, 6,1, 2014.

117. Zarea M.A., "*Life cycle assessment for municipal solid waste management: a case study from Ahvaz, Iran*. Environmental Monitoring Assessment 191(3):131. Doi: 10.1007/s10661-99-7273-y, 2019.

118. Abeliotis K, "*Life cycle assessment in municipal solid waste management*". Journal of Integrated waste management. Doi: 10.5772/20421, 2011.

119. Kavitha R., Elangovan K., "*Ground Water Quality and Characteristics at Erode District, Tamil Nadu, India‖,* International Journal of Environment Science, 1, (2), Issn:0976-440, 2010.

120. Sharma, D., Ganguly, R., "*Parametric analysis of leachate and water resources around municipal solid waste landfill area in Solan*. 4th Inter Conf on Advanc in Engg& Tech (ICAET – 2016). http://Doi.org/1051/matecconf/20165703011, 2016.

121. Wanwari S, Thakur I.S., Vijay V.K., Ghosh P., *"Scenario of landfilling in India: Problems, Challeneges and Recommenedations*". Journal of Environmental Materials Management, 2018. Doi: http://10.1007/978-3-319-58538-3-167-1.

122. Yedla S., "*Modified landfill design for sustainable waste management"*. International Journal of Global Energy Issues, 23(1), 93-105, 2009.

123. Hettiaratchi J.P.A., Soh I.E.T., Hunte C., "*Evaluation of an alternative material of leachate collection system design*", Journal of Waste Management, 13(3):156-164, 2009.

124. Stark T.D., Newman E.J., "*Design of landfill final cover System*", Geosynthetics International, 17(3):124-131, 2010.

125. Reddy K.R., Stark T.D., Marella A., "*Beneficial use of shredded tires as drainage material in cover systems for abandoned landfill*", Proceeding of Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 149(1):47-60, 2010.

126. Xu Q., Kin H., Jain P., Townsend T.G., "*Hydrologic evaluation of landfill performance (HELP) modelling in bioreactor landfill design and permitting*", Journal of Waste Management, 14(1):38-46, 2011.

127. Xu Q., Tolaymat T., Townsend T.G., "*Impact of pressurized liquids addition on landfill slope stability*", Journal of Geotechnical and Geo environmental Engineering, 138(4):472-480, 2012.

128. Feng S, Jiang WK., Li Xi, Gao Li Ya. "*Estimation of maximum saturated depth in two-layered drainage blanket over the barrier in landfill cover system*". Journal of Environmental Earth Sciences, 70(6). Doi: 10.1007/s12665-013-2817-x, 2012.

129. Naval S., Kaushik M.K., Verma S. (2014), "*Characteristics and hydraulic performance assessment of different size tyre chips and geotextile to be used as drainage layer in MSW landfill,* International journal for science and emerging technology, 14(1): 1-6.

130. Machad S.L., Fard M.K., Carvalho M.F., Vilar O.M., Santos A.C. (2014), "*MSW characteristics and landfill performance in tropical regions*", International journal of Civil Engineering, 12(3):238-250.

131. Yanful E. K., Quigley R. M., Nesbitt H.W., "*Heavy Metal Migration at A Landfill Site, Sarnia, Ontario, Canada- 2: Metal Partitioning and Geotechnical Implications*", Applied Geochemistry 3, 623-62, 1998.

132. Wu C.S., Hong Y.S., Yan Y.W., Chang B.S., "*Soil-nonwoven geotextile filtration behaviour under contact with drainage material",* Journal of Geotextiles and Geomembranes, 24(1):1-10, 2006.

133. Nagarajappa D.P., Rashmi B.N., "*Engineering landfill design for municipal solid waste management, Bangalore*. International Journal of Engineering Research & Technology. 4(2), 1117-1120, 2015.

134. Pamnani A., Srinivasarao M., "*Municipal Solid Waste Management in India: A Review and Some New Results",* International Journal of Civil Engineering (IJCIET), 5(2), 01-08, 2013.

135. Agrawal, A., Pandey, R., Agrawal, M.L., "*Water quality surrounding to MSW dumps of Raipur city - A case study*". Recent Research in Science and Technology,5, 7-11,2013.

136. Sharma A., Ganguly R., Gupta AK., "*Characterization of municipal solid waste in Sundernagar, Himachal Pradesh, India*. Research Journal of Pharm Bio Chem Science 8:276, 2017. https ://doi.org/10.4236/jep.2013.4 2019.

137. Bharti, O., Singh, A., Singh, D.P., Sood, V. (2014), "*Effective Municipal Solid Waste Management Practices: A case study of Shimla, Himachal Pradesh, India*." Waste Management and Resource Utilization, 1, 173-182.

138. Al-Khadi S., "*Assessment of Ground Water Contamination Vulnerability in the Vicinity of Abqaiq Landfill- A Gis Approach, Dissertation*", King Fahad University of Petroleum and Minerals, Saudi Arabia.

139. Moya, D., Aldas, C., Loper, G., Kaparju, P., "*Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using Waste-to-Energy technologies*". 9th International Conference on Sustainability in Energy and Buildings, SEB-17, Chania, Crete, Greece, Energy Procedia, 134, 286-295, 2017.

140. Chang, N.B., Pires, A., Martinho, G, *"Empowering Systems Analysis for Solid Waste Management: Trends and Perspectives*". Critical Reviews in Environmental Science and Technology, 41(16), 1449-1530, 2011.

141. Hancs, A., Novak, P., Dvorak, M., Habart, J. Svehla, P., "*Composition and parameters of household bio-waste in four seasons*". Waste Management, 31(7), 1450 –1460, 2011.

142. Thakur I.S., Ghosh P., Gupta A., "*Combined Chemical and Toxicological Evaluation of Leachate From Municipal Solid Waste Landfill Sites Of Delhi, India*", Environmental Science And Pollution Research Doi 10.1007/S11356-015-4077-7, 2015.

143. Lohri C.R., Camenzind, E.J., Zurbrugg C., "*Financial sustainability in municipal solid waste management-costs and revenues in Bahir Dar, Ethiopia*". Waste Management, 34 (2), 542-552, 2014.

144. ASTM D5231-92, "*Standard test method for determination of the composition of unprocessed municipal solid waste*". ASTM International, West Conshohock PA, 2008.

145. ASTM D. 1102-84, "*Standard test method for ash in wood*". American Society for Testing and361 Materials, West Conshohocken, PA, 2013.

146. ASTM D. 3176-09, "*Standard practice for ultimate analysis of coal and coke*". ASTM International, West Conshohocken, PA, 2002.

147. ASTM E1756-08, "*Standard Test Method for Determination of Total Solids in Biomass*", ASTM International, West Conshohocken, PA, 2015.

148. ASTM E872-82, "*Standard Test Method for Volatile Matter in the Analysis of Particulate359 Wood Fuels*", ASTM International, West Conshohocken, PA, 2013.

149. ASTM D. 5198-09 (2003), "*Standard practice for nitric acid digestion of solid waste*". ASTM International, West Conshohocken, PA.

150. Rana, R., Ganguly, R., Gupta, A.K., "*Physico-chemical characterization of solid waste management from Tricity region of northern India*". Journal of Material Cycles and Waste Management, 20(1), 678-689, 2018.

151. Nakibuuka M M, Tashobya D, Banadda N, Ayaa F, Nhapi I, Wali GU, Kimwaga R, "*New method for qualitative determination of methane gas at selected sites in Kampala city, Uganda*", Open Environmental Engineering Journal, 5, 50-55, 2012.

152. Mboowa D, Quereshi S, Bhattacharjee C, Tonny K, Dutta S., "*Qualitative determination of energy potential and methane generation from municipal solid waste (MSW) in Dhanbad (India)*". Energy, 123, 386-391, 2017.

153. Srivastva, R., Krishna, V., Sonkar, I., "*Characterization and management of municipal solid waste: a case study of Varanasi city, India*". International Journal of Current Research and Academic Review, 2(8), 10-16, 2014.

154. Das, S., Bhattacharyya, B.K., "*Estimation of Municipal Solid Waste Generation and Future Trends in Greater Metropolitan Regions of Kolkata, India*." Industrial Engineering and Management Innovation, 1, 31-38, 2014.

155. Katiyar R.B., Suresh S., Sharma A.K., "*Characterization of municipal solid waste generated by the city of Bhopal, India"*. International journal of ChemTech Research, 5(2), 623-628, 2013.

156. Pichtel J., "*Waste management practices: Municipal, Hazardous and Industrial*". 2ndedition Florida: CRC Press; 2014.

157. USEPA., "*A guide to the bio-solids risk assessments for the EPA, Part 503 Rule, United State Environmental Protection Agency, office of waste water management,* EPA/832-B-93-005-144, 1995.

158. Lee C.C., Hauffman G.L., "*Thermodynamics used in environmental engineering*". Chapter 2.1, Handbook of Environmental Engineering Calculations. McGraw-Hill Companies, New York, NY, 2.4-2.145, 2000.

159. Kazayuki Y, Katsuyuki M., "*Effect of organic matter applications on methane emission from some japnese paddy field".* Soil Science and Plant Nutrition, 36, 599-610, 2012.

160. Fricke, K, H. Santen, H, Wallmann, R., "*Comparison of selected aerobic and anaerobic procedures for MSW treatment".* Waste Management, 25, 799-810 2005.

161. Jouhara H., Czajczynska D., Ghazal H., Krzyzynska R., Anguilano L., Reynolds AJ., Spencer N., "*Municipal waste management systems for domestic use*". Energy, 139, 485-506, 2017.

162. Arena U., Di Gregorio F (2013). "*Element partitioning in combustion- and gasification-based waste-to-energy units"*. Waste Management, 33 (1142-1150), 2013.

163. Ashworth, D. C., Elliott, P., Toledano, M. B., "*Waste incineration and adverse birth and neonatal outcomes: a systematic review*", Environment International, 69, 120-132, 2014.

164. Wu M., Lin C., Zeng W., "*Effect of waste incineration and gasification processes on heavy metal distribution"*. Fuel Processing Technology, 125, 67-72, 2014.

165. Zafar S., "*Overview of Biomass Pyrolysis*". Available http://www.bioenergyconsult.com/tag/biofuels / Accessed online on 22nd November 2018 at 12.57 PM

166. Alessandro B. D., Amico, M. D., Desideri, U., Fantozzi., "*The IPRP (Integrated Pyrolysis Regenerated Plant) technology: From concept to demonstration*", Applied Energy, 101, 423-431, 2013.

167. Thakare, S., Nandi, S. (2016) "*Study on Potential of Gasification Technology for Municipal Solid Waste (MSW) in Pune City*". Energy Procedia, 90: 509-517, 2016.

168. Zhu, D., Asnani, P. U., Zurbrugg, C., Anapolsky, S., and Mani, S., "*Improving municipal solid waste management in India",* A source book for policymakers and practitioners, The World Bank, Washington, DC, 2008.

169. Andriamanohiarisoamanana F.J., Matsunami N., Yamashiro T., Iwasaki M., Ihara I., Umetsu K., "*High-solids anaerobic mono-digestion of riverbank grass under thermophilic conditions"*, Journal of Environmental Sciences, 52, 29-38, 2017.

170. Maria F., Barratta M., Bianconi F Placidi P. Passeri D., "*Aerobic digestion batch with liquid digestate recirculation and wet anaerobic digestion of organic waste: Comparison of system performances and identification of microbial guilds*". *Waste Management,* 59 (172-180), 2017.

171. Fernández-Rodríguez J., Pérez M., Romero, L. I., "*Comparison of mesophilic and thermophilic dry anaerobic digestion of MSW: Kinetic analysis*" Chemical Engineering Journal, 232: 59-64, 2013.

172. Krishna K.V., Reddy V., Rao P. *"Municipal solid waste management using landfills in Hyderabad city".* International Journal of Engineering Research & Technology, 4, 1047-1054, 2015.

173. Sudharmaidevi CR, Thampatti KCM, Saifudeen N (2017) Rapid production of organic fertilizer from degradable waste by thermochemical processing. International Journal of Recycling of Organic Waste in Agriculture 6:1–11. https://doi.org/10.1007/s4009 3-016-0147-1.

174. Gómez G. Meneses M., Ballinas L., Castells F., *"Characterization of urban solid waste in Chihuahua, Mexico"*, Waste Management, 28(12), 2465–2471, 2008.

175. Giusti L., "*A review of waste management practices and their impact on human health".* Waste Management, 29(8), 2227–2239, 2009.

176. Jacob, N.A., Dharmendra., "*Municipal solid waste management case studies in India: A review"*. International Journal of Modern Trends in Engineering and Research, 3(5), 254-261, 2016.

177. Ingelmo F., Jose M.M., Desamparados S.M., Gallardo A., Lapen L., "*Influence of organic matter transformations on the bioavailability of heavy metals in a sludge-based compost",* Journal of Environment and Management, 95,104–109, 2012.

178. Mandal P., Chaturvedi M.K., Bassin J.K., Vaidya A.N., Gupta R.K., "*Qualitative assessment of municipal solid waste compost by indexing method*". International Journal of Recycling of Organic Waste in Agriculture, 3:133-139, 2014.

179. FAI, "*The Fertilizer Control Order 1985. The Fertilizer Association of India*", New Delhi, 2007.

180. IS 2720-26, "*Method of test for soil, Part 26: Determination of pH value*", 1986

181. IS 10580, "*Methods for analysis of solid waste*", 1982.

182. ASTM D 5198-09, "*Standard practice for nitric acid digestion of solid waste".* ASTM International, West Conshohocken, PA, 2003.

183. Adefemi S.O., Awokunmi E.E., "*The impact of municipal solid waste disposal in Ado Ekiti metropolis, Ekiti State, Nigeria*. Journal of Environment Science & Technology, 3, 186-189, 2009.

184. Sharma S., Shah K.W., "*Generation and Disposal of Solid Waste in Hoshangabad"*, Book of Proceedings of the Second International Congress of Chemistry and Environment, Indore, India, 749-751, 2005.

185. Amadi A.N., Olasehinde P.I., Okosun E.A., Okoye N.O., Okunlola I.A., Alkali Y.B., Hassan M.A., "A *Comparative Study on the Impact of Avu and Ihie Dumpsites on Soil Quality in South eastern Nigeria*". American Journal of Chemistry, 2(1): 17-23, 2012.

186. Nayak S., Sunil B.M., Shrihari S.., "*Hydraulic and Compaction Characteristics of Leachate Contaminated Lateritic Soil"*. Journal of Engineering Geology, Science Direct, 94: 137-144, 2007.

187. Aziz S.Q., "*Contamination valuation of soil and groundwater sources at anaerobic municipal solid waste landfill site*", 187: 755. doi 10.1007/s10661-015-4971-y, 2015.

188. Mojiri A., Aziz H.A., Zaman N.Q., Aziz S.Q., Zahed M.A., "*Metals removal from municipal landfill leachate and wastewater using adsorbents combined with biological method"*. Desalination and Water Treatment, doi: 10.1080/ 19443994.2014.983180, 2014.

189. Goswami U., Sarma H.P., "*Study of the impact of municipal solid waste dumping on soil quality in Guwahati city*. Journal of Pollution Research, 27(2): 327-330, 2008.

190. Adefemi B.A., Wole A.C., *"Geotechnical Characterisation of Abandoned Dumpsite Soil"*. Journal of Earth Science 2013; 2(3): 90-100, 2013.

191. Baun D.L., Christensen T.H., "*Speciation of Heavy Metals in Landfill Leachate: A Review*", Waste Management 22:3–23, 2004.

192. Vanlalmawii Esther., Awasthi Mamta., "*Municipal Solid Waste Composting- A Review"*, Proceedings of Irf International Conference, Goa, India, Isbn: 978-93-85973-54-3, 2016.

193. Kanmani S., Gandhimathi R., "*Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site*". App Wat Sc. 3:193-205. Doi: 10.1007/s13201-012-0072-z, 2013.

