MUNICIPAL SOLID WASTE CHARACTERIZATION AND ANALYSIS IN TRICITY

THESIS

Submitted in fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

By

RISHI RANA
Enrollment No. 146601

Department of Civil Engineering

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,
WAKNAGHAT, DISTRICT SOLAN, H.P, INDIA

August, 2017

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August, 2017

……DEDICATED TO

MY FATHER……….

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DECLARATION BY THE SCHOLAR

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

(Rishi Rana)

Department of Civil Engineering

Jaypee University of Information Technology, Waknaghat, India

Date:

SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the PhD. Thesis entitled **"Municipal Solid Waste Characterization and Analysis in Tricity"**submitted by **Rishi Rana** at **Jaypee University of Information Technology, Waknaghat, Himachal Pradesh, India,** is a bonafied record of her original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

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Rishi Rana

ABSTRACT

Unscientific disposal of waste has been found to be related with numerous environmental concerns like air, water and soil pollution. This requires immediate attention for minimalizing the impacts of solid waste on environment and health. Generation of waste is directly influenced by economic development. Most of the municipal authorities in developing countries are facing challenge to manage it in an effective and efficient manner. Solid waste generation and its composition are influenced by a number of factors like geographic condition, seasons, life style, eating habits, population growth and social status. Therefore, it has become important to take into consideration all these factor and ascertain composition and quantity of waste before selecting and implementing waste management strategies for a particular area. Waste treatment option suitable for a particular area may not be necessarily effective for another area. Therefore, selection of treatment options for particular locality should be made keeping in view various factors like waste generation trends, variation in waste composition and population growth rate.

Considering the current environmental as well as public health issues the present study aims to investigate the current waste management practices in Tricity- Chandigarh, Mohali and Panchkula and to know the environmental repercussions due to the generation of leachate from the open dumping sites and to explore the life cycle assessment methodology to determine the impact of municipal solid waste management under different scenarios. The evaluation of the waste management in Tricity was determined using the ‘wasteaware’ benchmark indicators and remedial measures were suggested. The ‘wasteaware’ benchmark indicators for Mohali and Panchkula indicated very poor performance in environmentally controlled waste treatment, disposal method of waste and the *3R* methodology in comparison to Chandigarh.

The successful implementation of the integrated solid waste management system depends upon the amount and type of waste generated from various sources for better facilitating of the appropriate management system. In this context, the study also characterizes the physical and chemical properties of the Municipal Solid Waste (MSW) generated in all the three study locations for the different socio-economic groups. The characterization of the three cities indicates that MSW generated from all the three cities have high proportions of biodegradables (52% Chandigarh, 46.7% Mohali and 42.6% Panchkula) with inert fraction as (27% in Chandigarh, 28.6% in Mohali and 28.46% in Panchkula). Chemical characterization

results of MSW from all the three cities reveal that the variation in elemental carbon with carbon fraction reported an average of 32.2%. From the characterization study, it is suggested that the suitable alternatives to the existing MSW management practices including composting, vermicomposting, setting up of a formal recycling unit and installation of bio-methanation plant along with the existing refuse derived fuel (RDF) plant as a comprehensive process for handling the municipal solid waste generated in the Tricity region.

The study also assesses the impact from the open dumping pollution on the ground water quality of the three unlined landfill sites of Chandigarh, Mohali and Panchkula. Leachate and ground water samples were analyzed for various physico-chemical, biological and heavy metals. Contamination of ground water samples in all the three cities of Chandigarh, Mohali and Panchkula is owed to the percolation due to leachate. The effect of leachate samples on viability of Neuro-2a cell lines was also evaluated using MTT assay. The overall results of MTT assay suggest that the leachate from three dumping sites significantly contained cytotoxic compounds. The concentration of carcinogenic PAHs as specified by BaP TEQ's was found in the range from 54.71×10^{-8} to 305.031×10^{-8} mg/l. The cancer risk (CR) varied from 4.88×10^{-8} to 27.3×10^{-8}. The cancer risk measured due to PAHs did not exceed the risk threshold under the present conditions, however with the increased generation of MSW and no proper control measures in place, the cancer risk potential may increase in the very near future. Further, the toxic effects due to other organics as well as inorganic contaminants as specified in the results of the current study cannot be neglected.

The study assesses the pollution potential of leachate generated from three non-engineered dumping sites sites located in the Tricity region. LPI signifies the level of pollution concentration of a landfill. The calculated LPI values obtained for Chandigarh, Mohali and Panchkula dumping sites were 26.15, 27.02 and 27.88 respectively. These LPI values are much higher than the standard LPI value of the treated leachate disposal limit of 7.378 to inland surface water. WQI is calculated using oregon water quality index (OWQI) and Bureau of Indian Standards (BIS) BIS 10500 method and values for all the three cities of Chandigarh, Mohali and Panchkula respectively. The average WQI over the three monitoring campaigns for Chandigarh, Mohali and Panchkula was 74, 60 and 72 respectively using the OWQI. The results obtained from OWQI shows that the existing groundwater quality from the Tricity Region is 'poor quality'. As per BIS 10500, the groundwater quality for Chandigarh was poor quality but for Mohali and Panchkula were classified as good quality. However, the groundwater quality for Mohali and Panchkula is very close to being graded poor as the WQI values are on the borderline conditions. The Multivariate Analysis in the form of Principal component analysis (PCA) and Hierarchal Cluster analysis (HCA) was also performed. Principal component analysis (PCA) carried out established major components mainly from natural and anthropogenic sources with cumulative variance of 88% for Chandigarh, 87.1% for Mohali and 87.8% for Panchkula. Hierarchical cluster analysis (HCA) identifies three distinct cluster types for the groundwater samples. These clusters corresponds to a relatively low pollution, moderate pollution and high pollution regions.

Life cycle assessment (LCA) is a tool to quantify the environmental burdens associated with products or activities throughout their life cycle. The study analyses the impacts of different potential waste management alternatives for Tricity using LCA approach. Five potential scenarios of scientific solid waste management were analysed. The impact categories analysed were global warming, acidification, eutrophication and human toxicity. In the study, the LCA was accomplished using the SimaPro software version 8.3.0 and expressed with the Eco-Indicator 99 (H) and Eco-Invent method. The sensitivity analysis identifies sensitive parameters, that is, whether a small change in input parameter would induce a large change in impact category. The input parameters for sensitivity analysis focus on the recycling rate. Among the proposed alternative scenarios, the scenario with the combination of recycling, composting and sanitary landfill has least environmental impacts. The results show that the significant environmental savings are achieved through the energy recovery in the present waste management scenario. It is clear that there is no single MSW management scenario that performs best in all the impact categories.

Keywords: Municipal Solid Waste Management, Wasteaware Benchmark Parameters, Landfill Leachate, Neuro-2a Cell Lines, LCA

LIST OF ACRONYMS AND ABBERVIATIONS

AAA	Atomic Absorption Spectroscopy
AD	Anaerobic Digestion
AP	Acidification Potential
BAU	Business as usual
BARC	Bhabha Atomic Research Centre
BIS	Bureau of Indian Standards
BRICS	Brazil, Russia, India, China and South Africa
C&D Waste	Construction and Demolition waste
CDI	Chronic Daily Intake
CHD	Chandigarh
COM	Composting
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organization
CR	Cancer Risk
DMEM	Dulbecco's Modified Eagle's Medium
EP	Eutrophication Potential
EPA	Environmental Protection Agency Federal Register Rule
EU	European Union
GCV	Gross Calorific Value
GC-MS	Gas Chromatography Mass Spectroscopy
GDP	Gross Domestic Product
GHG	Green House Gas
GOI	Government of India
GWP	Global Warming Potential
HCA	Hierarchical Cluster Analysis

HCS	Hauled Container System
HIG	High Income Group
HTP	Human Toxicity Potential
INC	Incineration
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated Solid Waste Management
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
LIG	Low Income Group
LPI	Leachate Pollution Index
MIG	Medium Income Group
MOH	Mohali
MPN	Most Probable Number
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MTPD	Metric Tons per Day
MTT	Methylene Tetrazolium
ND	Not Detected
OD	Open Dumping
OEDC	Organization for Economic Cooperation and Development
OWQI	Oregon Water Quality Index
PAH’s	Polycyclic Aromatic Hydrocarbons
PCA	Principal Component Analysis
PKL	Panchkula
PPCB	Punjab Pollution Control Board
PPP	Public Private Partnership