194. Lydie S.A.Y., Temitope D.T.O., Corentin Y.C.S., Evarsiste C.D.D. "*Urban cities and waste generation in developing countries: A GIS evaluation of two cities in Burbina Faso"*. J of Urban and Environ Engg, 7 (2), 280-285. Doi: 10.4090/june. 2013. v7n2.280285, 2013.

195. Przydatak G., Kanownik W., "Impact of small municipal solid waste landfill on groundwater quality". Env Mon Assess. 191-169. http://doi.org/10.1007/s10661-019-7279-5, 2019.

196. Srigirisetty S., Jayasri T., Netaji C., "Open dumping of municipal solid waste-Impact on groundwater and soil". Inter J of Curr Engg and Sci Res, 4(6): 26-33. http://troindia.in/journal/ijcesr/vol4iss6/26-33.pdf, 2017.

197. Talalaj I. A., "Assessment of groundwater quality near the landfill site using the modified water quality index". Envir Mon and Assess. 186(6):3673-3683. https://doi.org/10.1007/s10661-014-3649-1, 2014.

198. Ali S.M., Pervaiz P., Afzal B., Hamid N., Yasmin A., "Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city. J of King Saud Uni- Sci. 26, 59-65. http://doi.org/10.1016/j.jksus.2013.08.003, 2014.

199. Chonattu, J., Prabhakar, K., Pillai, H.P.S., "Geospatial and statistical assessment of groundwater contamination due to landfill leachate – a case study". J of Water Res and Prot. 8, 121-134. http://dx.doi.org/10.4236/jwarp.2016.8, 2016.

200. Subramani, T., Karthikeyan, C., Priyanka, S., "*Impact of solid waste in open dumping and its effects on groundwater and soil*". Inter J of app Inn Engg and Manag. 6 (5): 251-261. https://www.ijaiem.org/Volume6Issue5/IJAIEM-2017-05-24-25.pdf, 2017.

201. Asuma O.O., Aweto K.E., "Leachate characterization and assessment of groundwater and surface water qualities near municipal solid waste dumpsite in Effurun, Delta State, Nigeria". J of Environ and Earth Sci. 3 (9), 126-135, 2013. https://www.iiste.org/Journals/index.php/JEES/article/view/7333 .

202. Zhan T.L.T., Guan C., Xie H.J., Chem Y.M., "*Vertical migration of leachate pollutants in clayey soil beneath an uncontrolled landfill at Huainan, China: A field and theoretical investigation".* Sc of the Total Env. 470-471, 290-298. Doi: 10.1016/j.Scitotenv.2013.09.08, 2014.

203. Singh S., Raju N. J., Gossel W., Wycisk P., "*Assessment of pollution potential of leachate from the municipal solid waste disposal site and its impact on groundwater quality, Varanasi environs, India*". Arabian J of Geo. 9(2): 131.Doi: 1007/s12517-015-2131-x, 2016.

204. Talalaj I. A., Biedka P., "*Use of the landfill water pollution index (LWPI) for groundwater quality assessment near the landfill sites*". Environ sci and poll res. 23 (24): 24601–24613. https://doi.org/10.1007 /s11356-016-7622-0, 2016.

205. Bhalla B., Saini M.S., Jha M.K., 2014a., "*Leachate contamination potential of unlined municipal solid waste landfill sites by leachate pollution index".* Int J of Sci, Envir and Tech, 3, 2, 4, 444–457. http://www.ijset.net/journal/271.pdf, 2014 a.

206. Bhalla B., Saini M. S. Jha M. K., "*Assessment of municipal solid waste landfill leachate treatment efficiency by leachate pollution index*". Int J of Inn Res in Sc, Engg and Tech. 3, (1), 8447-8454, 2014 https://pdfs.semanticscholar.org/4a31/83384efeaa8f4a0b439084d2b9e038d085fa.pdf

207. Vathsalan A.B., Indu K.S., Ramasany E.V. "*Leachate pollution index – an effective tool in determining the phytotoxicity of municipal solid waste leachate*". J of Waste Manag., 68. Doi: 10.1016/j.wasman.2017.07.012, 2017.

208. Kumar D., Alappat B.J., "*Nsf-Water Quality Index: Does It Represent the Exerts' Opinion"* Practice Periodical of Hazardous, Toxic and Radioactive Waste Management, 13:75-79, 2009.

209. De, S., Maiti, S.K., Hazra, T., Debsarkar, A., Dutta, A., "*Leachate characterization and identification of dominant pollutants using leachate pollution index for an uncontrolled landfill site"*, Glob j of envir sci and manag. 2(2): 177–186. Doi: 10.7508/gjesm, 2016.02.008, 2016.

210. Hossain M.L., Das S.R., Hussain M.K., “*Impact of landfill leachate on surface and groundwater quality”*, J of Env Sc and Tech. 7 (6): 337-346. Doi: 10.3923/jest.2014.337.346, 2014.

211. Agbozu I.E., Oghama O.E., Odhikorij O., “*Physico-chemical characterization and pollution index determination of leachate from Warri waste dumpsite, Southern Nigeria*, J of App Sci. Envir Manag, 19 (3), 361-372. http://dx.doi.org/10.4314/jasem.v19i.4, 2015.

212. Ilaboya I. R., Oti E.O., Ekoh G.O., Umukoro L.O., Enamuotor B.O., “*Assessment of water quality index of some selected boreholes around dump sites in Nigeria*”, Int j of Environ Mon and Prot. 1(2): 47–55. http://www.openscienceonline.com/journal/ijemp, 2014.

213. Kolekar K., Hazra T., Chakrabarty S. N., “*A review on prediction of municipal solid waste generation models*”, Inter conf on solid waste manag. 5IconSWM, Procedia envirsc 35(238–244). http://doi.org/10.1016/j.proenv.2016.07.087, 2016.

214. Naminata, S., Koffi, K.E.K., Marcel, K.A., Marcellin, Y.K., “Assessment and impact of leachate generated by the landfill city in Abidjan on the quality of groundwater and surface water”, J of Water Res and Prot. 10, 145-165. Doi: 10.4236/Jwarp.2018.101009, 2018.

215. Krcmar D., Tenodi S., Grba N., Kerkez D., Watson M., Rancevic S., Dalmacijia B., “*Preremedial assessment of the municipal landfill pollution impact on soil and shallow groundwater in Subotica, Serbin*, Sc of The Total Env. 615, 1314-1354. http://doi.org/10.1016/J.Scitotenv.2017.09.283, 2018.

216. Badmus B.S., Ozebo V.C., Idowu O.A., Ganiyu S.A., Olurin O.T., “*Seasonal variations of physico chemical properties and quality index of groundwater of hand dug wells around Ajakanga dumpsite in Southwestern Nigeria”,* Res J of Physics. 9(1), 1-10. Doi: 10.3923/rjp.2015.1.10, 2015.

217. Milivojevic J., Kerstic D., Smit B., Djekic V., “*Assessment of heavy metal contamination and calculation of its pollution index for Ugljesnica River, Serbia*”. Bull of Envir Cont and Toxic. 97: 737-742.Doi: 10.1007/s00128-016-1918-0, 2016.

218. Wagh V.M., Panaskar D.B., Varade A.M., Mukate S.V., Gaikwad S.K., Pawar R.S., Muley A.A., Aamalawar M.L., “Major ion chemistry and quality assessment of the groundwater resources of Nanded tehsil, a part of southeast Deccan Volcanic Province, Maharashtra, India”, Environ Earth Sci. 75(21): 1418.Doi: 10.1007/s12665-016-6212-2.

219. Swamee T., Sharma S., Singh P., Dobhal R., "*Water quality assessment in terms of water quality index*". American J of Water Res. 1(3): 34–38. Doi: 10.12691/ajwr-1-3-3, 2013.

220. Gibrilla A., Bam E.K.P., Ayanu G., "*Application of water quality index (WQI) and Multivariate analysis for groundwater quality assessment of the Birimian and cape coast Granitoid complex: Densu River Basin of Ghana*". Water Qual Expo Health. 3, 63-78. Doi: 10.1007/s12403-011-0044-9, 2011.

221. Tirkey P., Bhattacharya T., Sukalyan C., "*Water quality indices – Important tool for water quality assessment: A Review*". Int J of Adv in Chem. 1 (1), 15-28. https://www.researchgate.net/publication/262730848, 2013.

222. Sayadi M.H., Ghaleno O.R., "*Study of water quality using the NSFWQI in the year 2014 case study: Chahnimeh reservoir of Sistan*". Int J of Chem st, 4 (3):35-37. https://www.researchgate.net/publication/304675442, 2016.

223. Zakhem, B.A., Hafez, R., "*Heavy metal pollution index for groundwater quality assessment in Damasaws Oasis*". J of Envir Earth Sc. 73(10), Doi: 10.1007/s12665-014-3882-5, 2014.

224. Manikandan S., Chidambaam S., Ramanathan A. L., Prasanna M. V., *"A study on the high fluoride concentration in the magnesium-rich waters of hard rock aquifer in Krishanagiri district, Tamil Nadu, India"*, Ar j of Geo. 7(1): 273–285. Doi: 10.1007/s12517-012-0752-x, 2014.

225. Bhuiyan M.A.H., Doza M.B., Islam A.R.M.T., Rabib M.A., Rahman M.S., Ramanashan A.L., "*Assessment of groundwater quality of Lakshimpur district of Bangladesh using water quality indices, geostatistical methods and multivariate analysis*", J of Environ Earth Sci 75:1020, 1-23. http:// doi. 10.1007/s1266-014-3822-5, 2016.

226. Ranjan R.K., Ramanathan A.L., Parthasarthy P., Kumar A., "*Hydro chemical characteristics of groundwater in the plains of Phaglu River in Gaya, Bihar, India*" Arj of Geosc. 6(9): 3257–3267.Doi: 10.1007/s12517-012-0599-1, 2013.

227. Jolliffe I.T., Cadima J., "*Principal component analysis: a review and recent developments",* The Royal Soc. A374: 20150202. http://dx.doi.org/10.1098/rsta.2015.0202, 2016.

228. Abd EI-Salam M.M., I. Abu-Zuid G., "*Impact of landfill leachate on the groundwater quality: A case study in Egypt".* J. Adv. Res. 6, 579-586. http://doi.org/10.1016/J.JARE.2014.02.003, 2015.

229. Loganathan K., Ahamed A.J., "*Multivariate statistical techniques for the evaluation of groundwater quality of Amaravati River Basin, South India*". J of App Water Sc. 7(8), 4633-464. http://link.springer.com/article/10.1007/s13201-017-0627-0 2017.

230. Yim O., Ramdeen K.T., "*Hierarchical cluster analysis: comparison of three linkage measures and application to psychological data*", J of Quant Methods for Psych, 11: 8-20. Doi: 10.20982/tqmp.11.10008, 2015.

231. Tiri A., Lahbari N., Boudokha A., "*Assessment of the quality of water by hierarchical cluster and variance analysis of the Koudia Medouar Watershed, East Algeria*", J of App Water Sc. 7(8), 4197-4206. http://10.1007/s13201-014-0261-z 2017.

232. WHO, "*Guidelines for Drinking-water Quality*", *Third edincorp the First and second addition Volume 1 Recommendations, 2008.*

233. WHO 2004 "*Guidelines for drinking water Quality*", 3rd Edn. Recommendation, Geneva, 1: 515, 2004.

234. Bureau of Indian Standards, "*Drinking water-specification*". New Delhi: Second Revision. Govt. of India, 2012.

235. Chidanand P., Shreekant N, Arjun V., "*Assessment of groundwater quality around solid waste landfill area - a case study*", Int J of Inn Res in Sci, Engg and Tech. 2, 7. ISSN: 2319-8753, 2013.

236. Longe E.O., Balogun M.R., "*Groundwater quality assessment near a municipal landfill, Lagos, Nigeria*, Journal of applied science, engineering and technology, 2(1): 39-44, 2010.

237. Salam M., Zuid G., "*Impact of landfill leachate on the groundwater quality: A case study in Egypt",* J of Ad Res. 6(4): 579-586. http://doi.org/10.1016/j.jare.2014.02.003, 2014.

238. ISO 14040, "*Environmental Management-Life Cycle Assessment- General Principles and Framework"*, International Organization for Standardization, Geneva, 2006.

239. Forastiere F., Badaloni C., Hoogh K.D., Kraus M.K.V., Martuzzi M., Mitis F., Palkovicova L., Porta D., Preiss P., Ranzi A., Perucci C.A., Briggs D., — *Health Impact*

Assessment of Waste Management Facilities in Three European Countries‖, Environmental Health, 10:53. Doi: 10.1186/1476-069x-10-53, 2011.

240. Faccio M., Persona A., Zanin G., "*Waste Collection Multi Objective Model with Real Time Tracebility Data*‖, Journal of Waste Management, 31, 2391- 2405, 2011.

241. Winkler J., "*Evaluation of Life Cycle Assessment Models for Solid Waste Management",* Phd Thesis, Tu Dresden, Dresden University, Germany, 127, 2004.

242. Winker J., Bilitewski B., "*Comparative Evaluation of Life Cycle Assessment Models for Solid Waste Management‖,* Waste Management, 27, 1021-1031, 2007.

243. Rajaeifar M., Tabatbaei M., Ghanavati S., Hossein., Rafiee S., "*Comparative Life Cycle Assessment of Different Municipal Solid Waste Management Scenarios in Iran",* Renewable and Sustainable Energy Reviews, 51, 2015.

244. Rana R., "*Characterization and analysis of Municipal solid waste in tricity*", PhD. Thesis, Jaypee University of Information Yechnology, Waknaghat, Solan, Himachal Pradesh, India, 2017.

245. Khorasani N., Naghibzadeh S., Ghadiryanfar M., Badehian Z., "*Life Cycle Assessment (Lca) of Municipal Solid Waste System of Karaj", 256,* 2012.

246. Mc Dougall F., White P., Franke M., Hindle P., "*Integrated Solid Waste Management: A Life Cycle Inventory",* 2nd Edition, Blackwell Science, 2001.

247. Saheri S., Masoud A.M., Noor E.A.M., Noor Z.B.M, Rawshan A.B., "*Life Cycle Assessment for Solid Waste Disposal Options in Malaysia",* Pol. J. Environ. Stud, 21 (5): 1377-1382, 2012.

248. Malla O.B., Khatiwada N.R., "*Life Cycle Assessment of Municipal Solid Waste Management System in Kathmandu Metropolitan City",* International Journal of Scientific and Engineering Research, 7 (10), Issn 2229-5518, 2016.

249. Mohapatra P., "*Improving Eco-Efficiencies of Amerstradam Water Supply: Lca Approach",* Int. Journal of Life Cycle Assessment, 21: 217-228, 2013.

250. Harrison G.P., Maclean E.N., Kalamanlis S., Ochoa L., "*Life Cycle Assessment of Transmission Network in Great Britain,* Energ Pol, 38(7), 3662-3631, 2011.

251. Velumani A., Meenakshi P., "*Life Cycle Inventory Analysis of Emissions from Solid Waste Management Scenarios in Coimbatore City",* In: Proceedings of International Conference on Sustainable Solid Waste Management, 5-7, 2007.

252. Ghosh P., Das M.T., Thakur I.S., "*Mammalian Cell Line-Based Bioassays for Toxicological Evaluation of Landfill Leachate Treated by Pseudomonas Sp. Ist df",* Environmental Science and Pollution Research, 21, 8084–8094, 2014a.

253. Ghosh P., Swati T., Thakur I.S., "*Enhanced Removal of Cod and Color from Landfill Leachate in A Sequential Bioreactor",* Bioresource Technology 170, 10–19, 2014b.

254. Lu H.J., Luan M.T., Zhang J.L., "*Study on Transport Of Cr (Iv) Through The Landfill Liner Composed Of Two Layer Soils",* Desalination 266(1–3), 87–92, 2011.

255. Meegoda J.N., Hettiarachchi H., Hettiarachchi J.P.A., "*Landfill design and operation",* Sustainable Solid Waste Management, 2016, DOI: 10.1061/9780784414101.ch18.