RDF	Refuse Derived Fuel
RCC	Reinforced Cement Concrete
SCS	Stationary Container System
SLF	Sanitary Landfill
SSK’s	Sehaj Safai Kendra’s
SWM	Solid Waste Management
TEF	Toxic Equivalency Factor
TPD	Tons per day
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
VFA	Volatile Fatty Acids
WQI	Water Pollution Index
WHO	World Health Organization

LIST OF SYMBOLS

3R's method	Reduce, Reuse and Recycle
µl	Micro litres
$BaSO_4$	Barium Sulphate
C	Carbon
Ca^{+2}	Calcium
F^-	Fluoride
H	Hydrogen
H_2SO_4	Sulphuric Acid
HNO_3	Nitric Acid
Kg	Kilograms
KCal/kg	Kilo calorie per kilogram
L	Low
M	Medium
L/M	Low/Medium
LPI	Weighted Additive Leachate Pollution Index
Mg^{2+}	Magnesium
M/H	Medium/High
m^3	Cubic Meter
m	A positive number
NH_3-N	Ammonical Nitrogen
N	Nitrogen
n	Number of leachate pollutant variables
NO_3^-	Nitrate
ND	Not Detected
O	Oxygen

PO_4^{3-}	Phosphate
p_i	Sub-index value of the i^{th} Leachate Pollutant Variable
q	Quality Variable
q_c	Characteristic value of q
S	Sulphur
SO_4^{2-}	Sulphate
w_i	Weight for the i^{th} Pollutant Variable

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CHAPTER-1

INTRODUCTION

1.1 Background

One of the ubiquitous facts of the human existence is the generation of wastes. In the process of satisfying the rapidly growing needs of the habitat, enormous consumption and drainage of natural resources has resulted in generation of large amounts of waste [1, 2]. This waste can be classified as solid waste, liquid waste and gaseous waste. Much emphasis is being given to the control of the liquid waste and atmospheric emissions; one area of concern often neglected is solid waste management. Rapid urbanization and industrialization in the developing countries has added a major blow to it and pose severe problems in collection, transportation, treatment and disposal of waste [3, 4, 5].

"Solid waste" term is now days described as the non-liquid waste material arising from domestic, commercial, industrial, agriculture, mining, public services activities [3,6]. Solid waste comprises of different materials like papers, glasses, wood, plastics, vegetable wastes, food wastes, construction and demolition (C&D) wastes, radioactive wastes and hazardous wastes. Solid wastes generated by domestic, commercial and industrial activities are often indiscriminately disposed [6]. The unscientific management and disposal of such wastes leads to serious environmental problems. However, many of these waste materials can be reused and thus can become a source of energy generation, if managed properly. With an aim of bringing together ecological, economic and social developments [7, 8, 9, 10], the concept of sustainable waste management was put forward in the Earth Summit (1992, 2002) by the UNCED. The concept of effective and sustainable waste management deals not only with the repercussions of inappropriate waste management on human health and environment but also the effect of current waste management practices on sustainability of environment and conservation of resources [11, 5]. The term 'Municipal Solid Waste (MSW)' is commonly referred to as the rejected or unwanted material generated by the daily activities from residential, institutional, commercial, and other areas excluding the bio-medical and hazardous wastes as shown in *figure 1.1*. The Central Pollution Control Board [12] defined the term MSW as the leftover materials consisting of garbage from household including kitchen waste, waste from the street-sweeping, and construction and demolition debris. Commonly, MSW is classified into three main categories: (1) organic materials including kitchen waste, vegetable waste, agricultural waste and yard waste, (2) inert materials like sand, dust, gravels etc. and (3) recyclable waste like glass, metals, paper, plastics and tin cans. In developing countries, majorly in urban areas, the problems associated with the efficient waste management are more acute than in a developed country [13, 14] as major fraction of the waste is either managed unscientifically or not properly attended. MSW in urban centers has outpaced the population growth in recent years. The unscientific approach for managing the waste is not only placing stress on all the scarcely available resources but also has aggravated various problems related to pollution, land use, hygiene and the health of the people [15, 16]. For a better future and sustainable development, it becomes necessary to understand the sources, composition, waste generation rate, collection, transportation and disposal practices for efficient planning and managing the solid waste for a particular area.

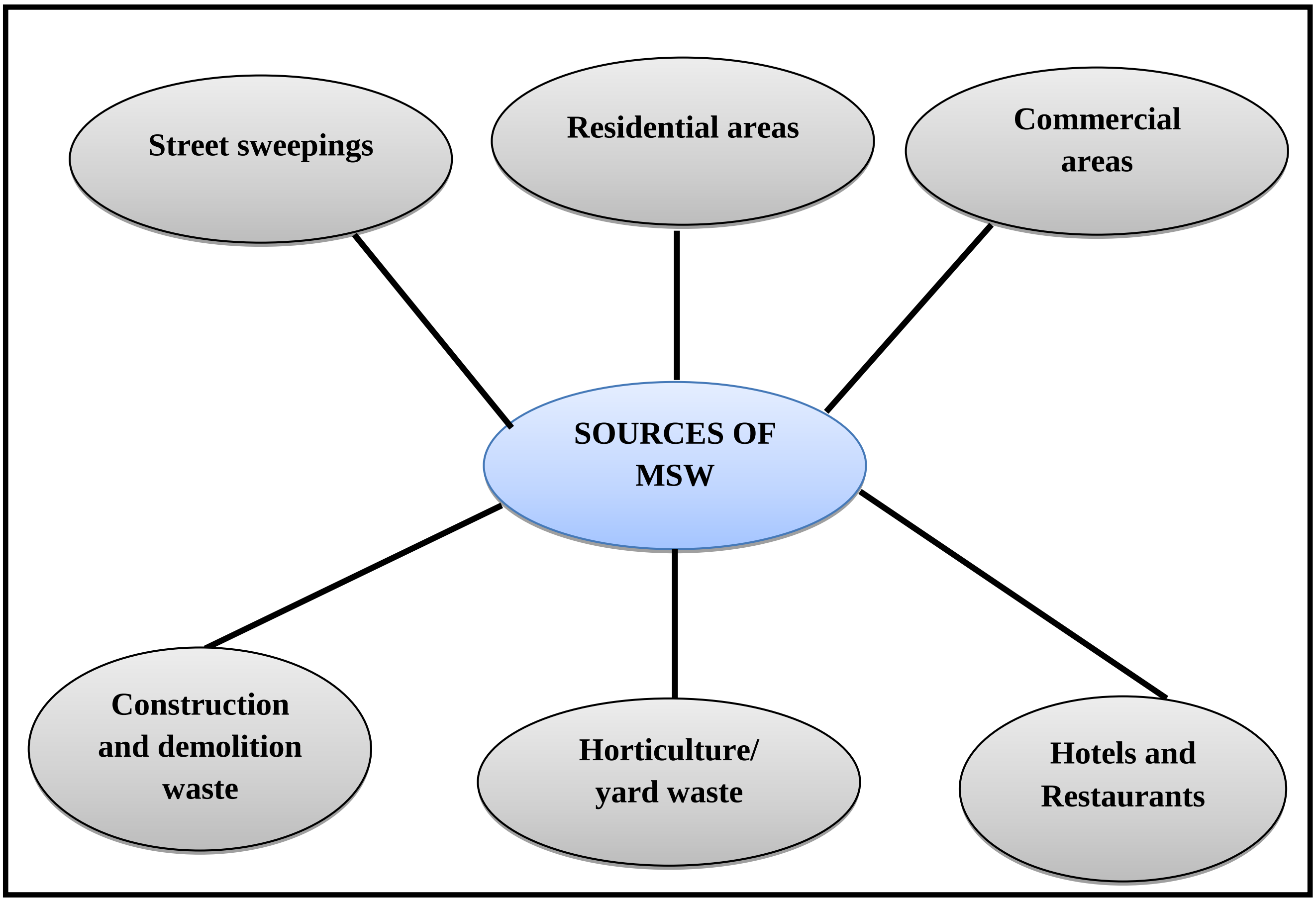


Figure 1.1: Sources of solid waste

1.2 Waste Generation Scenario

It is a familiar datum that humans are the principal factors for disturbing the ecological diversity in the environment which has finally arise in the form of environmental pollution. A survey onducted by [17] states that the solid waste disposal is the second most serious problem being confronted in various cities. The global population rose to 7.4 billion in 2016 and majority of people living in developing countries [18]. Current global MSW generation levels are approximately 1.3 billion tonnes per year and are expected to increase 4.3 billion by 2025 [18]. In Asia urban areas are generating MSW in the range of 103-760 TPD [19, 20, 21]. USA has the highest per capita generation rate of 2.58 kg/day [18]. Similarly countries in the EU like Germany, France and UK, have higher per capita generation rates of 2.11kg/day, 1.92kg/day and 1.79 kg/day respectively. In context of the developed countries in Asia, Japan and China have greater per capita generation rate of 1.71kg/day and 1.02kg/day. Amongst BRICS country, the per capita generation of MSW is less than other developed countries but is still significantly greater than India. For example, Russia has a per capita generation of 0.93 kg/day while Brazil has a generation rate of 1.03 kg/day per capita. *Figure 1.2* represents the generation of waste in various countries.

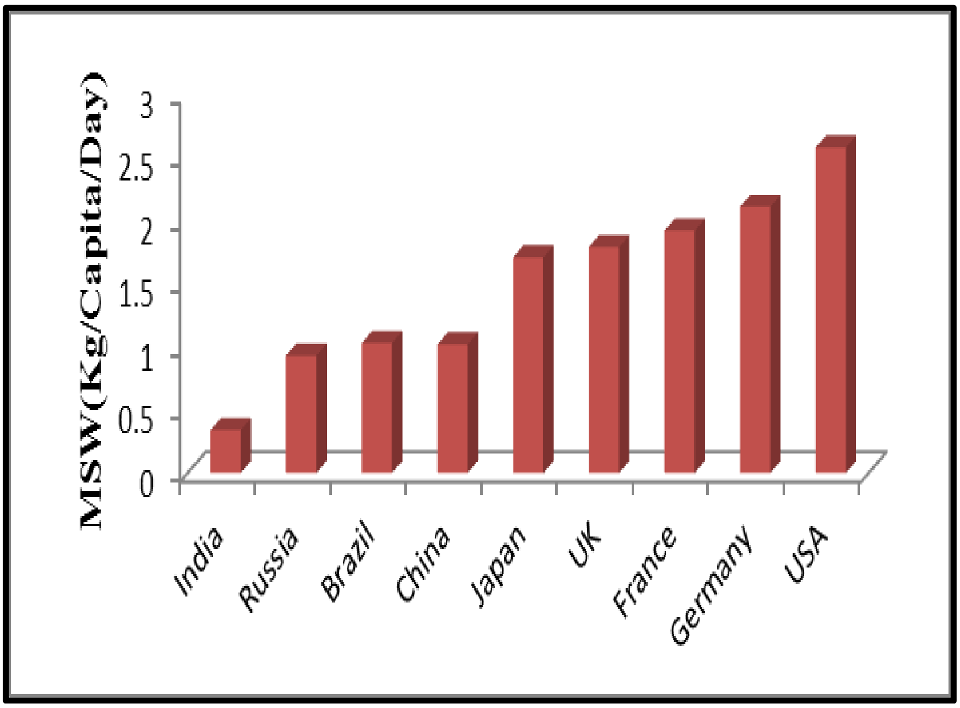


Figure 1.2: MSW generation in various countries

[18]

The waste management becomes a great challenge in developing countries. The per capita MSW generation in India ranges for 350-600 g/capita/day [22, 23, 24]. The gross domestic product (GDP) of a country is also correlated with the per capita waste generation as high income countries are found to generate more waste as compared to low income countries. The range of average MSW generation in low income, middle income and high income countries has been given in *Table 1.1*.

Table 1.1: Average MSW generation rates by income

Income Level	Average MSW generation (kg/capita/day)
Low Income	0.6-1.0
Middle Income	0.8-1.5
High Income	1.1-4.5

[18]

The composition of MSW (physical and elemental) plays a vital role and also varies among various countries, regions and cities which leads to major difference in composition of MSW in developed and developing countries [8, 25, 15, 26]. The MSW generated in the developed countries generally tend to have lower densities with lesser organic fraction although the presence of recyclable materials like paper and plastics are on a higher side. Whereas, MSW generated in developing countries is rich in organic fraction along with high density and inert materials. The composition of MSW in developed and developing nations is presented in *Table 1.2*.

Waste management technologies and policies are followed up more efficiently in developed countries as compared to the developing nations which reduces the harmful environmental impacts of waste. Studies [27, 28, 29, 4] have reported that more than 50% of the waste produced in low income group countries remains unattended due to lack of collection services. Emphasis must be on acquiring sound waste management which not only should ensure proper disposal of waste but focuses on reducing the waste by opting 4-R’s methodology (reduce, reuse, recycle and recover).

Table 1.2: MSW Composition in different countries

Country	Organic*	Plastic*	Paper*	Metal*	Glass*	Others*
USA	25	9	38	7	6	15
Canada	34	11	29	6	7	13
Mexico	53	4	14	3	7	19
Japan	27	9	45	8	7	4
Denmark	40	8	33	3	6	10
Australia	51	7	23	5	7	7
France	27	10	30	10	10	13
Bangladesh	84	1.7	5.7	3.2	-	3.2
India	42	3.9	5.7	1.9	2.1	44.6
China	36	3.8	3.7	0.3	2	54.2
Nepal	80	2.5	7	0.5	3	7
Sri Lanka	76	5.7	10.6	1.3	1.3	5.1
Malaysia	43	11.2	23.7	4.2	3.2	14.7
Hong Kong	37.2	15.7	21.6	3.9	3.9	17.7

[18], *values in %

1.3 Status of Solid Waste Management in India

With rapid urbanization and globalization coupled with large population in India, there has been rapid change in consumer patterns in India leading massive quantities of generation of Municipal Solid Waste (MSW) [30, 31] along with its unscientific handling leading to degradation of environment causing health hazards. An efficient MSW management system refers to a combination and interrelationship of elements like waste generation, collection, storage, transportation and disposal as shown in *figure 1.3*. Like any other developing country, India also follows the basic footsteps in expressing the MSW management as "not in my backyard" syndrome and leaves it entirely to be taken care by municipal authorities [32]. According to the constitution act, 1992 (74th amendment) in India, municipal authorities are responsible for the management of solid waste within their respective boundaries. The management of MSW in India has risen to be a severe problem not only because of the environmental and aesthetic concern but also because of the enormous amount being generated every day [12]. As the Central Pollution Control Board of India (CPCB) the total amount of MSW generated is 1, 27,486 TPD of which 89,334 TPD (70%) is collected and 15,881 TPD (13%) is processed or treated. However, MSW management in India remains the most neglected areas due to financial and infra-structural constraints, lack of awareness and weak implementation of laws [33, 34, 35].