256. Qian X., Koerner R.M., Gray D.H., "*Geotechnical aspects of landfill design and construction"* 1st edition, ISBN 0-13-01250b-7, 2002.

257. Solid Waste Management Rules, 2000: S.O. 783 (E), 1999.

258. Solid Waste Management Rules, 2016: S.O. 1357 (E), 2015.

PUBLICATIONS

Journal Publications

1. Sharma, A., Ganguly, R., Gupta, A.K., "*Matrix Method for Evaluation of Existing Solid Waste Management System in Himachal Pradesh*", Journal of Material Cycles and Waste Management, 20 (3), 1813-1831, 2018. **(Springer Publications, Scopus/SCI Indexed).**

2. Sharma, A., Ganguly, R., Gupta, A.K., "*Impact of Open Dumping of Municipal Solid Waste on Soil properties in Mountainous Region",* Journal of Rock Mechanics and Geotechnical Engineering, 10 (4), 725-739, 2018. **(Elsevier Publications, Scopus Indexed).**

3. Sharma, A., Ganguly, R., Gupta, A.K. *"Spectral Characterization and Quality Assessment of Organic Compost for Agricultural Purposes",* International Journal of Recycling of Organic Waste in Agriculture, 8 (2), 197-213, 2019. **(Springer Publications, Scopus Indexed).**

4. Sharma, A., Ganguly, R., Gupta, A.K., "*Characterization and Energy Generation Potential of Municipal Solid Waste from Non-engineered Landfill Sites in Himachal Pradesh",* Journal of Hazardous, Toxic, and Radioactive Waste, 23 (4), 1-15, 2019 **(ASCE).**

5. Sharma, A., Ganguly, R., Gupta, A.K., "*Impact Assessment of Pollution Potential of Leachate on Ground water – An Index Method"* Manuscript Submitted to Journal of Environmental Engineering **(ASCE) (Accepted).**

Book Chapters

1. Sharma, A., Ganguly, R., Gupta, A.K., "Matrix method for evaluation of existing solid waste management processes in Jalandhar city, Punjab, India", In Agarwal R., Agarwal

A., Gupta T., Sharma N., Pollutants from Energy Sources: energy, environment and sustainability. (pp. 253 - 268). Singapore: Springer. [ISBN: 9783030027063], 2018.

2. Sharma, A., Ganguly, R., Gupta, A.K., "Comparative analysis of solid waste management processes in Himachal Pradesh and Punjab", In Singh H., Garg P., Kaur I., Proceedings of the 1st International conference on sustainable waste management through design. ICSWMD 2018. Lecture notes in Civil Engineering, Vol. 21 (pp. 343 – 352). Switzerland: Springer, Cham. [ISBN: 9783030027063], 2019.

3. Ganguly, Rajiv., Sharma, D., Sharma, A., Gupta, A.K., Gurjar, B.R., "Parametric evaluation of leachate generated from a non – engineered landfill site and its contamination potential of surrounding soil and water bodies", In Agarwal R., Agarwal A., Gupta T., Sharma N., Pollutants from Energy Sources: energy, environment and sustainability. (pp. 307 - 322). Singapore: Springer. [ISBN: 9789811332807] 2019.

Conference Proceedings

1. Ganguly, R., Sharma, D., Sharma, A., Gupta, A.K, "Evaluation of Contamination of Groundwater and Soil Characteristics of Non-engineered landfill Site", Proceedings of the International Conference on Sustainable Environment and Energy *(ICSEE-2017)*, Hindustan University, Chennai, India, April 6-7, 2017.

2. Sharma, A., Ganguly, R., Gupta, A.K., "Characterization of Municipal Solid Waste in Sunder Nagar, Himachal Pradesh, India", Proceedings of the International Conference on Recent Advances in Chemical, Environment and Energy Engineering *(RACEEE-2017),* SSN College of Engineering, Chennai, India, February 23-24, 2017.

3. Sharma, A., Ganguly, R., Gupta, A.K., "Evaluation of Existing Solid Waste Management Practices in Jalandhar, Punjab Using 'Wasteaware' Benchmark Indicators", Proceedings of the International conference on Waste Management *(ISWMAW-2017)*, PJTSAU, Hyderabad, Telangana, India, December 15-17, 2017.

APPENDIX-A

LIST OF SUPPLEMENTARY TABLES

Table 1: Heavy metal analysis of municipal solid waste in rainy season

Parameters	Solan	Mandi	Sundernagar	Baddi	Permissible limits [150]
Cadmium	0.71±0.04	0.78±1.08	0.61±0.05	1.06±0.06	5.00
Chromium	42.34±0.54	23.43±2.32	27.51±1.52	72.89±3.79	50.00
Copper	38.90±0.72	30.05±0.78	22.52±1.94	57.84±1.25	300.00
Iron	2418.70±12.76	2352.86±12.65	2072.05±47.15	4641.06±22.46	-
Manganese	29.45±3.12	24.43±0.06	18.29±1.62	37.12±4.75	-
Nickel	26.31±0.57	17.21±1.04	10.00±1.62	45.15±0.85	50.00
Lead	19.16±0.78	9.24±0.43	14.52±0.75	34.92±8.69	100.00
Zinc	39.28±1.92	31.20±0.75	36.78±4.52	47.00±1.64	1000.00

Note: All the units are in mg/kg

Table 2: Heavy metal analysis of municipal solid waste in winter season

Parameters	Solan	Mandi	Sundernagar	Baddi	Permissible limits [150]
Cadmium	0.84±0.07	0.74±1.23	0.68±0.34	0.90±0.07	5.00
Chromium	49.83±1.25	26.65±1.85	21.67±1.82	81.43±1.95	50.00
Copper	40.24±2.63	37.83±0.92	24.91±1.25	66.81±1.75	300.00
Iron	2498.03±11.69	2374.24±16.91	2179.09±39.16	4721.09±25.82	-
Manganese	54.52±2.64	26.39±2.83	39.18±1.72	82.32±6.82	-
Nickel	27.24±0.76	19.22±1.53	16.84±1.42	31.62±1.95	50.00
Lead	21.82±0.75	9.91±1.45	15.83±0.76	39.81±4.21	100.00
Zinc	42.65±2.12	35.92±2.57	32.21±5.63	51.72±1.92	1000.00

Note: All the units are in mg/kg

Table 3: Chemical characterization of municipal solid waste in rainy season

Proximate analysis of municipal solid waste					
Parameters	**Units**	**Solan**	**Sundernagar**	**Mandi**	**Baddi**
pH	-	6.62±0.27	6.18±1.29	6.32±0.76	6.12±0.35
Moisture content	% by wet weight	50.00±1.33	43.00±2.34	48.00±1.00	42.00±1.67
Ash Content	% by dry weight	23.80±0.33	25.67±0.78	26.59±1.66	30.08±1.33
Volatile matter	% by dry weight	24.28±2.54	28.38±1.33	22.16±1.66	23.65±1.67
Fixed carbon	% by dry weight	1.92±0.66	2.95±0.33	3.25±0.33	4.27±2.34
Calorific value	(kcal/kg)	2371±245.06	2592±129.00	2458±67.58	2612±194.82
Ultimate analysis of municipal solid waste					
Parameters	**Units**	**Solan**	**Sundernagar**	**Mandi**	**Baddi**
Carbon	% by dry weight	42.24±1.25	39.05±0.44	47.24±1.33	48.03±1.33
Nitrogen	% by dry weight	1.23±0.67	1.10±0.14	1.49±0.02	1.78±0.04
Hydrogen	% by dry weight	6.01±0.32	4.27±0.52	4.67±0.22	7.91±0.87
Potassium	% by dry weight	0.72±0.25	0.79±0.10	0.82±0.04	0.92±0.03
Phosphorus	% by dry weight	0.67±0.09	0.36±0.08	0.54±0.02	0.95±0.22
Sulphur	% by dry weight	0.20±0.02	0.15±0.02	0.22±0.03	0.29±0.05
Oxygen	% by dry weight	11.39±0.56	12.43±1.78	9.82±0.63	11.04±1.33
Mineral Content	% by dry weight	37.54±2.34	41.85±0.92	35.20±2.14	30.62±1.47
C/N	-	30.21±1.07	23.73±1.33	26.41±0.33	32.02±1.33

Table 4: Chemical characterization of municipal solid waste in winter season

Proximate analysis of municipal solid waste					
Parameters	**Units**	**Solan**	**Sundernagar**	**Mandi**	**Baddi**
pH	-	6.69±0.67	6.12±0.16	6.27±0.28	5.98±0.61
Moisture content	% by wet weight	48.00±1.33	42.00±2.82	44.00±4.26	40.00±1.66
Ash Content	% by dry weight	25.28±0.66	27.92±1.33	28.48±2.67	31.57±3.19
Volatile matter	% by dry weight	24.60±2.33	26.83±1.68	23.60±4.12	23.57±1.67
Fixed carbon	% by dry weight	2.12±0.33	3.25±0.98	3.92±0.56	4.86±0.33
Calorific value	(kcal/kg)	2327±82.68	2620±161.30	2542±98.53	2667±246.89
Ultimate analysis of municipal solid waste					
Parameters	**Units**	**Solan**	**Sundernagar**	**Mandi**	**Baddi**
Carbon	% by dry weight	39.95±1.98	38.34±0.88	42.40±1.31	46.83±1.27
Nitrogen	% by dry weight	1.18±0.33	1.04±0.33	1.33±0.02	1.62±0.89
Hydrogen	% by dry weight	7.89±1.03	6.83±0.77	5.67±0.33	8.54±1.02
Potassium	% by dry weight	0.79±0.33	0.91±0.33	0.88±0.33	0.97±0.03
Phosphorus	% by dry weight	0.82±0.33	0.42±0.06	0.71±0.02	0.99±0.33
Sulphur	% by dry weight	0.32±0.02	0.12±0.06	0.34±0.43	0.45±0.33
Oxygen	% by dry weight	13.04±1.28	12.36±0.94	10.41±0.34	9.06±1.22
Mineral Content	% by dry weight	32.14±2.32	36.58±2.68	32.09±1.02	29.0±0.54
C/N	-	31.83±1.84	26.89±1.67	28.02±1.67	33.93±2.83

Table 5: Advanced anaerobic digestion technologies to produce biogas, their advantages and Disadvantages [139]

Anaerobic digestion technologies	Operating temperature	Advantage	Disadvantage
Wet waste	Mesophilic (35–40 °C)	• Prior treatment services for improving the efficacy of biogas plants • Sludge generation is low	• Diffusion of the technology is low • Investment services are low • Low government subsidies
	Thermophilic (55–60 °C)	• Generation methane • Higher organic loading • Maintenance cost is low	• Volatile concentration is higher • Digesters are inadequate in numbers
Dry waste	Mesophilic (35°C)	• Volatile acids are lesser • Rate of micro-organisms are low • Organic content removal is high	• Reduction of cellulose and hemicelluloses are low • More time to acquire methane and organic content decomposition
	Thermophilic (55 °C)	• Greater reduction of cellulose and hemicelluloses • Lesser time to attain organic content decomposition • Coefficient of methane production is high.	• Growth of volatile acids • Specific growth rate of micro-organisms is high.

Table 6: Classification of MSW compost for their marketability and use in different area [179].

Sr. No.	Class	FI	CI	Quality control compliance	Remarks
1.	A	>3.5	>4.0	Complying for heavy parameters	Best quality, low heavy metal, used for high value crops
2.	B	3.1-3.5	>4.0	Complying for heavy parameters	Very good quality, medium fertilizing potential, low heavy metal
3.	C	>3.5	3.1-4.0	Complying for heavy parameters	Good quality, high fertilizing potential, medium heavy metal
4.	D	3.1-3.5	3.1-4.0	Complying for heavy parameters	Medium quality, medium fertilizing potential, medium heavy metal
5.	RU-1	<3.1	-	Complying for heavy parameters	Low fertilizing potential, Should not be allowed to market, only used as soil conditioner
6.	RU-2	>3.5	>4.0	Not complying for heavy parameters	Restricted use, Should not be allowed to market, used only for growing non-food crops
7.	RU-3	>3.5	-	Not complying for heavy parameters	Restricted use, Should not be allowed to market, used only for developing lawns/gardens

Table 7: Water quality rating as per OWQI, BIS and NSFWQI methods

OWQI	BIS	NSFWQI	Water quality rating
90-100	≤50	90-100	Excellent
85-89	50-100	70-90	Good
80-84	100-200	50-70	Fair
60-79	200-300	25-50	Poor
0-59	≥300	0-25	Very poor

Table 8: Physico-chemical characterization of Solan after reduction of waste load (April 2018)

Parameter	pH					TDS				
Distance (Km)	**1**	**2**	**2.5**	**3**	**4**	**1**	**2**	**2.5**	**3**	**4**
Value	7.47	7.4	7.36	7.32	7.11	372.4	351.8	346.3	322.6	312.4
Parameter	**TSS**					**COD**				
Distance (Km)	**1**	**2**	**2.5**	**3**	**4**	**1**	**2**	**2.5**	**3**	**4**
Value	8.57	8.03	6.18	5.89	4.76	3.29	2.84	2.71	2.39	2.08
Parameter	**BOD**					**Turbidity**				
Distance (Km)	**1**	**2**	**2.5**	**3**	**4**	**1**	**2**	**2.5**	**3**	**4**
Value	0.3	0.23	0.15	0.11	0.08	6	4	4	2	2
Parameter	**Phosphate**					**Sulphate**				
Distance (Km)	**1**	**2**	**2.5**	**3**	**4**	**1**	**2**	**2.5**	**3**	**4**
Value	0.039	0.024	0.02	0.016	0.011	39.89	24.34	23.18	22.62	21.15
Parameter	**Calcium**					**Magnesium**				
Distance (Km)	1	**2**	**2.5**	**3**	**4**	**1**	**2**	**2.5**	**3**	**4**
Value	136.4	128.6	121.9	116.4	104.8	62.9	53.4	51.6	44.8	36.3
Parameter	**Chlorides**					**Electrical Conductivity**				
Distance (Km)	**1**	**2**	**2.5**	**3**	**4**	**1**	**2**	**2.5**	**3**	**4**
Value	8.43	7.12	6.99	4.72	4.51	489.9	478.4	452.6	438.3	406.3
Parameter	**Ammonical Nitrogen**					**Nitrate**				
Distance (Km)	1	**2**	**2.5**	**3**	**4**	**1**	**2**	**2.5**	**3**	**4**
Value	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Parameter	**Fluoride**									
Distance (Km)	**1**	**2**	**2.5**	**3**	**4**					
Value	0.024	0	0	0	0					

Table 9: Relative weight of groundwater parameters for evaluation of WQI based on BIS

Sr. No.	Parameters	BIS (mg/l)	Weight (wi)	Relative weight (Wi)
1.	TSS	500	5	0.1
2.	NH_3 -N	0.5	5	0.1
3.	SO_4^{2-}	200	5	0.1
4.	TH	300	4	0.08
5.	Ca^{2+}	75	4	0.08
6.	Mg^{2+}	30	3	0.06
7.	TA	200	4	0.08
8.	NO_3^{2-}	45	5	0.1
9.	cl^-	250	5	0.1
10.	EC	300	5	0.1
11.	F^-	1	5	0.1
Summation of weights			50	1.00

Table 10: Heavy metal analysis based on seasonal variation of groundwater in study regions (mg/l)

Parameters (mg/l)	S1				S2				S3			
	Solan	Mandi	Sunder nagar	Baddi	Solan	Mandi	Sunder nagar	Baddi	Solan	Mandi	Sunder nagar	Baddi
Fe	0.228	0.197	0.017	0.854	0.271	0.246	0.022	0.887	0.279	0.273	0.027	0.923
Zn	0.132	0.111	0.108	0.729	0.185	0.124	0.115	0.753	0.263	0.133	0.162	0.769
Cu	0.038	0.019	0.011	0.082	0.051	0.020	0.053	0.083	0.052	0.022	0.058	0.088
Cr	0.284	ND	0.067	0.068	0.330	0.002	0.071	0.072	0.412	ND	0.072	0.076
Ni	0.004	0.002	ND	0.007	0.006	ND	ND	0.008	0.006	ND	0.002	0.112
Pb	0.027	0.013	ND	0.074	0.028	0.001	ND	0.089	0.033	0.001	0.003	0.103
Cd	0.019	0.010	0.016	0.029	0.022	0.015	0.021	0.035	0.025	0.018	0.026	0.036