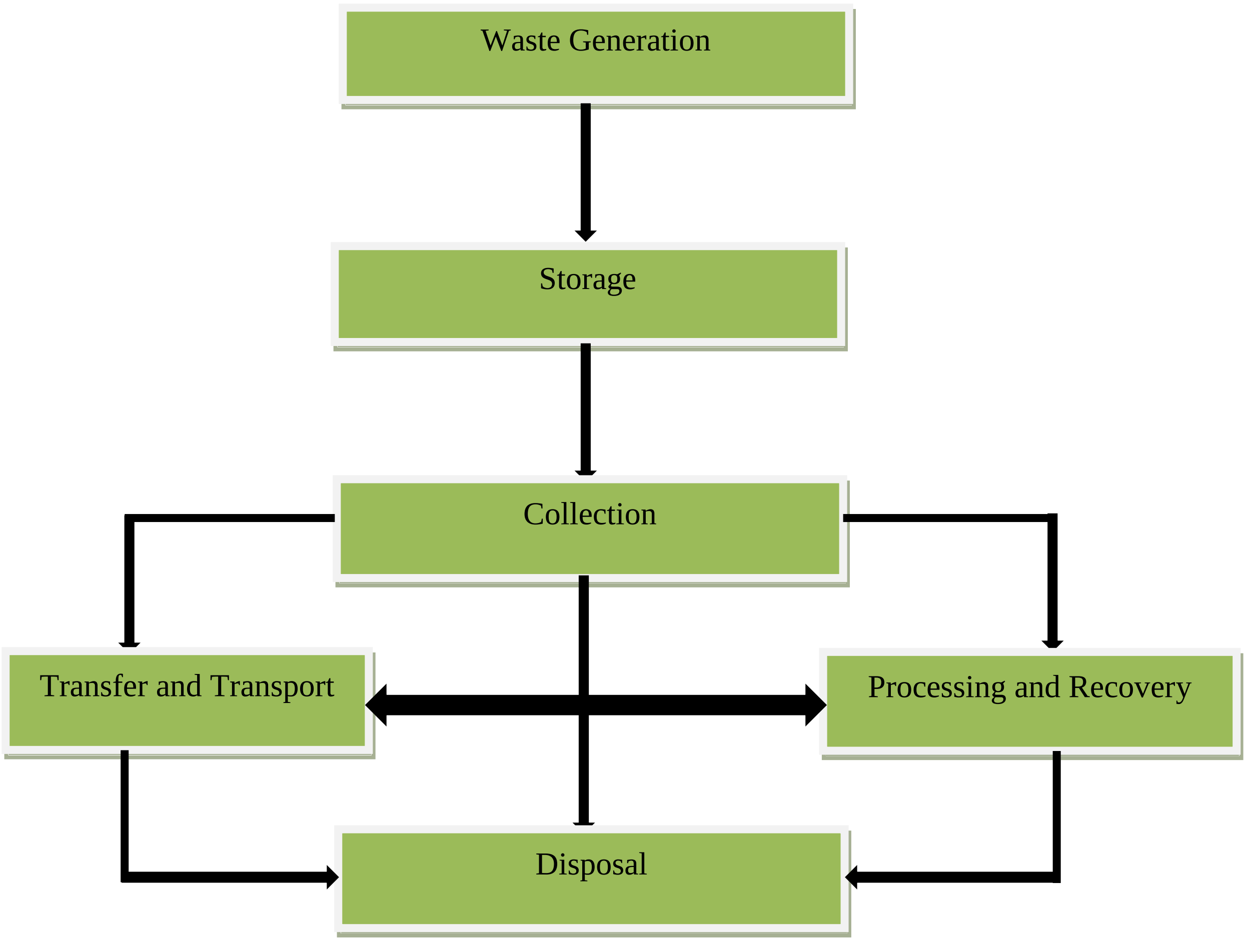


Figure 1.3: Interrelationship of functional elements of MSW system

Over the past few decades, India has witnessed high population growth particularly in urban areas, mainly due to the migration of people which leads not only to the generation of high amount of solid waste as well as put tremendous pressure on resources. As per Census of India, 2011; the population of urban India is 377 million, which accounts for 31% of the total population. Presently, urban population in India generates about 1, 43,449 Metric Tons per day (MTPD) of MSW [2, 36, 37, 38]. For an effective waste management system utilization of data including quantity, quality and composition (both physical and chemical) of waste (from different socio-economic groups) plays a very vital role. As such, these parameters depend on number of varied factors like living standards, seasonal variations, food habits, source of generation and socio-economic conditions of the area [10, 39, 123]. An outline of waste statistics and population in India over the past few years and a future projection till 2031 is presented in *Table 1.3*. The present population of India [40] is 1.324 billion with a decennial growth of 17.64%.

Table 1.3: Population and Waste statitics in India

	1947	**1971**	**1991**	**2001**	**2011**	**2021**	**2031**
Urban Population (million)	56.9	109	21.7	285	377	530	600
Daily per capita waste generated (kg/day)	0.295	0.3	0.37	0.44	0.50	0.65	0.79
Total waste generated (million tons/year)	6.0	14.9	23.86	39	49	70.15	107.01

[40, 18]

Table 1.4 shows the state wise MSW generation in Indian cities. In India, because of the lack of data on the per capita waste generation and characteristics, different studies [41, 42, 43] have reported different values and projections. The per capita waste generation in India is estimated to rise at a rate of 1% to 1.33% annually. *Figure 1.4* presents the projected rise in MSW from 1997 to 2047. Proper management of MSW is a complex process which has been further affected due to reduced budgetary provisions available to the municipal authorities [44, 45, 46, 47, 48, 11, 49, 50, 51]. As a result of the existing practices and non-implementation of proper legislative guidelines, about 90% of the MSW generated in India is openly dumped or burned leading to contamination of the surrounding environment [52, 53, 54, 55, 56, 57, 58, 59].

Table 1.4: State-wise MSW Generation in India

S.No	Name of the State/UT	Municipal Solid Waste MT/Day (2009-2012)	S.No	Name of the State/UT	Municipal Solid Waste MT/Day (2009-2012)
1.	Andaman & Nicobar	50	18.	Lakshadweep	21
2.	Madhya Pradesh	4500	19.	Maharashtra	19204
3.	Uttaranchal	752	20.	Manipur	112.9
4.	Assam	1146.28	21.	Meghalaya	284.6
5.	Bihar	1670	22.	Daman Diu & Dadra	41
6.	Orissa	2239.2	23.	Andhra Pradesh	11500
7.	Chhattisgarh	1167	24.	Nagaland	187.6
8.	Mizoram	4742	25.	Chandigarh	380
9.	Delhi	7384	26.	Puducherry	380
10.	Goa	193	27.	Punjab	2793.5
11.	Gujarat	7378.775	28.	Rajasthan	5037.3
12.	Haryana	536.85	29.	Sikkim	40
13.	Himachal Pradesh	304.3	30.	Tamil Nadu	12504
14.	Jammu & Kashmir	1792	31.	Tripura	360
15.	Jharkhand	1710	32.	Uttar Pradesh	11.585
16.	Karnataka	6500	33.	Arunachal Pradesh	93.802
17.	Kerala	8338	34.	West Bengal	12557
					Total **127485.107**

[12]

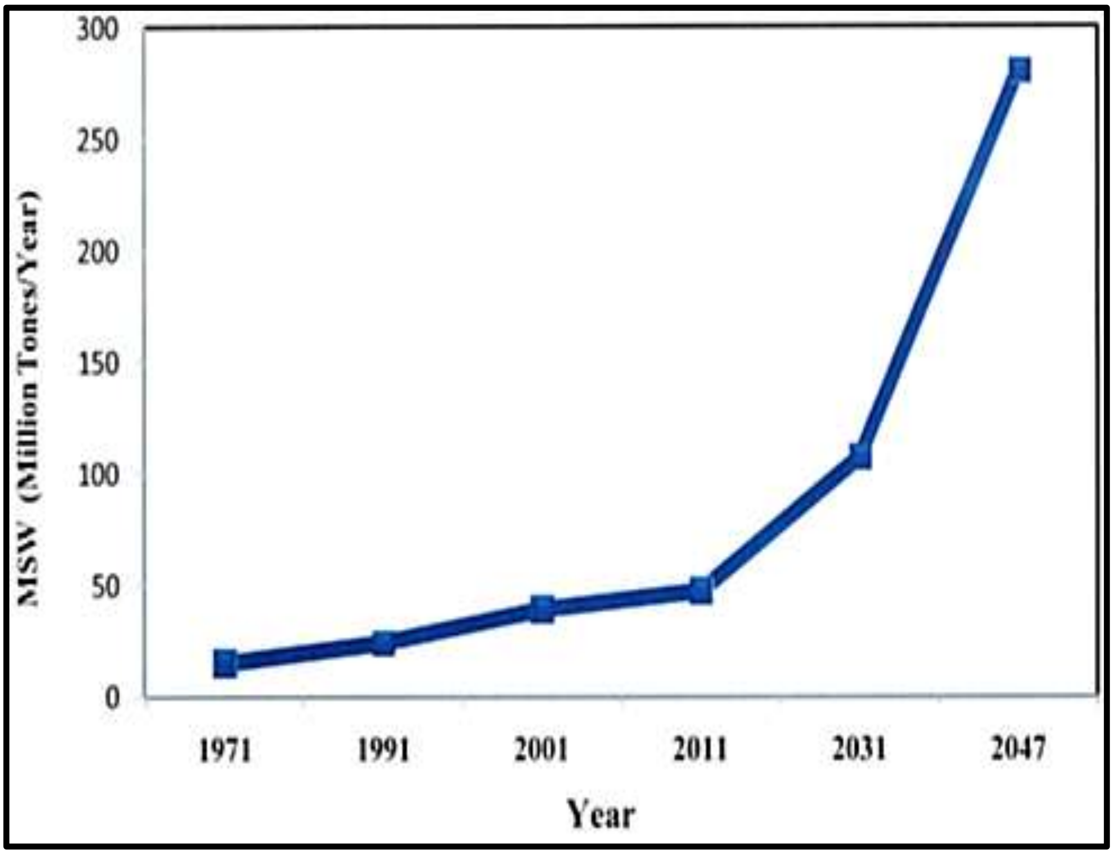


Figure 1.4: Predicted trends in the generation of MSW

[59, 73]

1.3.1 Generation of Waste

Generation of MSW has a strong correlation with the population of the area or a city. India is growing and so are the mountains of waste its cities and villages are producing. The generation of MSW begins with the daily routine activities of the day. The quantities of MSW generated are highly influenced by economic development, geographic locations, variations in seasons, lifestyle and standard of living and population [18, 25]. So it becomes essential to acquire data on quantity variation and generation for implementing effective MSW management practices and efficient recovery of resources [8]. For an effective waste management strategy it is necessary to identify the nature and composition of the waste [60, 58, 61, 62, 51]. *Figure 1.5* shows the typical average physical composition of MSW in India.