Table 11: Correlation matrix for groundwater samples in Solan region

	TDS	TSS	COD	BOD	Turbidity	Phosphate	Sulphate	Calcium	Magnesium	Chlorides	Electrical Conductivity	Ammonical Nitrogen	Nitrate	Fluoride	Total Alkalinity	pH
TDS	1	0.80	0.66	0.81	0.80	0.80	0.16	0.80	0.84	0.77	0.82	0.73	0.58	0.48	0.757	0.85
TSS	0.80	1	0.78	0.95	0.95	0.90	-0.06	0.71	0.89	0.82	0.96	0.89	0.68	0.62	0.60	0.94
COD	0.668	0.78	1	0.85	0.68	0.83	-0.13	0.78	0.92	0.84	0.82	0.79	0.53	0.53	0.60	0.82
BOD	0.81	0.95	0.85	1	0.93	0.92	-0.08	0.77	0.92	0.85	0.93	0.93	0.67	0.58	0.67	0.95
Turbidity	0.80	0.95	0.68	0.93	1	0.86	-0.01	0.63	0.84	0.75	0.92	0.83	0.68	0.59	0.58	0.92
Phosphate	0.80	0.90	0.83	0.92	0.86	1	-0.08	0.79	0.93	0.93	0.94	0.93	0.56	0.71	0.64	0.96
Sulfate	0.161	-0.06	-0.13	-0.08	-0.01	-0.08	1	0.06	0.01	0.11	-0.03	-0.05	-0.02	-0.02	0.04	-0.01
Calcium	0.80	0.71	0.78	0.77	0.63	0.79	0.06	1	0.82	0.80	0.74	0.79	0.55	0.33	0.92	0.74
Magnesium	0.84	0.89	0.92	0.92	0.84	0.93	0.01	0.82	1	0.93	0.92	0.85	0.63	0.64	0.66	0.93
Chlorides	0.77	0.82	0.84	0.85	0.75	0.93	0.11	0.80	0.93	1	0.87	0.87	0.45	0.59	0.60	0.88
Electrical Conductivity	0.82	0.96	0.82	0.93	0.92	0.94	-0.03	0.74	0.92	0.87	1	0.90	0.66	0.71	0.62	0.97
Ammonical Nitrogen	0.73	0.89	0.79	0.93	0.83	0.93	-0.05	0.79	0.85	0.87	0.90	1	0.54	0.59	0.69	0.91
Nitrate	0.58	0.68	0.53	0.67	0.68	0.56	-0.02	0.55	0.63	0.45	0.66	0.54	1	0.29	0.55	0.60
Fluoride	0.48	0.62	0.53	0.58	0.59	0.71	-0.02	0.33	0.64	0.59	0.71	0.59	0.29	1	0.20	0.76
Total Alkalinity	0.75	0.60	0.60	0.67	0.583	0.64	0.04	0.92	0.66	0.60	0.62	0.69	0.55	0.20	1	0.63

Table 12: Correlation matrix for groundwater samples in Mandi region

	TDS	TSS	COD	BOD	Turbidity	Phosphate	Sulfate	Calcium	Magnesium	Chlorides	Electrical Conductivity	Ammonical Nitrogen	Nitrate	Fluoride	Total Alkalinity	pH
TDS	1	0.865	0.79	0.876	0.821	0.875	0.838	-0.086	0.852	0.844	0.822	0.873	0.81	0.69	0.914	0.908
TSS	0.865	1	0.748	0.825	0.825	0.845	0.83	-0.134	0.903	0.863	0.879	0.846	0.799	0.721	0.879	0.891
COD	0.79	0.748	1	0.883	0.906	0.905	0.834	-0.252	0.902	0.89	0.899	0.881	0.982	0.9	0.751	0.811
BOD	0.876	0.825	0.883	1	0.961	0.959	0.78	-0.062	0.909	0.87	0.853	0.895	0.937	0.815	0.812	0.889
Turbidity	0.821	0.825	0.906	0.961	1	0.957	0.819	-0.067	0.909	0.898	0.882	0.929	0.955	0.848	0.823	0.898
Phosphate	0.875	0.845	0.905	0.959	0.957	1	0.867	0.001	0.951	0.945	0.924	0.964	0.946	0.895	0.871	0.942
Sulfate	0.838	0.83	0.834	0.78	0.819	0.867	1	-0.182	0.867	0.951	0.952	0.89	0.83	0.758	0.885	0.897
Calcium	-0.086	-0.134	-0.252	-0.062	-0.067	0.001	-0.182	1	-0.189	-0.203	-0.19	0.004	-0.17	-0.135	0.002	-0.031
Magnesium	0.852	0.903	0.902	0.909	0.909	0.951	0.867	-0.189	1	0.955	0.959	0.921	0.926	0.905	0.837	0.918
Chlorides	0.844	0.863	0.89	0.87	0.898	0.945	0.951	-0.203	0.955	1	0.979	0.942	0.903	0.865	0.879	0.926
Electrical Conductivity	0.822	0.879	0.899	0.853	0.882	0.924	0.942	-0.19	0.959	0.979	1	0.915	0.909	0.878	0.849	0.902
Ammonical Nitrogen	0.873	0.846	0.881	0.895	0.929	0.964	0.89	0.004	0.921	0.942	0.915	1	0.921	0.869	0.943	0.917
Nitrate	0.81	0.799	0.982	0.937	0.955	0.946	0.83	-0.17	0.926	0.903	0.909	0.921	1	0.915	0.8	0.843
Fluoride	0.69	0.721	0.9	0.825	0.848	0.895	0.758	-0.135	0.905	0.865	0.878	0.869	0.915	1	0.707	0.788
Total Alkalinity	0.914	0.879	0.751	0.812	0.823	0.871	0.885	0.002	0.837	0.879	0.849	0.943	0.8	0.707	1	0.89
pH	0.908	0.891	0.811	0.889	0.898	0.942	0.897	-0.031	0.918	0.926	0.902	0.917	0.843	0.788	0.89	1

Table 13: Correlation matrix for groundwater samples in Sundernagar region

	TDS	TSS	COD	BOD	Turbidity	Phosphate	Sulfate	Calcium	Magnesium	Chlorides	Electrical Conductivity	Ammonical Nitrogen	Nitrate	Fluoride	Total Alkalinity	pH
TDS	1	0.57	0.56	0.90	0.82	0.90	0.89	0.31	0.85	0.85	0.92	0.85	0.85	0.89	0.94	0.88
TSS	0.87	1	0.51	0.94	0.87	0.97	0.94	0.31	0.89	0.89	0.88	0.53	0.87	0.63	0.96	0.90
COD	0.56	0.51	1	0.59	0.40	0.44	0.59	0.10	0.55	0.51	0.62	0.40	0.73	0.46	0.53	0.58
BOD	0.90	0.94	0.59	1	0.80	0.92	0.93	0.41	0.90	0.94	0.93	0.62	0.87	0.72	0.96	0.96
Turbidity	0.82	0.87	0.40	0.80	1	0.92	0.74	0.27	0.75	0.66	0.80	0.52	0.69	0.55	0.86	0.71
Phosphate	0.90	0.97	0.44	0.92	0.92	1	0.91	0.36	0.88	0.87	0.89	0.58	0.84	0.67	0.96	0.89
Sulfate	0.89	0.94	0.59	0.93	0.74	0.91	1	0.33	0.93	0.95	0.86	0.59	0.92	0.69	0.93	0.94
Calcium	0.31	0.31	0.10	0.41	0.27	0.36	0.33	1	0.34	0.47	0.29	0.27	0.11	0.35	0.39	0.47
Magnesium	0.85	0.89	0.55	0.90	0.75	0.88	0.93	0.34	1	0.90	0.85	0.53	0.85	0.60	0.91	0.88
Chlorides	0.85	0.89	0.51	0.94	0.66	0.87	0.95	0.47	0.90	1	0.85	0.59	0.83	0.72	0.91	0.96
Electrical Conductivity	0.92	0.88	0.62	0.93	0.80	0.89	0.86	0.29	0.85	0.85	1	0.68	0.86	0.76	0.93	0.918
Ammonical Nitrogen	0.85	0.53	0.40	0.62	0.52	0.58	0.59	0.27	0.53	0.59	0.68	1	0.59	0.96	0.67	0.61
Nitrate	0.85	0.87	0.73	0.87	0.69	0.84	0.92	0.12	0.85	0.83	0.86	0.59	1	0.65	0.86	0.85
Fluoride	0.89	0.63	0.46	0.72	0.55	0.67	0.69	0.35	0.60	0.72	0.76	0.96	0.65	1	0.75	0.73
Total Alkalinity	0.94	0.96	0.53	0.96	0.86	0.96	0.93	0.39	0.91	0.91	0.93	0.67	0.86	0.75	1	0.94
pH	0.88	0.90	0.58	0.96	0.71	0.89	0.94	0.47	0.88	0.96	0.91	0.61	0.85	0.73	0.94	1

Table 14: Correlation matrix for groundwater samples in Baddi region

	PH	TDS	TSS	COD	BOD	Turbidity	Phosphate	Sulfate	Calcium	Magnesium	Chlorides	Electrical Conductivity	Ammonical Nitrogen	Nitrate	Fluoride	Total Alkalinity
pH	1	0.84	0.88	0.74	0.86	0.80	0.93	0.90	0.81	0.88	0.86	0.85	0.91	0.80	0.97	0.88
TDS	0.84	1	0.89	0.89	0.90	0.78	0.89	0.91	0.92	0.90	0.92	0.86	0.79	0.77	0.84	0.89
TSS	0.84	0.89	1	0.93	0.94	0.90	0.88	0.95	0.94	0.87	0.93	0.92	0.86	0.91	0.90	0.97
COD	0.74	0.89	0.93	1	0.91	0.81	0.82	0.86	0.96	0.86	0.91	0.85	0.81	0.88	0.77	0.91
BOD	0.86	0.90	0.94	0.91	1	0.91	0.95	0.91	0.96	0.89	0.92	0.97	0.92	0.89	0.90	0.95
Turbidity	0.80	0.78	0.90	0.81	0.91	1	0.86	0.87	0.90	0.83	0.83	0.95	0.88	0.85	0.88	0.90
Phosphate	0.93	0.89	0.88	0.82	0.95	0.86	1	0.92	0.89	0.92	0.91	0.92	0.93	0.85	0.93	0.92
Sulfate	0.90	0.91	0.95	0.86	0.91	0.87	0.92	1	0.92	0.90	0.95	0.90	0.86	0.86	0.94	0.96
Calcium	0.81	0.92	0.94	0.96	0.96	0.90	0.89	0.92	1	0.90	0.93	0.94	0.87	0.87	0.86	0.93
Magnesium	0.88	0.90	0.87	0.86	0.89	0.83	0.92	0.90	0.90	1	0.93	0.87	0.88	0.84	0.88	0.89
Chlorides	0.86	0.92	0.93	0.91	0.92	0.83	0.91	0.95	0.93	0.93	1	0.88	0.83	0.86	0.87	0.95
Electrical Conductivity	0.85	0.86	0.92	0.85	0.97	0.95	0.925	0.90	0.94	0.87	0.88	1	0.90	0.85	0.90	0.92
Ammonical Nitrogen	0.91	0.79	0.86	0.81	0.92	0.88	0.93	0.86	0.97	0.88	0.83	0.90	1	0.92	0.92	0.90
Nitrate	0.80	0.77	0.91	0.88	0.89	0.85	0.85	0.86	0.87	0.84	0.86	0.85	0.92	1	0.86	0.93
Fluoride	0.97	0.84	0.90	0.77	0.90	0.88	0.93	0.94	0.86	0.88	0.87	0.90	0.92	0.86	1	0.92
Total Alkalinity	0.88	0.89	0.97	0.91	0.95	0.90	0.92	0.96	0.93	0.89	0.95	0.92	0.90	0.93	0.92	1

Table 15: Total variance explained in component matrix for Solan region

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	11.818	73.863	73.863	11.818	73.863	73.863
2	1.218	7.614	81.476	1.218	7.614	81.476
3	1.013	6.329	87.805	1.013	6.329	87.805
4	0.722	4.515	92.32			
5	0.372	2.325	94.645			
6	0.334	2.086	96.731			
7	0.227	1.419	98.15			
8	0.131	0.821	98.971			
9	0.065	0.405	99.376			
10	0.052	0.327	99.703			
11	0.027	0.17	99.873			
12	0.014	0.085	99.957			
13	0.005	0.03	99.988			
14	0.002	0.012	100			
15	1.08E-15	6.72E-15	100			
16	-7.83E-17	-4.89E-16	100			

Table 16: Component matrix explained for dataset of Solan region

Parameters	Component		
pH	1	2	3
Electrical Conductivity	0.978	-0.117	0.128
BOD	0.972	-0.12	-
Magnesium	0.971	-	-
Phosphate	0.968	-	-
TSS	0.968	-0.127	-
Ammonical Nitrogen	0.951	-0.121	-
Chlorides	0.934	-	-
Turbidity	0.912	-	0.162
TDS	0.912	-	-
COD	0.873	0.259	-
Calcium	0.871	-	-0.118
Total Alkalinity	0.847	0.388	-0.215
Nitrate	0.734	0.49	-0.338
Fluoride	0.675	0.122	-0.266
Sulphate	0.654	-0.461	0.44
	-	0.673	0.715

Table 17: Rotated component matrix explained for dataset of Solan region

	Component		
	1	2	3
Fluoride	0.911		
pH	0.853	0.508	
Electrical Conductivity	0.824	0.533	
Phosphate	0.814	0.537	
TSS	0.78	0.551	
Turbidity	0.755	0.52	
Magnesium	0.754	0.608	
Chlorides	0.741	0.54	0.14
BOD	0.737	0.63	0.102
Ammonical Nitrogen	0.721	0.593	
COD	0.646	0.582	0.148
Total Alkalinity	0.17	0.928	
Calcium	0.36	0.882	
TDS	0.56	0.691	0.205
Nitrate	0.336	0.642	-0.127
Sulphate			0.981

Table 18: Total variance in component matrix for Mandi region

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13.34	83.149	83.149	13.304	83.149	83.149
2	1.11	6.942	90.091	1.111	6.942	90.091
3	0.604	3.376	93.687			
4	0.318	1.989	95.857			
5	0.206	1.286	97.143			
6	0.144	0.901	98.043			
7	0.113	0.704	98.747			
8	0.096	0.6	99.347			
9	0.049	0.304	99.651			
10	0.026	0.162	99.814			
11	0.014	0.085	99.898			
12	0.01	0.064	99.962			
13	0.005	0.028	99.99			
14	0.002	0.01	100			
15	4.54E-16	2.84E-15	100			
16	-1.94E-16	-1.21E-15	100			

Table 19: Component matrix explained for dataset of Mandi region

	Component	
	1	2
Phosphate	0.98	0.122
Magnesium	0.973	
Chlorides	0.973	
Ammonical Nitrogen	0.97	0.137
Electrical Conductivity	0.965	
Nitrate	0.956	
Turbidity	0.952	
pH	0.95	0.12
BOD	0.94	
COD	0.929	-0.176
Sulphate	0.922	
Total Alkalinity	0.908	0.174
TDS	0.905	
TSS	0.901	
Fluoride	0.89	
Calcium	0.129	0.974