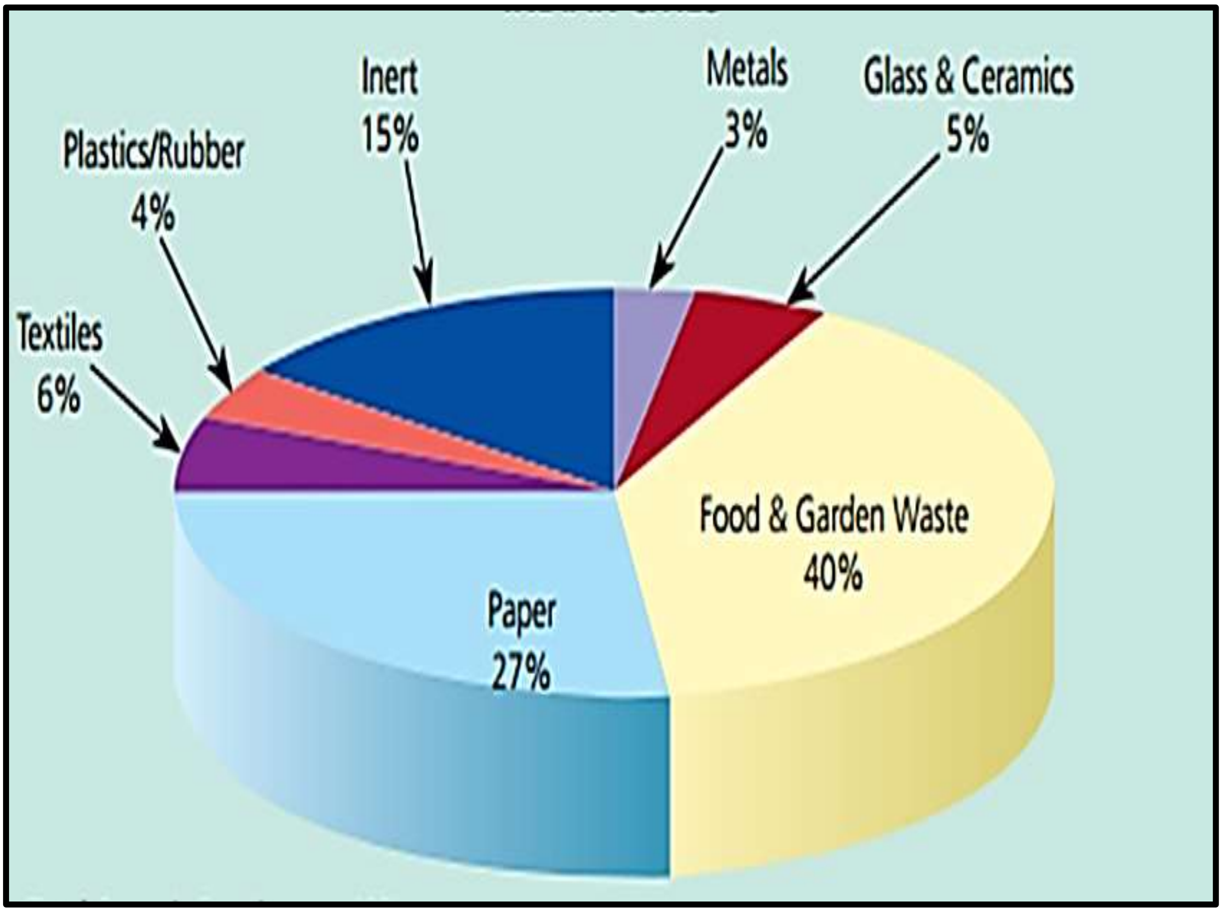


Figure 1.5: Composition of MSW in India
[73]

In developing country like India, reports states that the organic fraction of MSW varies between 35 to 60% in different parts of country [8, 11]. The organic fraction includes paper, plastics, yard waste, food waste, wood, textiles and disposable diapers [63, 51, 7, 64, 65, 123]. The organic matter in MSW in developing countries like India is much higher than that in the waste in developed countries [67, 66, 68, 52, 69]. *Table 5.1* presents the composition of MSW in Indian cities and *Table 1.6* and *1.7* gives the overview of the physical and chemical composition as per populations.

Table 1.5: MSW Compostion in Indian cities

City	Organic Matter*	Textile*	Leather*	Plastic*	Metals*	Glass*	Ash*	Paper*	Moisture Content*
Ahmadabad	41.0	1.0	-	3.0	-	-	50.0	6.0	32.0
Bengaluru	52.0	5.0	-	6.0	3.0	6.0	27.0	8.0	35.0
Bhopal	52.0	5.0	2.0	2.0	-	1.0	35.0	10.0	43.0
Mumbai	62.0	4.6	0.4	2.0	-	0.2	44.0	12.0	54.0
Delhi	54.0	5.6	0.6	1.5	2.9	1.7	51.5	6.8	50.0
Hyderabad	51.0	1.7	-	1.3	-	-	5.0.0	7.0	50.0
Jaipur	45.0	2.0	-	1.0	-	2.0	47.0	6.0	40.0
Lucknow	49.0	2.0	-	4.0	1.0	-	50.0	4.0	60.0
Ludhiana	45.0	6.0	-	5.0	2.0	-	50.0	3.0	50.0
Pune	55.0	-	-	5.0	-	10.0	15.0	5.0	40.0
Surat	40.0	5.0	-	3.0	-	3.0	45.0	4.0	30.0
Kolkata	51.0	5.5	0.5	1.7	0.4	1.6	50.0	10.0	46.0
Puducherry	50.0	4.0	-	2.0	0.2	1.5	26.0	11.0	54.0

[12] *Values in %

Table 1.6: Typical Physical characteristics of MSW

Population (million)	Organic Fraction (%)	Recyclables (%)	Moisture Content (%)	Calorific Value (kcal/kg)
0.1-0.5	29-63	14-37	65	591-3766
0.5-1	35-65	11-24	17-64	591-2391
1-2	39-54	9-25	25-65	520-2559
>2	40-62	11-22	21-63	800-2632

[24, 73]

Table 1.7: Typical Chemical characteristics of MSW

Population (million)	Nitrogen (total nitrogen) (%)	Phosphorous (P_2O_5) (%)	Potassium (K_2O) (%)	Carbon: Nitrogen Ratio
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

[24, 73]

1.3.2 Collection and Storage

For an effective MSW management system, the collection efficiency of waste must be equal to or higher than the rate of waste generated [5, 11]. MSW collection is an important aspect in maintaining the public health in cities or towns. Collection of MSW involves the assembling of waste from various points of production like residential, commercial and institutional to the site of disposal [6, 11, 70]. The methods developed for the collection of waste are generally classified on the basis of type of waste collected and mode of operation [3, 6, 11].

Based on the mode of operation, the collection systems are categorized as: - hauled container systems (HCS) and stationary container systems (SCS). Container systems in which the containers used for storage are hauled to the disposal sites and then returned back to the original location after emptying are defined as HCS [3, 6] Whereas for SCS, the waste storage container remains at their original location [3,6]. It has been reported in many studies [8, 5, 71, 26] that MSW is stored and collected in the common bins without any segregation. Storage bins can be classified as movable and fixed bins. In India, types of bins used for collection of waste include reinforced cement concrete (RCC), masonry, plastic and metallic containers. Collection bins used in various cities are not properly designed and installed which results in poor collection efficiency.

As per the Municipal Solid Waste Management Rules, 2016 [72], it is the responsibility of the municipalities to prohibit littering of waste in cities, towns and in urban areas. To facilitate this, the authorities of municipalities have organized house to house collection by community bin collection and pre-informed collection timings etc. which can be helpful in increasing the collection efficiency. It has been observed from various studies that collection efficiency of waste in Indian cities has an approximate value of 70% [11]. *Table 1.8* shows the collection efficiency of MSW of Indian cities.