Table 20: Rotated component matrix explained for dataset of Mandi region

	Component	
	1	2
Phosphate	0.987	
Ammonical Nitrogen	0.978	
Magnesium	0.963	0.159
Chlorides	962	0.167
pH	0.957	
Electrical Conductivity	0.953	0.174
Turbidity	0.953	
Nitrate	0.945	0.16
BOD	0.942	
Total Alkalinity	0.92	
Sulphate	0.913	0.141
COD	0.91	0.255
TDS	0.909	
TSS	0.899	
Fluoride	0.88	0.156
Calcium		-0.981

Table 21: Total variance in component matrix for Sundernagar region

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	12.338	77.115	77.115	12.338	77.115	77.115
2	1.089	6.804	83.919	1.089	6.804	83.919
3	1.034	6.463	90.382	1.034	6.463	90.382
4	0.720	4.500	94.882			
5	0.385	2.405	97.287			
6	0.153	0.955	98.241			
7	0.119	0.742	98.983			
8	0.055	0.341	99.324			
9	0.034	0.215	99.539			
10	0.030	0.186	99.725			
11	0.021	0.131	99.856			
12	0.015	0.091	99.948			
13	0.005	0.032	99.980			
14	0.003	0.020	100.00			
15	-2.381E-16	-1.488E-15	100.00			
16	-4.839E-16	-3.024E-15	100.00			

Table 22: Component matrix explained for dataset of Sundernagar region

	Component		
	1	2	3
Total Alkalinity	0.983		
BOD	0.974		
TDS	0.964	0.113	-0.182
Sulphate	0.961	-0.125	
pH	0.959		0.119
Electrical Conductivity	0.951		
Phosphate	0.951		0.17
TSS	0.951	-0.177	0.161
Chlorides	0.939		0.158
Magnesium	0.923	-0.155	0.139
Nitrate	0.909	-0.29	-0.17
Turbidity	0.832	-0.113	0.134
Fluoride	0.8	0.446	-0.381
Ammonical Nitrogen	0.715	0.471	-0.49
COD	0.616	-292	-0.348
Calcium	0.392	0.625	0.554

Table 23: Rotated component matrix explained for dataset of Sundernagar region

	Component		
	1	2	3
TSS	0.943	0.244	0.107
Sulphate	0.906	0.34	
Phosphate	0.904	0.296	0.186
Magnesium	0.904	0.258	0.104
BOD	0.888	0.378	0.169
Total Alkalinity	0.878	0.412	0.179
Nitrate	0.866	0.382	-0.208
pH	0.854	0.393	0.225
Chlorides	0.84	0.366	0.26
Electrical Conductivity	0.824	0.483	
Turbidity	0.806	0.243	0.119
TDS	0.744	0.645	
COD	0.565	0.362	-0.37
Ammonical Nitrogen	0.297	0.937	
Fluoride	0.4	0.89	0.155
Calcium	0.229	0.17	0.878

Table 24: Total variance in component matrix for Baddi region

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	14.412	90.076	90.076	14.412	90.076	90.076
2	0.489	3.054	93.13			
3	0.369	2.307	95.436			
4	0.223	1.394	96.83			
5	0.183	1.142	97.972			
6	0.109	0.68	98.652			
7	0.08	0.5	99.153			
8	0.049	0.306	99.459			
9	0.029	0.18	99.639			
10	0.023	0.143	99.782			
11	0.021	0.129	99.91			
12	0.01	0.06	99.97			
13	0.005	0.028	99.998			
14	0	0.002	100			
15	6.09E-16	3.80E-15	100			
16	-4.97E-16	-3.11E-15	100			

Table 25: Component matrix for Baddi region

Parameters	Component
	1
Total Alkalinity	0.982
BOD	0.979
TSS	0.97
Sulphate	0.967
Calcium	0.965
Phosphate	0.961
Electrical Conductivity	0.959
Chlorides	0.957
Fluoride	0.95
Magnesium	0.943
Ammonical Nitrogen	0.938
TDS	0.925
Nitrate	0.924
Turbidity	0.924
COD	0.921
pH	0.918

APPENDIX-B

LIST OF SUPPLEMENTARY FIGURES

The comparison in the geotechnical assessment of dumpsite soil and natural soil of Baddi region site has been shown in Figure 1-7.

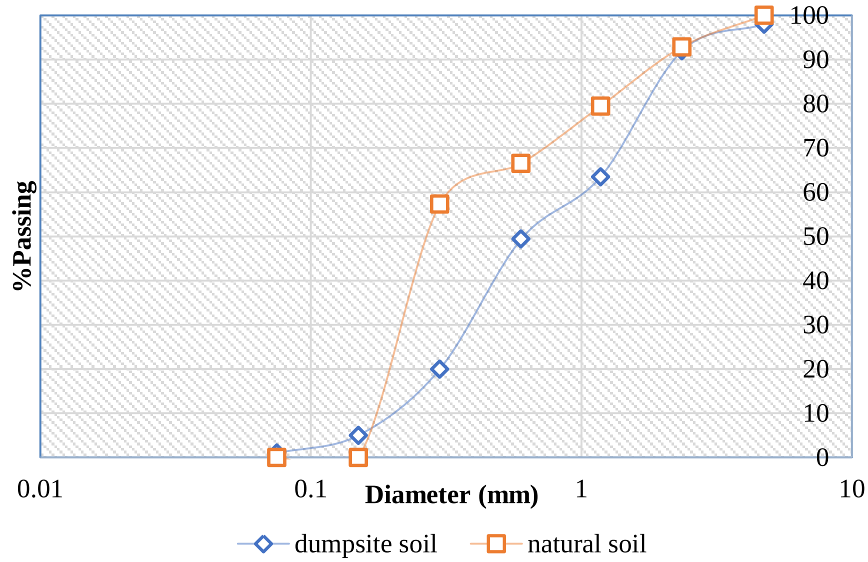


Figure 1: Grain size analysis of dump soil and natural soil

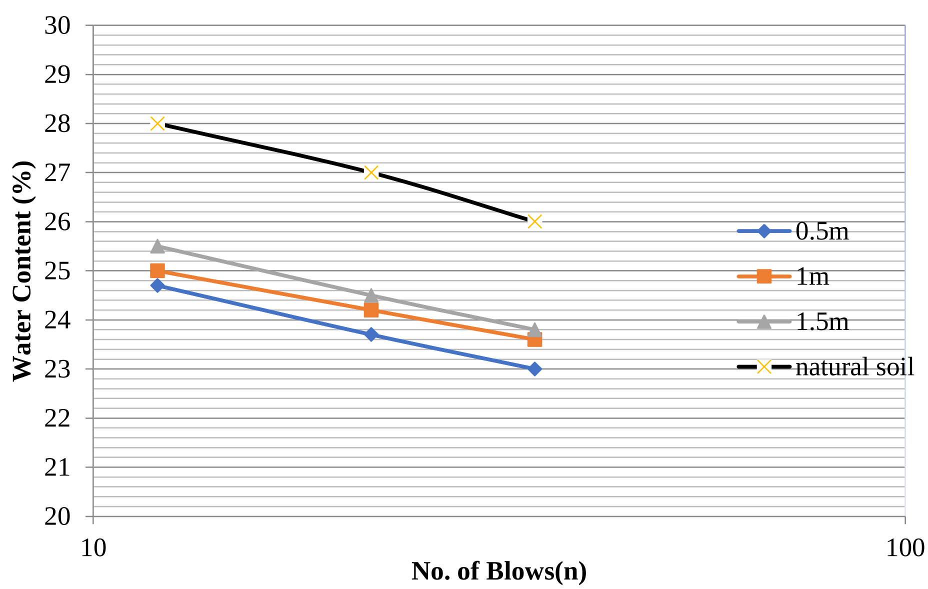


Figure 2: Variation in water content with number of blows of dump soil and natural soil

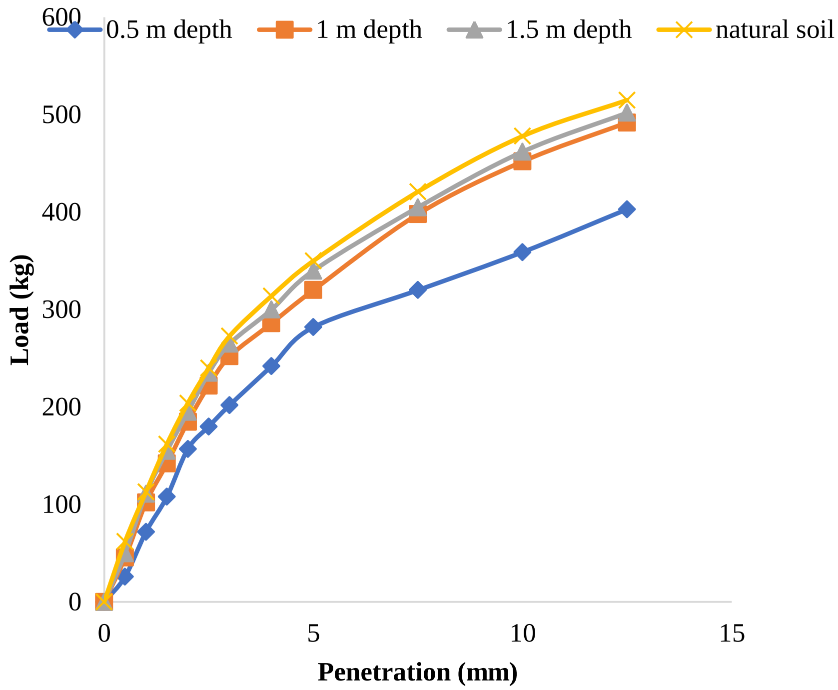


Figure 3: Load Vs Penetration curve (un-soaked) of dump soil and natural soil

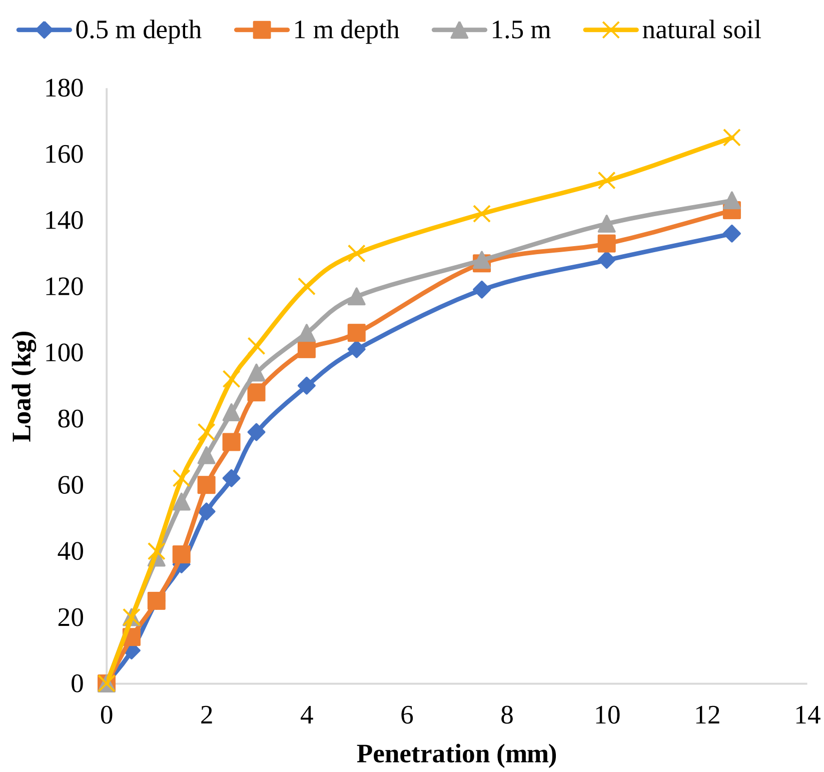


Figure 4: Load Vs Penetration curve (soaked) of dump soil and natural soil

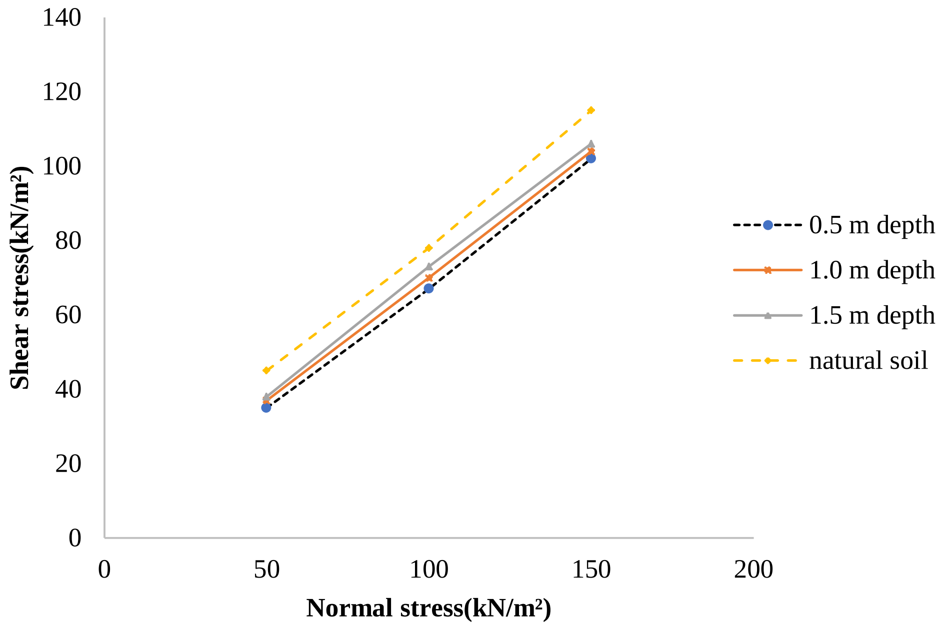


Figure 5: Shear stress Vs Normal stress curve of dumpsite soil and natural soil

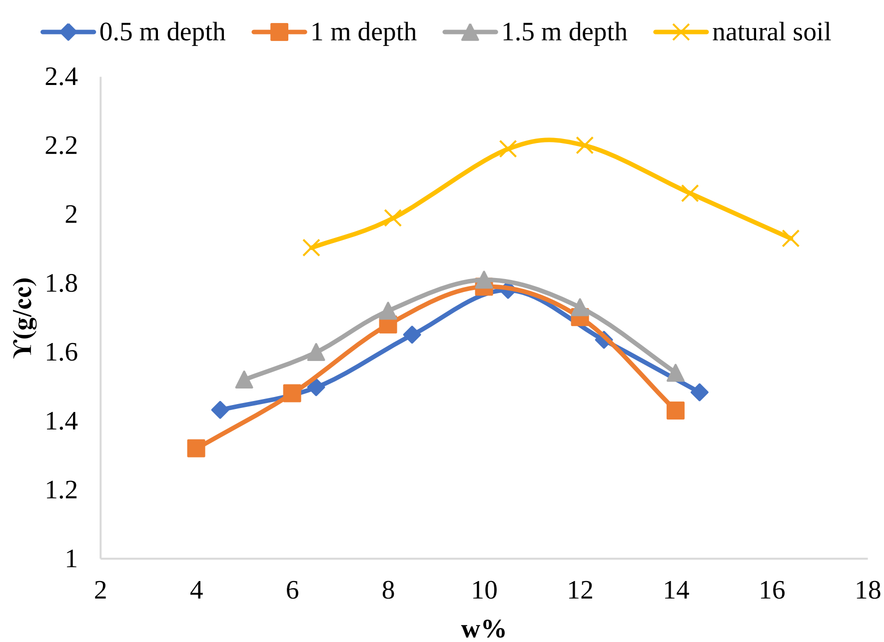


Figure 6: Variation of MDD with OMC of dumpsite soil and natural soil

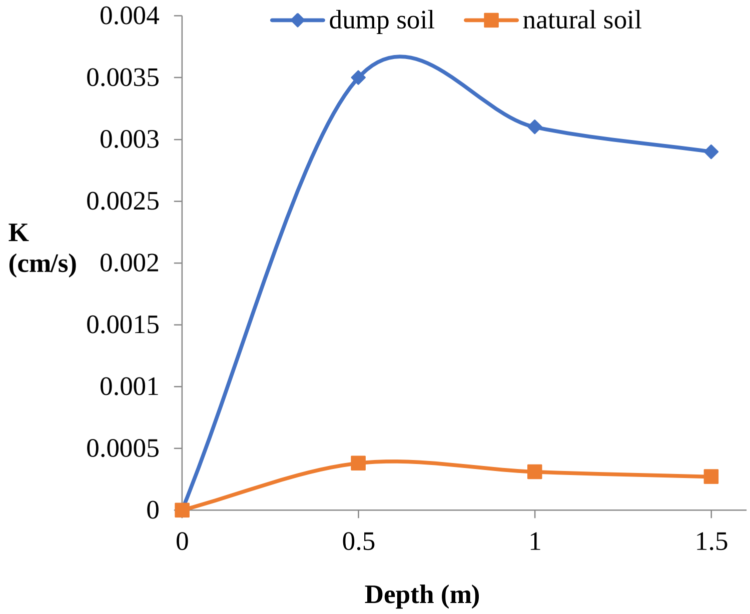


Figure 7: Comparison in variation of permeability with depth of natural soil and dumpsite soil

The comparison in the geotechnical assessment of dumpsite soil and natural soil of Mandi region site has been shown in Figure 8-14.