Table 1.8: Collection efficiency of MSW in Indian cities

City	Collection efficiency (%)	City	Collection efficiency (%)
Mumbai	96.6	Madurai	51.6
Chennai	90	Pune	70
Bengaluru	68.1	Baroda	60
Coimbatore	64.6	Bhopal	93.5
Ahmedabad	90	Andhra Pradesh	74
Kanpur	70	Bihar	59
Indore	83.3	Gujrat	61

[12]

1.3.3 Transportation

In the field of solid waste management, the functional element of transportation refers to the means or facilities used to transfer the wastes from one location to another [6]. Most commonly used vehicles are trailers, semi-trailers, compactors, tippers and dumpers, hand carts, tri-cycles, electric carts, trucks and trolleys. Factors which are taken into consideration for transportation of the waste include the cost, density of the waste, route followed, and capacity of vehicles and design of vehicles [6]. In India, around 70% cities lack the adequate transportation facilities [73]. Many studies have reported that the vehicles used for transportation of the waste in Indian cities are outdated and designing of the vehicles is also not proper. This leads to increase in operations and maintenance costs, reduces transfer efficiency and ultimately causes the air as well as noise pollution [12]. The vehicles must be maintained properly so as to avoid such problems. In most of the cities, vehicles are provided by the municipalities but in some cities private contractors are hired for collection and transportation of the waste [74, 16]. The collection and transportation activities alone utilizes approximately 80 to 90% of the total budget allocated for solid waste management leaving very less funds for the treatment and disposal of waste.

1.3.4 Waste Treatment and Disposal

Disposal on or in the earth's mantle is at present, the only viable method being followed for long-term handling of waste [6]. Land filling of MSW is considered most economical and viable practice for waste management in many parts of world [75, 76, 77]. In India, dumping of MSW on non-engineered land fill sites (or open dump sites) accounts for more than 90% of disposal conditions [78, 79]. Even though, treatment processes like segregation, recycling, composting and incineration processes are often used, direct disposal on the landfill sites remain the most preferred way for disposal of solid waste [80]. Further, environmental inequality studies show that such waste facilities are often disproportionally located in the most deprived regions or locations where minority groups reside [81, 2], leading to the unequal pollutant exposure. Unscientific dumping of solid wastes leads to several associated environmental hazards like air, soil and ground water pollution causing adverse public health impacts [82, 83, 84]. In particular, contamination of ground water by leachate generated from unlined landfill sites is highly predominant and is most prevalent in developing countries due to disposal of MSW in open dump sites [2, 85, 86, 87, 66, 68].

The MSW generated in Asian countries including India consists of high fraction of organics and due to tropical climate, they get dissolved in rainwater or in runoff generating leachate which depending on soil permeability can cause ground water contamination [76, 86, 87]. Characteristic properties of leachate vary and depends on the actual composition of the MSW, precipitation, site hydrology, interaction of leachate with environment, landfill design and operation procedures [88, 89, 62]. Contamination of groundwater by leachate is a serious environmental hazard and can stay undetected for long periods [90, 62, 91] thereby making it unsuitable for drinking or other miscellaneous purposes [77].

It has been stated that no single technology is sufficient for attaining sustainable management of waste owing to the diverse composition of waste therefore a combination of technologies like sanitary landfilling, composting, refuse derived fuel (RDF), recycling and incineration etc. must be adopted to attain integrated waste management system. In India, the major fraction of waste comprises of organics followed by paper and plastics. Therefore, for treatment of MSW, by means of composting (aerobic, anaerobic or vermi-composting) and waste to energy (bio-methanation, gasification and incineration) are mainly adopted in Indian cities. *Table 1.9* shows the treatment and disposal of MSW in Indian cities.

Table 1.9: Disposal and Treatment of MSW in Indian municipalities

City	Disposal (%)	Treatment (%)
Mumbai	91	9
Ahmedabad	95	5
Hyderabad	94	6
Bhopal	82	18
Surat	75	25
Chandigarh	30	70

[12, 196]

1.4 Environmental Impacts of Solid Waste

It is very important to ensure a safe and proper disposal of the generated solid waste to maintain the serenity and the efficiency of the city. However, disposal of solid waste is a serious problem because if burnt it can lead to increase in air pollutants and if openly dumped can lead to soil and water contamination of the surrounding regions [11, 22, 23, 92]. In developing countries including India, unscientific disposal methods are most common and it has been reported that about 90% of the solid waste produced in India is dumped off directly in the landfills in an unsatisfactory manner particularly in the bigger cities and towns [11, 93]. Landfill gas emissions emanating from landfills are also responsible for causing global climate changes [94]. This has led to an increased awareness in disposing of the generated solid wastes in more environmental friendly manner [95, 96]. The major portion of MSW includes organic fraction, therefore soon after the dumping of the waste, the biodegradable portion of the waste undergoes changes leading to the generation of harmful gases and leachate. The effect of leachate on the surface and ground water has been described in a number of different studies [16, 97, 98, 52, 99]. The problem is further compounded as landfills have the potential to generate leachate for a number of years even after the closure of landfill sites [100, 101, 102, 103, 104, 105]. The studies have shown that areas near the landfill have a higher chance of ground water contamination because of the potential pollution source of leachate originating from the nearby sites [16, 106, 46]. *Figure 1.6* gives the overview of the various environmental impacts caused due to unscientific disposal of MSW.

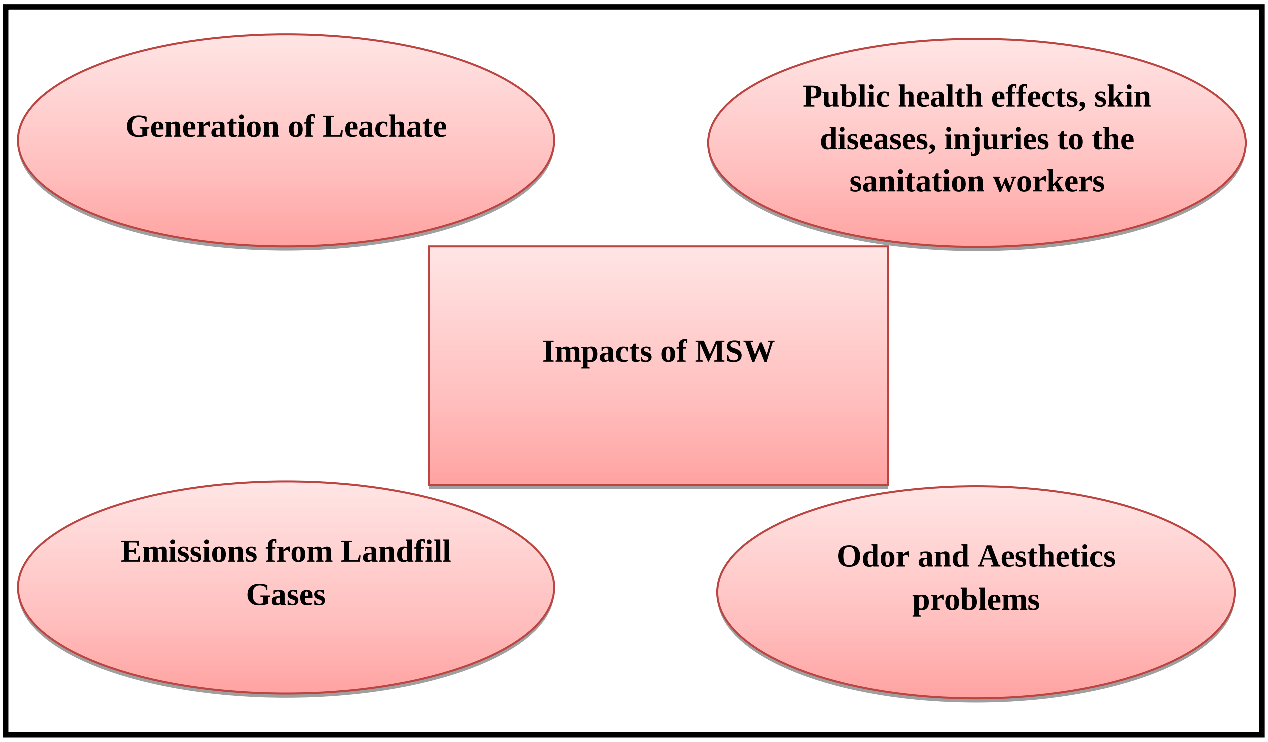


Figure 1.6: Impacts of MSW

1.4.1 Leachate Generation

Leachate is defined as liquid that has percolated through waste and has extracted materials (suspended or dissolved) present in the waste. Leachate from the landfills is generated owing to number of factor like infiltration of ground water, precipitation, water from the deposited waste and evaporation from the site. Leachate discharge is a growing concern as it is characterized by high concentration of organic and inorganic chemicals [11, 107, 19, 108, 109, 97]. The pollutant load in leachate can be divided into four major groups including dissolved organic matter, inorganic salts, heavy metals and xenobiotic organic compounds [110, 52, 107]. Few studies have also reported the presence of hazardous organic compounds like chlorinated aliphatic, phenols, phthalates and pesticides in leachate [111, 123, 16, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121]. The problem is further compounded as landfills have the potential to generate leachate for a number of years even after the closure of landfill sites [100, 102]. The studies have shown that areas near the landfill have a greater possibility of ground water contamination because of the potential pollution source of leachate originating from the nearby sites [16, 106, 47]. The pollutants from the landfill leachate can enter into the food chain through the vegetation grown in nearby areas causing more harmful effects. Though numerous studies [122, 123, 124, 125, 126] have reported presence of heavy metals in leachate, detection of these metals in such low concentrations using existing chemical analysis methods is a major limitation [110, 117]. Hence, toxicological analyses are currently considered to be an improved method for assessment of chemical composition along with the toxicity potential of the leachate [124]. The combined study of both chemical and toxicological characterization determines not only the long term impact and adverse effect on human and ecosystem but also gives a suitable risk assessment [127, 128, 30,]. The representative data on the characteristics of leachate is reported in *Table 1.10*. The leachate should either be contained within the landfill or removed for treatment.

Table 1.10: Characteristics of leachate generated from MSW

Parameters	**Values (mg/l)**	
	Range	**Typical**
pH	5.3-8.5	6
BOD_5 (5-day Biochemical Oxygen Demand)	2000-30,000	10,000
COD (Chemical Oxygen Demand)	1500-20,000	6000
Total Suspended Solids	3000-45,000	18,000
Organic Nitrogen	10-600	200
Ammonia Nitrogen	10-800	200
Total Phosphorous	1-70	30
Alkalinity as $CaCO_3$	1-50	20
Calcium	200-3000	1000
Magnesium	50-1500	250
Potassium	200-2000	300
Sodium	200-2000	300
Chloride	100-3000	500
Sulphate	100-1500	300
Total Iron	50-600	60

All Values in mg/l except pH; [3, 6]

1.4.2 Landfill Gas Emissions

Gases found in landfills include air, ammonia, carbon monoxide, carbon dioxide, hydrogen, hydrogen sulfide, methane, nitrogen and oxygen. Methane and carbon dioxide are the principal gases produced from the anaerobic decomposition of the organic based waste components. Landfill gases are a serious threat to environment associated with the disposal of waste. *Table 1.11* shows the constituents in MSW landfill gas.

Table 1.11: Components in MSW landfill gas

Components	Percent (dry volume basis)
Methane	45-50
Carbon dioxide	40-60
Nitrogen	2-5
Oxygen	0.1-1.0
Sulfides, disulfides, mercaptans etc.	0-1.0
Ammonia	0.1-1.0
Hydrogen	0-0.2
Carbon monoxide	0-0.2
Trace constituents	0.01-0.6

[3]

The landfill gase thus generated in a landfill involves five main phases: initial adjustment, transition phase, acid phase, methane fermentation and maturation phase. *Figure 1.7* gives an overview of the various phases involved in production of landfill gases. The anaerobic conversion of organic fraction of waste into by products can be represented by following reaction:

$$\mathbf{C_aH_bO_cN_d + H_2O \longrightarrow nC_w\,H_x\,O_y\,Nz + CH_4 + CO_2 + H_2O + NH_3 + other\ gases}$$

(Organic fraction of waste) **(Biodegraded organic fraction ofwaste)**

Where, the expressions- '$C_a\,H_b\,O_c\,N_d$' and '$nC_w\,H_x\,O_y\,Nz$' represent the composition of the substantance present at the start and end of the process.

The emission of gases from the landfill depends upon the quantity and composition of the MSW. Methane is estimated to account for 3% to 19% from the anthropogenic sources in the world [129]. Emission of gases from the open dump sites are directly released to the atmosphere and are measured as the major contributor to global warming due to emission of methane (CH_4), a major greenhouse gas (GHG). India currently produces about 16 tons of CO_2 equivalents per year which is predicted to rise up to almost 20 ton of CO_2 equivalent per year by 2020 [130]. Appropriate remedial measures like scientifically planned landfill with provision of tapping landfill gas for its fuel value must be taken to ensure that there is no direct emission of these harmful landfill gases in the atmosphere.

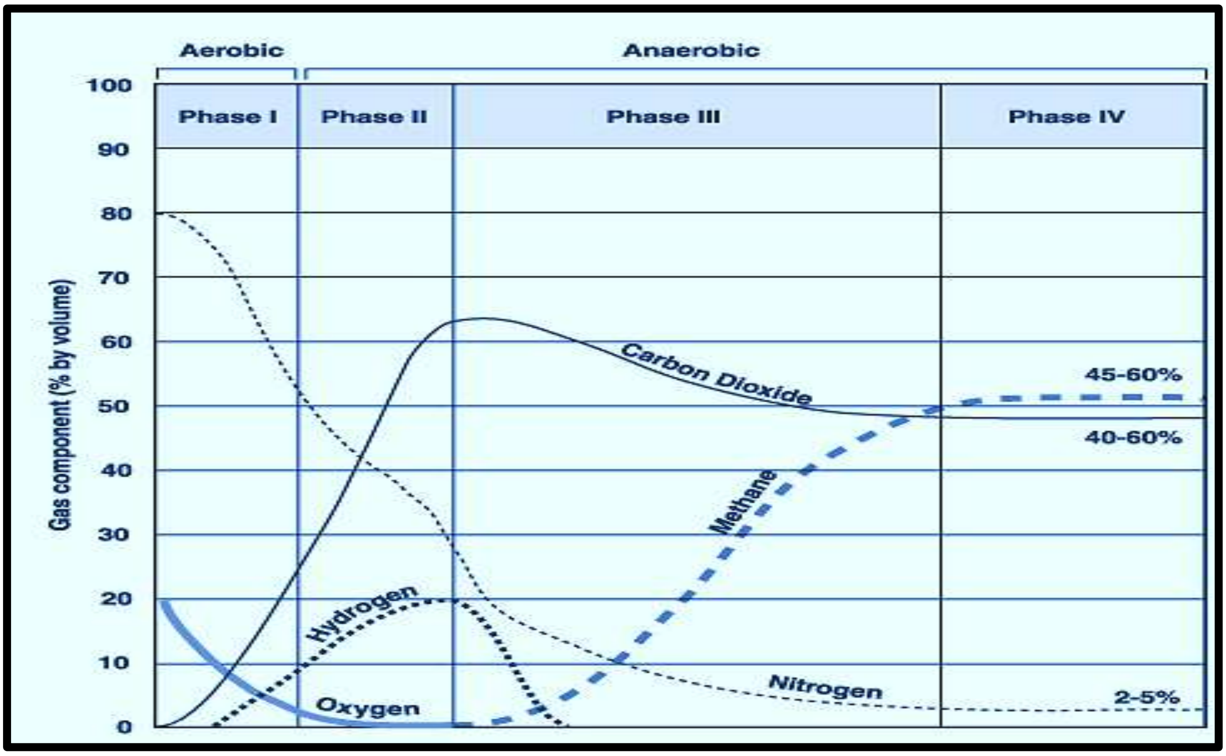


Figure 1.7: Phases in generation of landfill gases
[3, 6]

1.4.3 Risks to Public Health

The potential risks to health from improper handling of solid waste concerns mainly the workers in this field who need to be protected as far as possible from contacting with wastes directly. The health problems may be caused due to inhalation of smokes or fumes emanating from the open burning of the waste or the bio aerosol compounds present in the organic fraction of the waste. Majorly the bins used for collection of waste or open and insufficient in volume, which creates havoc and nuisance to public. A number of studies have reported [16, 33, 34, 58, 11, 123] that the rodents, insects and pests present in the waste transmit the pathogenic agents leading to problems like plague, diarrhea, cholera, gastrointestinal worms, parasites and fever etc. and most commonly affected are either the individuals residing near the disposal sites or the sanitation workers. Moreover, due to the casual attitude, lack of awareness and work culture, the waste handlers are exposed to various hazards caused from MSW.