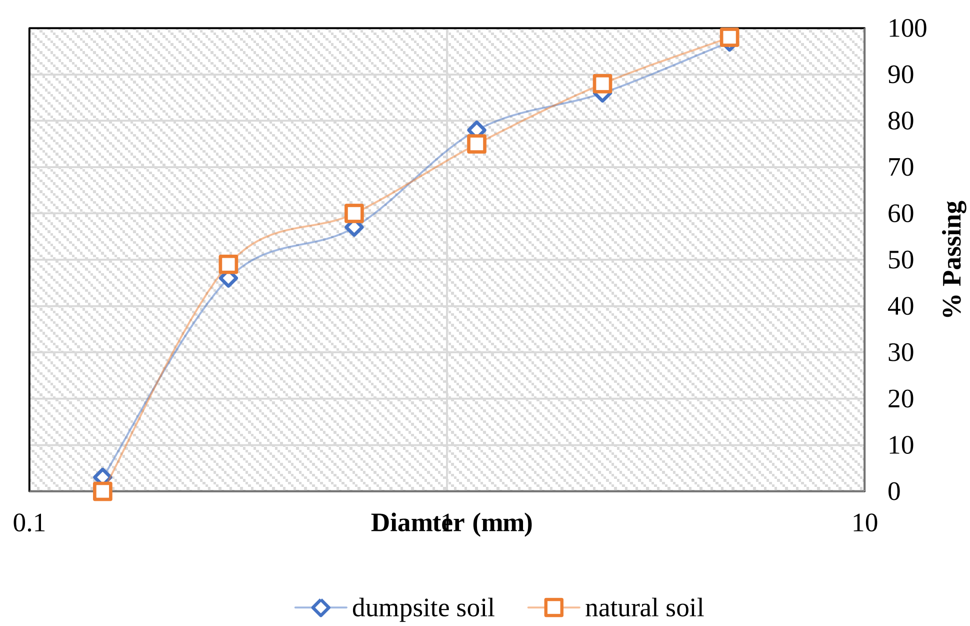


Fig 8: Grain size analysis of dump soil and natural soil

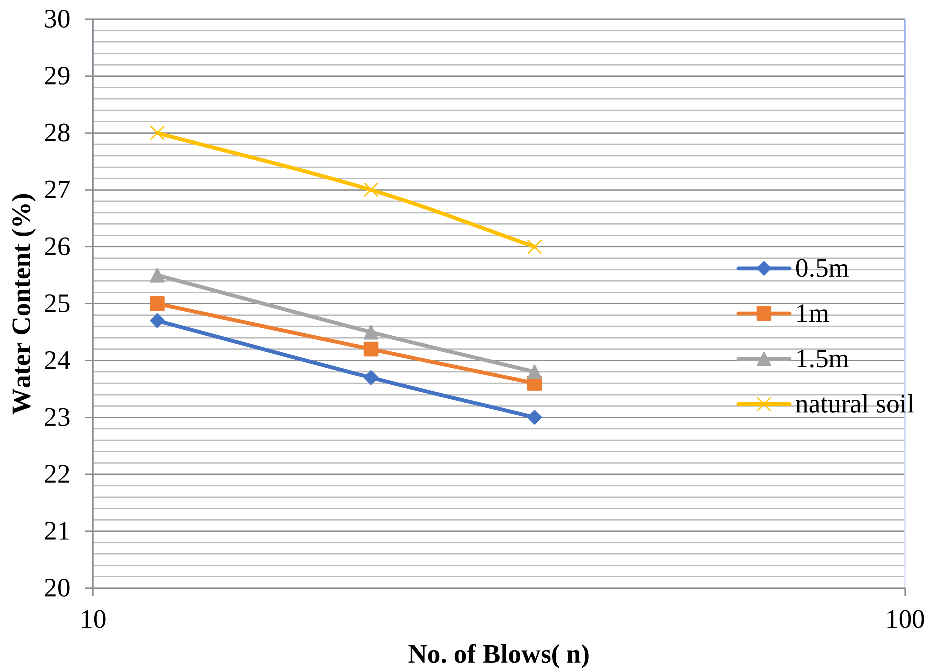


Fig 9: Variation in water content with number of blows of dump soil and natural soil

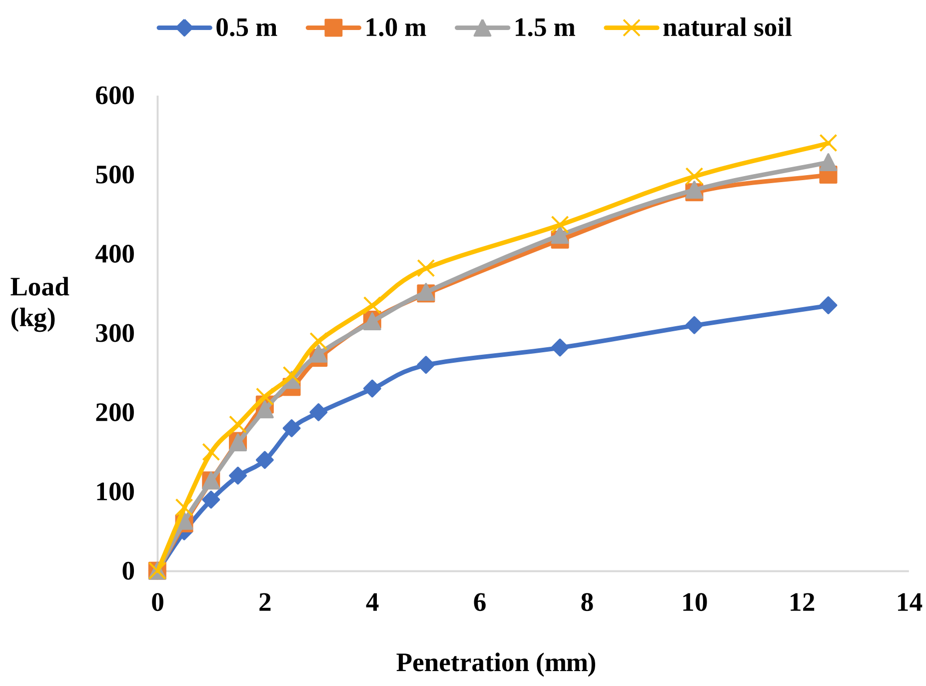


Fig 10: Load Vs Penetration curve (un-soaked) of dump soil and natural soil

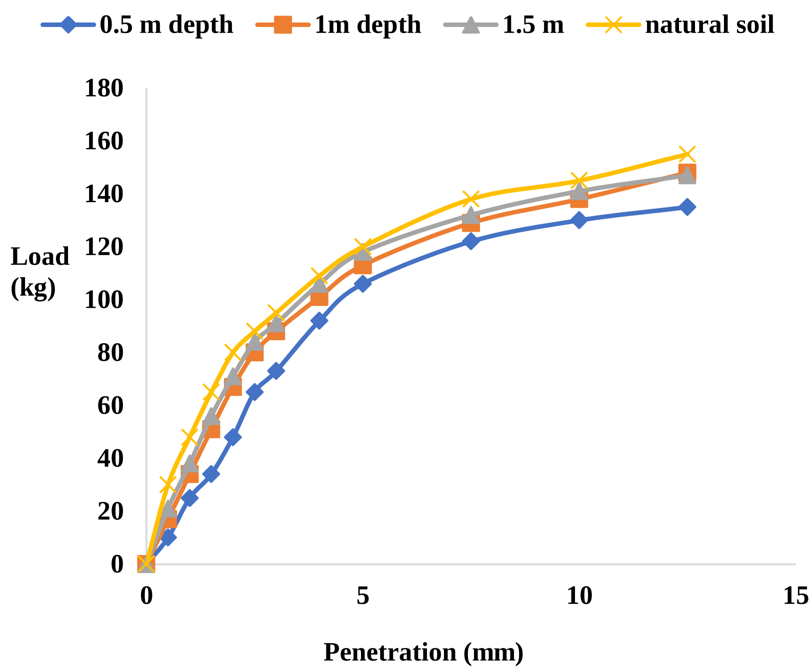


Fig 11: Load Vs Penetration curve (soaked) of dumpsite soil and natural soil

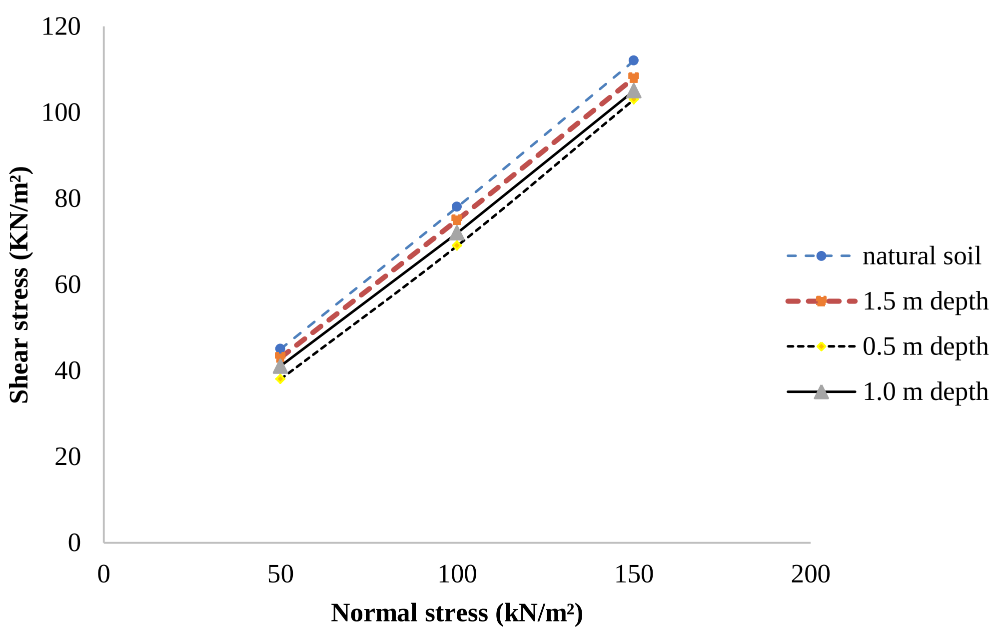


Fig 12: Shear stress Vs Normal stress curve of dump soil and natural soil

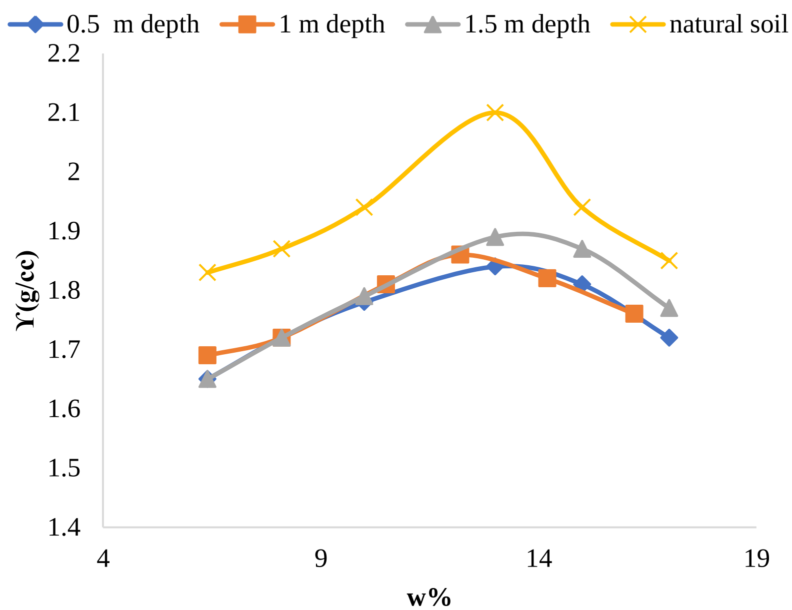


Fig 13: Variation of MDD with OMC of dump soil and natural soil

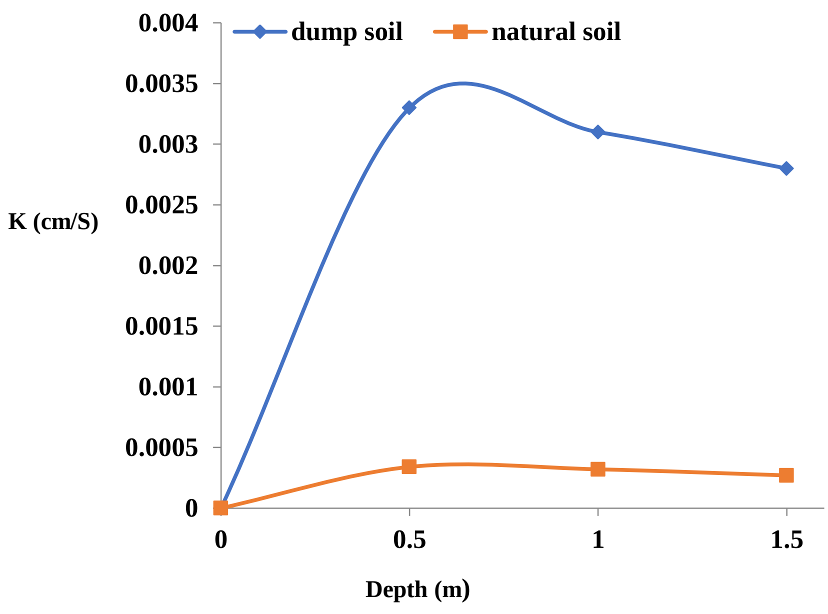


Fig 14: Comparison in variation of permeability with depth of natural soil and dump soil

The comparison in the geotechnical assessment of dumpsite soil and natural soil of Sundernagar region has been shown in Figure 15-21.

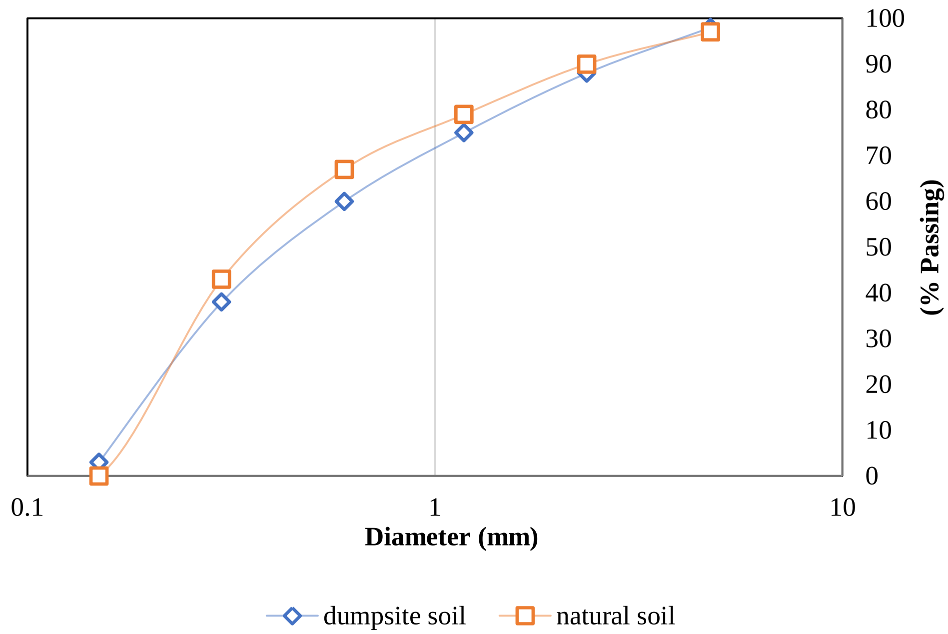


Figure 15: Grain size analysis of dump soil and natural soil

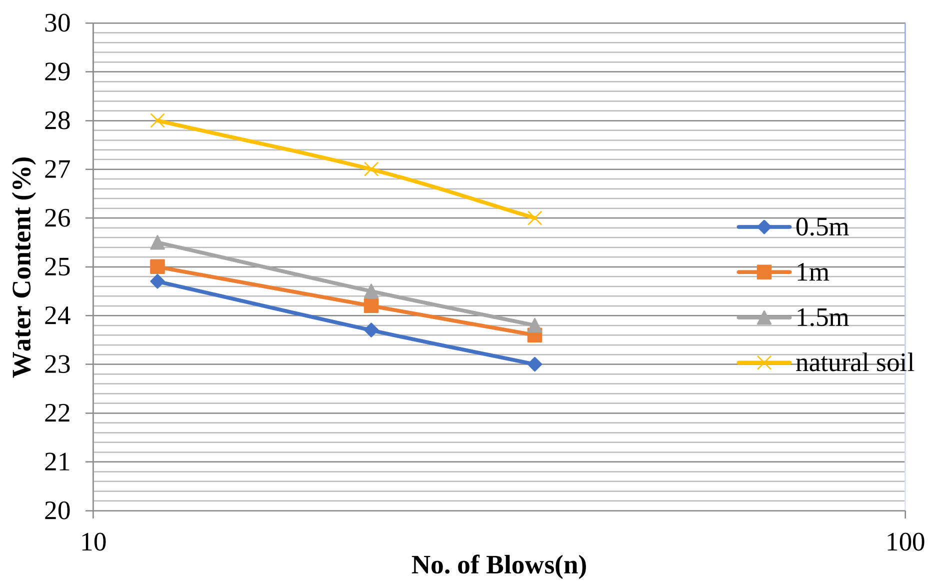


Figure 16: Variation in water content with number of blows of dump soil and natural soil

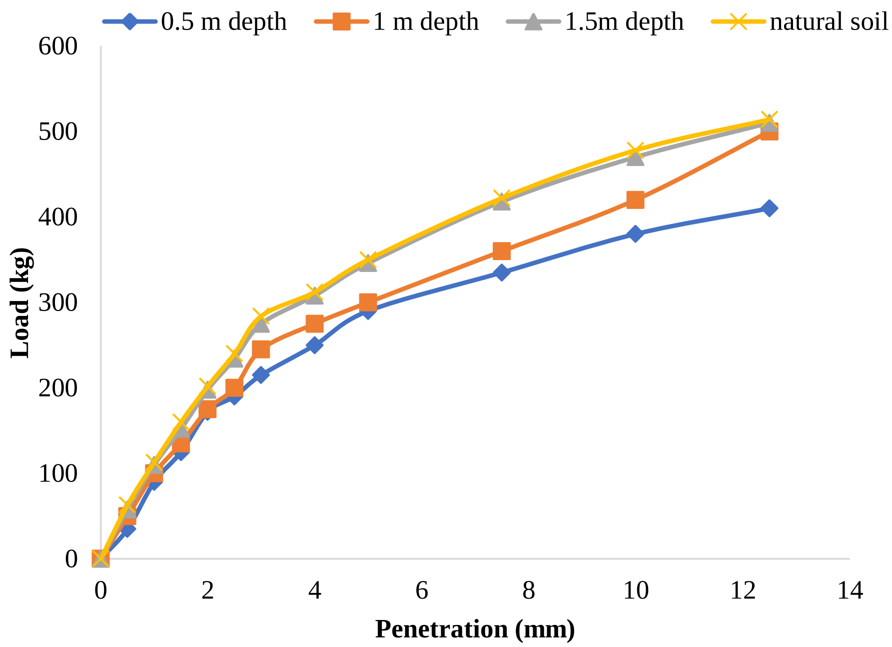


Figure 17: Load Vs Penetration curve (un-soaked) of dump soil and natural soil

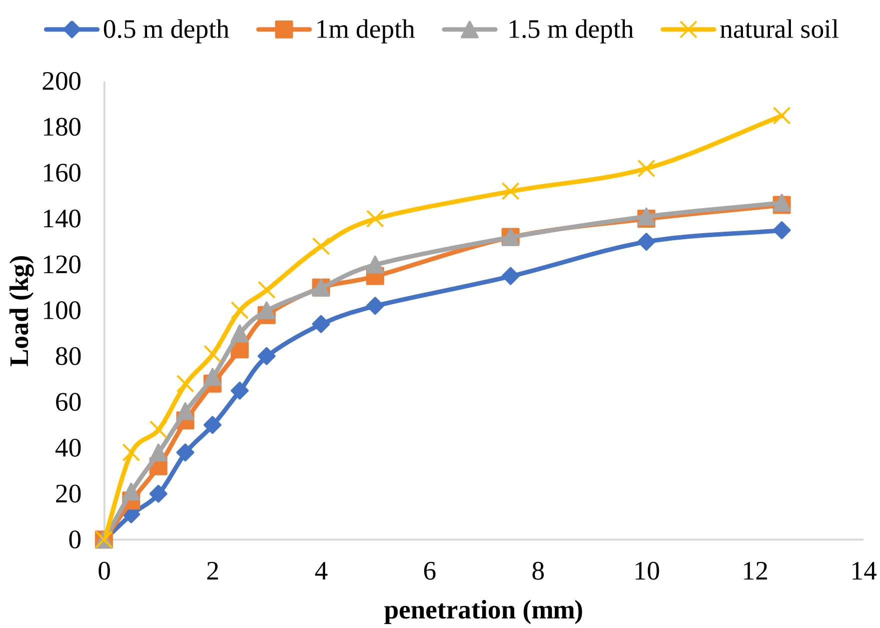


Figure 18: Load Vs Penetration curve (soaked) of dump soil and natural soil

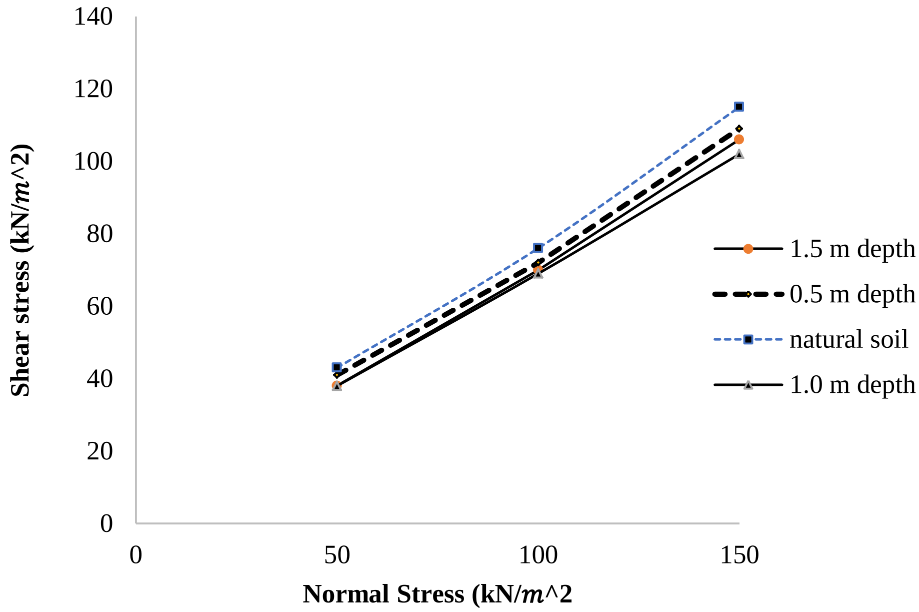


Figure 19: Shear stress Vs Normal stress curve of dump soil and natural soil

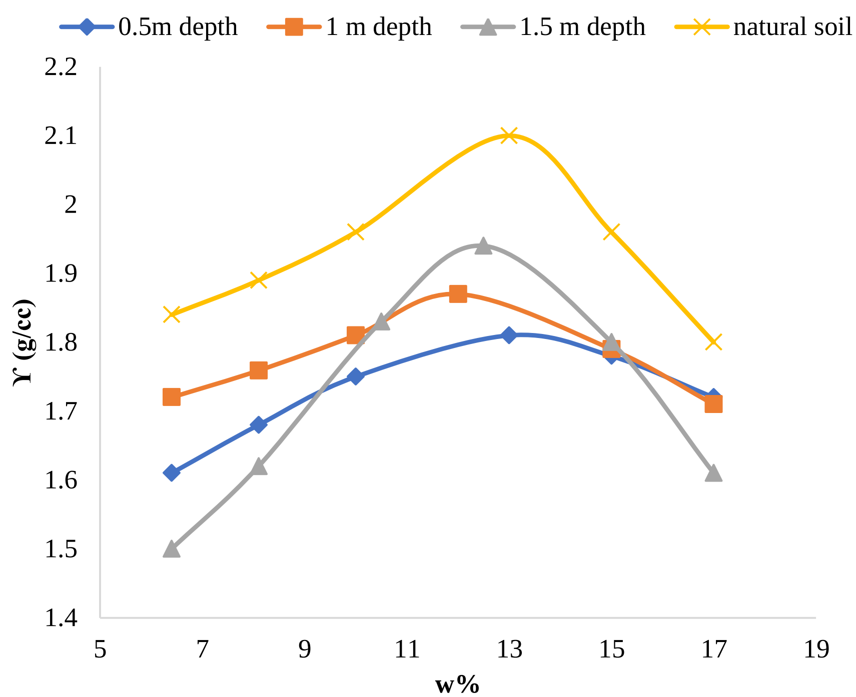


Figure 20: Variation of MDD with OMC of dumpsite soil and natural soil

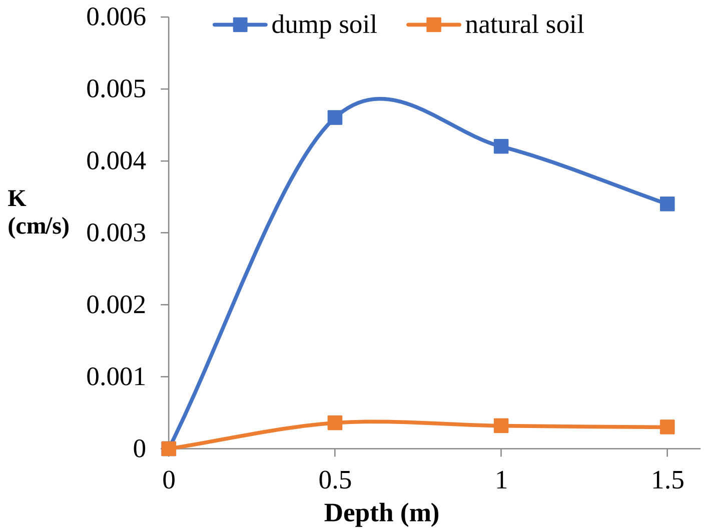


Figure 21: Comparison in variation of permeability with depth of natural soil and dumpsite soil

The comparison in the geotechnical assessment of dumpsite soil and natural soil of Solan region site has been shown in Figure 22-28.

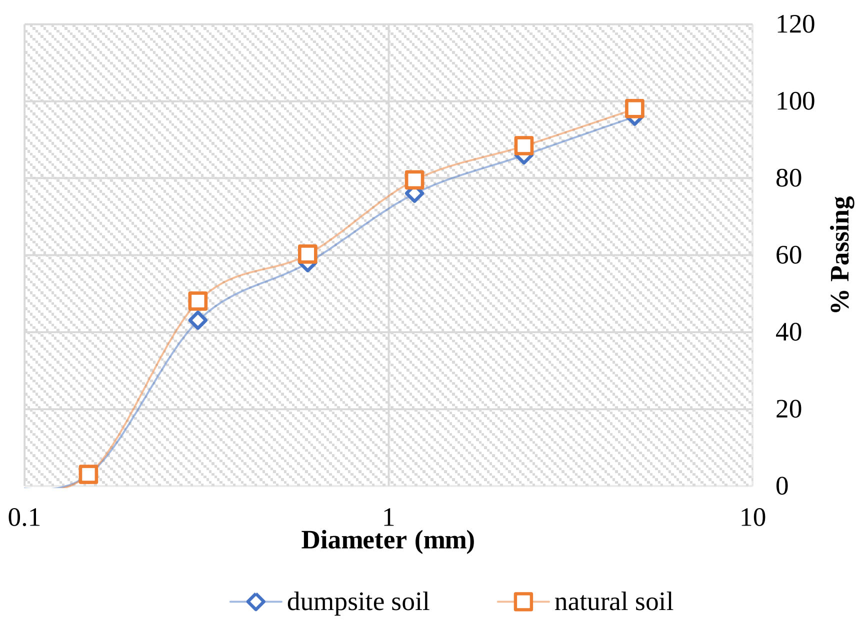


Figure 22: Grain size analysis of dump soil and natural soil

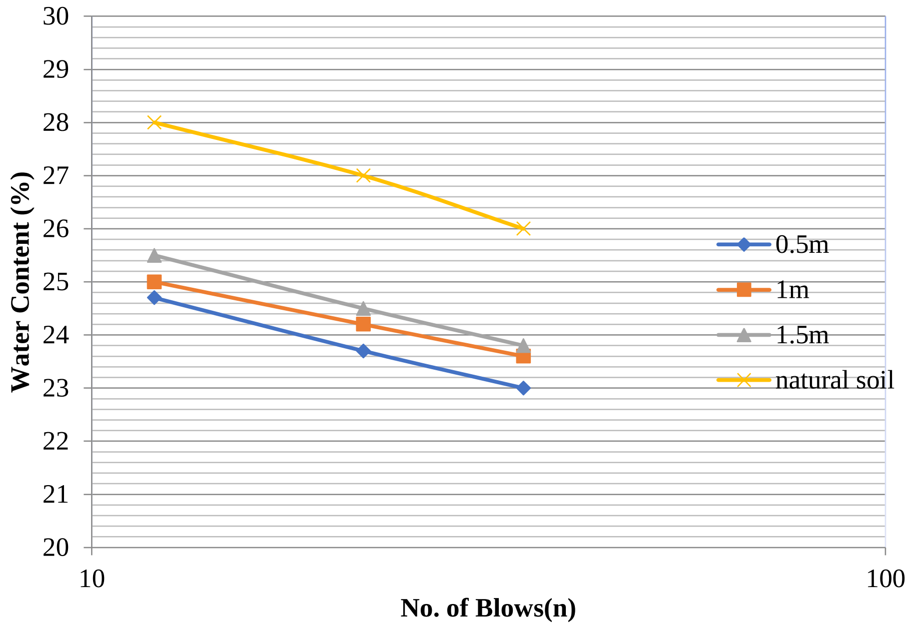


Figure 23: Variation in water content with number of blows of dump soil

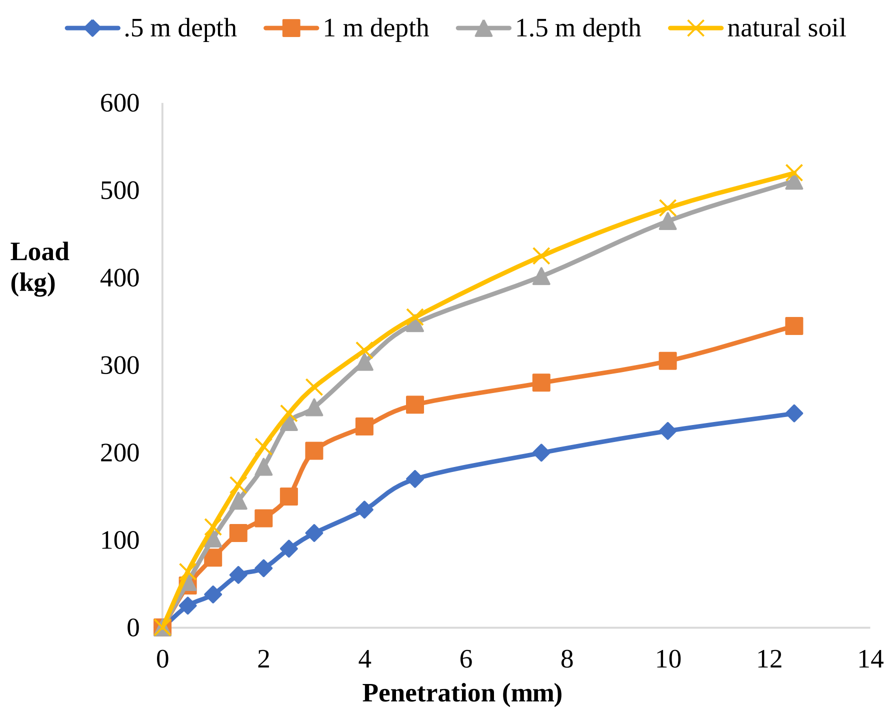


Figure 24: Load Vs Penetration curve (un-soaked) of dump soil and natural soil

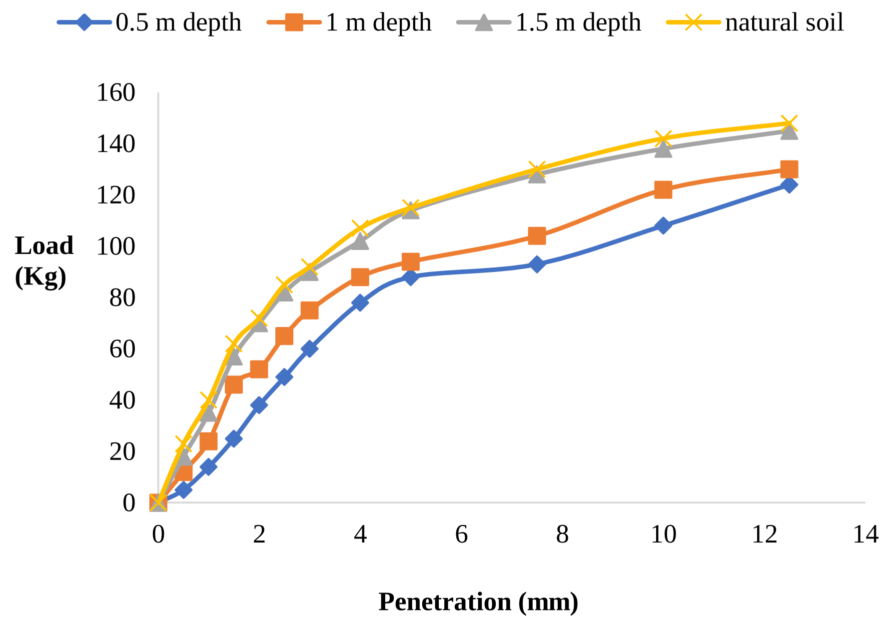


Figure 25: Load Vs Penetration curve (soaked) of dump soil and natural soil

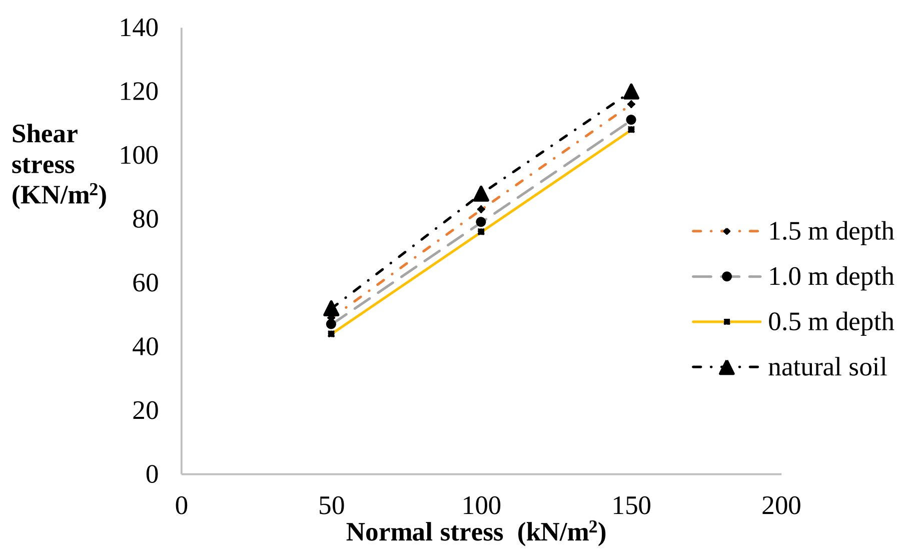


Figure 26: Shear stress Vs Normal stress curve of dump soil and natural soil

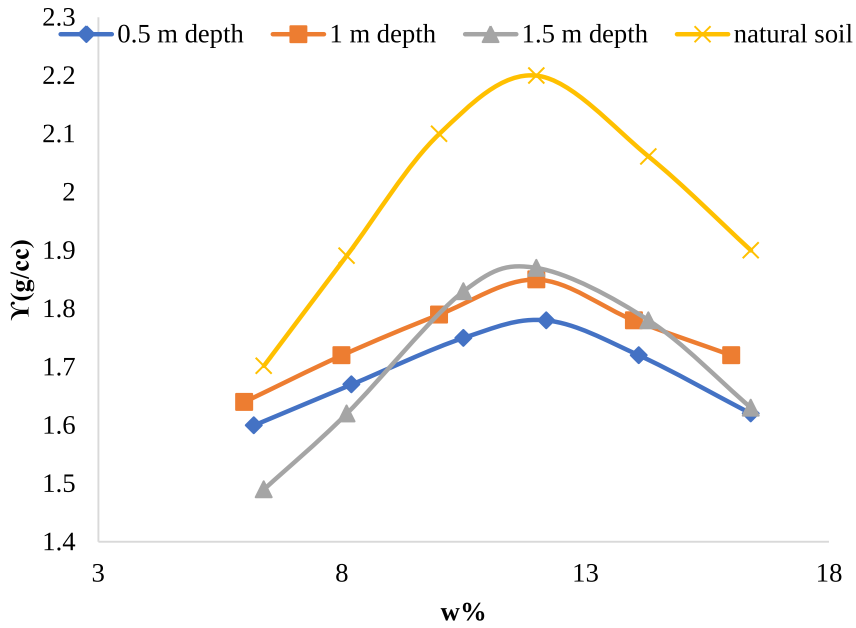


Figure 27: Variation of MDD with OMC of dumpsite soil and natural soil

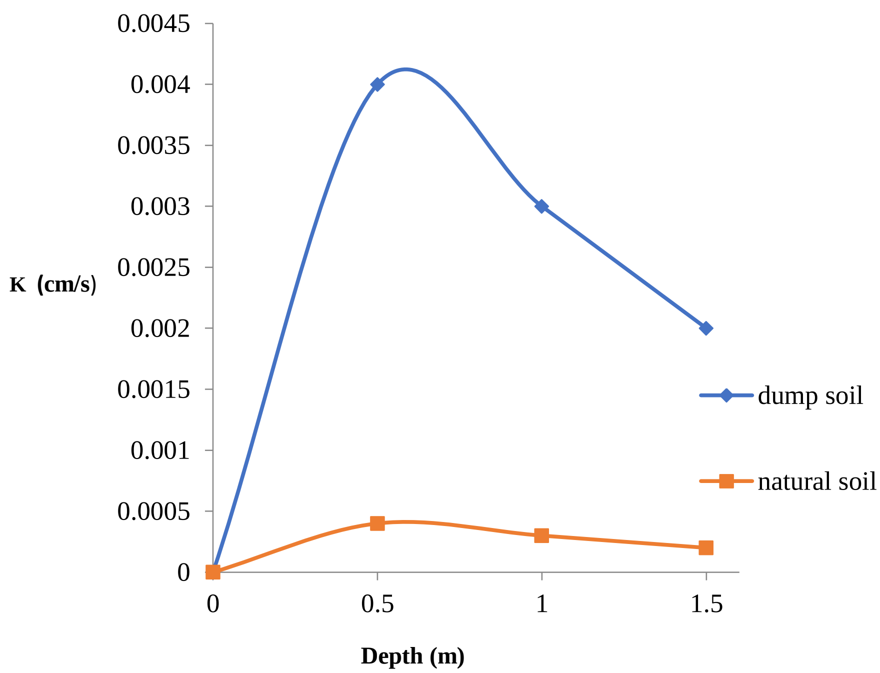


Figure 28: Comparison in variation of permeability

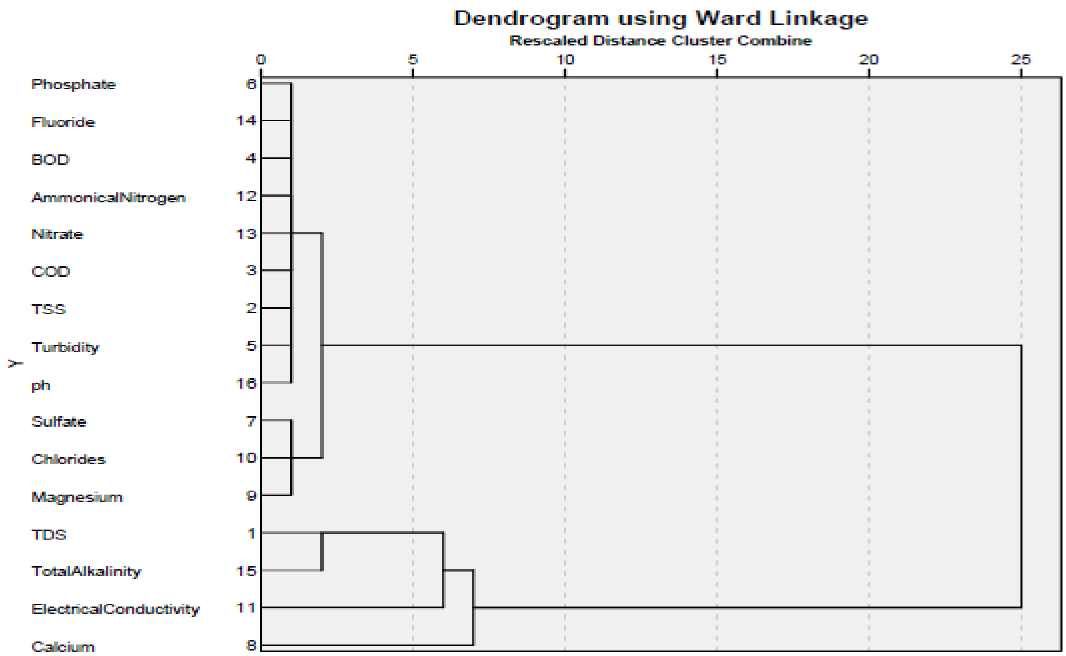


Figure 29: Hierarchical dendrogram for ground water samples in Mandi region

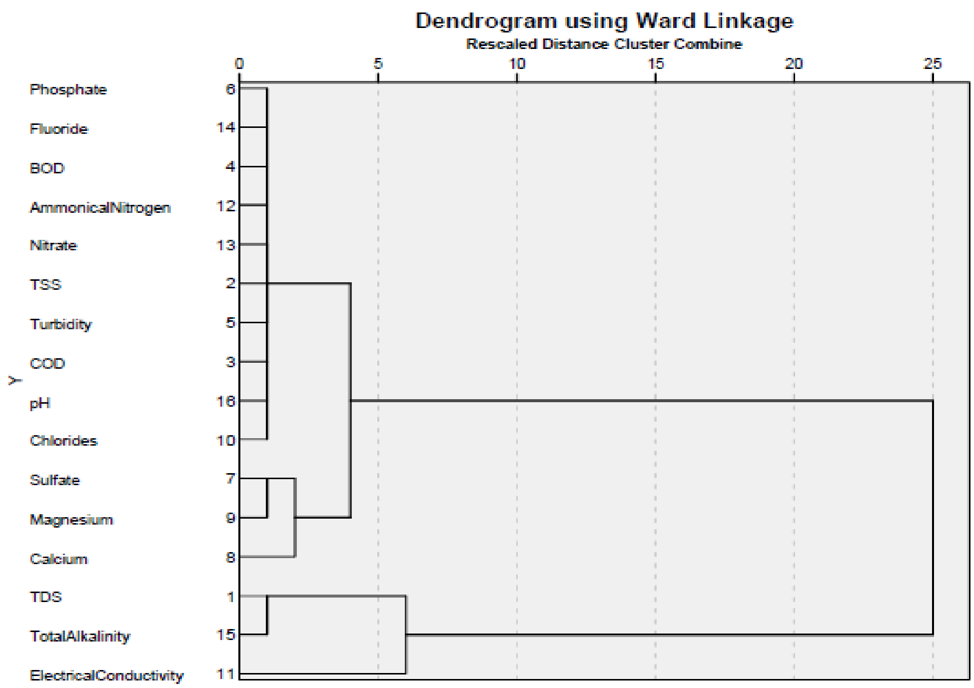


Figure 30: Hierarchical dendrogram for ground water samples in Sundernagar region

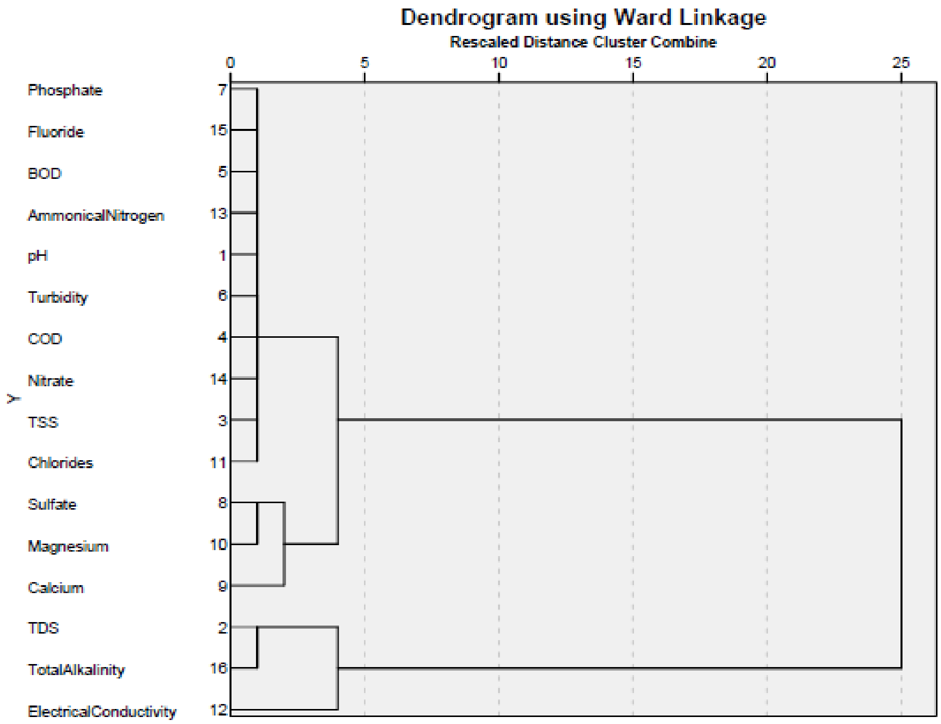


Figure 31: Hierarchical dendrogram for ground water samples in Baddi region