1.4.4 Other Impacts

Apart from the production of leachate and harmful landfill gas emissions, other potential impacts like odor and aesthetics problems are also associated with the disposal of MSW. The odorous compounds like hydrogen sulphide, hydrocarbons, esters and organosulphurs are responsible for odor which creates environmental nuisance. The presence of these odorous compounds is influenced by waste composition, weather conditions, decomposition stage and microbial activities. The improper handling of the waste leads to littering in streets which causes clogging of drains, breeding of insects, rodents and spreading of diseases. A very recent incidence of Delhi, Ghazipur landfill collapse is an example of improper solid waste management. The episodes like these and many more require responsiveness and alertness of whole country indicating that the appropriate management of the waste is necessary for well being of the public as well as environment.

1.5 Policies for Waste Management in India

Many rules and policies have been framed from time to time to tackle the problem of waste with an aim to lessen the risks to health and environment [11]. In the ancient time, it was considered a sin to pollute the air, water or land as they were regarded as a 'God' and 'Goddesses'. The emphasis was to maintain hygiene, cleanliness and uncontaminated atmosphere. Government of India (GOI) has initiated in making efforts for management of solid waste by providing financial supports to the municipalities initially under the 4^{th} five year plan (1964-1974). These plans were then further improved by forming National Scheme of Solid Waste Disposal, setting up of many composting plants etc. in the country. Ministry of Environment and Forest [72] in the year 2000 had set up guidelines for collection, segregation, storage, transportation, processing, treatment technologies and dumping of waste. These guideline and policiess were recently renewed and are now called as Solid Waste Management Rules, 2016 [72]. *Table 1.12* gives an overview of rules formulated for different types of waste.

Table 1.12: Various waste management rules in India

Rules	Objectives
The Environment (Protection) Act, 1986	Protection and improvement of environment,prevention of hazards to human beings, any other living creature, plants and properties
The Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016	To encourage the proper management of hazardous waste to evadeany damage to human health and environment
Plastic Waste Management Rules, 2016	Prevent manufacturing and sale of recycled plastic bags for packaging of food and ban on using and throwing of non-biodegradable plastics in drains or public places
Bio-Medical Waste Management Rules, 2016	Control indiscriminate disposal of hospital or bio-medical waste
Solid Waste Management Rules, 2016	To set guidelines for collection, storage, transportation, treatment and disposal of MSW to reduce its environmental impacts
E-Waste Management Rules, 2016	To enable recovery and reuse of valuable and beneficial material from Waste Electrical and Electronics Equipment (WEEE) so as to have an environmentally sound management
Construction and Demolition (C&D) Waste Management Rules, 2016	Control indiscriminate dumping of C& D waste along with MSW and make separate disposal sites used particularly to dump the waste

Solid Waste Management Rules, 2016 have laid down the guidelines and procedures for the collection, segregation, storage, transportation, processing and disposal of MSW throughout India. These policies are applicable to all the municipalities and are made in order to make the municipalities responsible towards the practice of guidelines for an effective waste management. These rules are divided into main two schedules as given in *Table 1.13*. Many rules and regulations have been framed in India, still the existing waste management practices face many short comings as compliance to these rules are not upto the mark.

Table 1.13: Schedules for MSW Rules, 2016

Schedule- I	Criteria for site selection, development of facilities at sanitary landfills, criteria for specifications for landfilling operations and closure on completion of landfilling, criteria for pollution prevention, criteria for water quality monitoring, ambient air monitoring, plantation at landfill site, post-care at landfill site, criteria for special provisions for hilly areas and closure and rehabilitation of old dump sites
Schedule- II	Standards for processing and treatments of solid waste, standards for treated leachates, standards for incineration and standards for composting

1.6 Need for the study

MSW is considered as a doorway of environmental problems as each individual deals with the waste in every single day of their lives along with the growing issues around MSW than for any other environmental concern. Whatever the reasons for the attention it receives, it is clear that MSW treatment systems and the associated environmental effects are not very well quantified. The composition of solid waste varies with different factors like climatic conditions, living standards and socio-economic factors [123]. Hence, it becomes important to take into consideration all the factors before implementing waste management strategies. In the past, majority of the studies [107, 108, 109, 16, 19, 123] reported for India are primarily based on Metropolitan and Tier-I cities like Mumbai, Kolkata, Pune, Bangalore, New Delhi etc. Very limited studies have been reported for characterization of municipal solid wastes in Tier-II cities of India [11, 123]. As such, the study highlights the MSW management and characterization from one of the top tier-II cities of India. Further, no such studies of these cities have been reported in literature earlier which adds to the novelty aspect of the research work carried out in the context of these cities. Tricity is well-planned and has been designated as an important upcoming business city in India and hence with an increase in population and a possible increase in its business potential will lead to further increased MSW generation, hence it is important to evaluate the MSW management practices and waste generation scenario in the city to plan for the future.

Considering the present environmental and public health issues the present study aims to investigate the current waste management practices in Tricity of Chandigarh, Mohali and Panchkula, to identify the environmental implications of leachate generated from dumping sites and its effect on the ground water in the vicinity areas of the three cities.

1.7 Objectives of the Research Work

The main objectives of the study include:

1) To understand the existing waste management practices in Tricity of Chandigarh, Mohali and Panchkula.

2) To characterize (both physical and chemical) the municipal solid waste generated in Tricity.

3) Characterization of leachate and investigation of impact of leachate on ground water quality in the vicinity area of dumping sites of Chandigarh, Mohali and Panchkula.

4) To determine the Water Quality Index (WQI) and Leachate Pollution Index (LPI) for the present dumping sites of Chandigarh, Mohali and Panchkula.

5) To make a Life Cycle Assessment of potential municipal solid waste management strategies in Tricity.

1.8 Organization of Thesis

- The first chapter of the thesis provides a brief introduction to solid waste and trend of status and existing waste management practices in India. This chapter also highlights the environmental implications of unscientific management of municipal solid waste. Further, various steps taken by Government of India to improve waste management practices are also discussed.

- The second chapter deals with the detailed review of available literature and related studies carried out at national and international locations to find out the effect of solid waste dumping sites on environment.

- The third chapter provides an outline of the waste management options practiced in Tricity. Recommendations to improve the existing waste management practices in Tricity and for compliance of MSW management rules in more comprehensive manner are also presented in this chapter. A set of integrated solid waste management (ISWM) benchmark indicators called as the ‘wasteaware’ ISWM benchmark indicators, were generated for Chandigarh, Mohali and Panchkula along with the quantification method using matrix methodology for a better understanding of the system analysis approach carried out to help Tricity to evaluate its own performance as regard to delivery of SWM services provided, information for decision making on priorities for the limited funds available for service improvements and monitor changes over time.

- The fourth chapter provides a detailed characterization (both physical and chemical) of MSW to enable suitable decision making for proper management of solid waste generated. Majority of the characterization studies in the past have utilized different socio-economic groups using High Income Group, Low Income Group, and Medium Income Group. However, in the present study two more categories are included viz., institutional and commercial as they are responsible for 49% of the total MSW generated in the Tricity region.

- The fifth chapter presents environmental impact of leachate generation from the dumping sites of Tricity. Leachate samples were analyzed for various physico-chemical and biological parameters, heavy metals and toxicological analysis. It has been observed that leachate has shown high concentration of all physico-chemical and biological parameters analyzed. The toxicological studies along with the cytotoxic potential of leachate not only help in assessing the risk but also make projections on its long term impact and possible adverse effect on environment as well as humans in Tricity. The toxicity potential for polycyclic aromatic hydrocarbons (PAH's) present in the leachate is also presented. Methyl tetrazolium (MTT) assay for cytotoxicity was carried out in Neuro-2a cell lines to further evaluate the potential toxicity of the leachate samples. The chapter gives a detail of leachate pollution indexing which is used to examine the pollution potential from the dumping sites of Tricity. The toxicity potential of leachate in form of Leachate Pollution Index (LPI), gives an immediate assessment regarding remedial measures to be carried out at a landfill site.

- The chapter six presents the impact of leachate generated on the ground water quality in surrounding areas. Ground water samples were collected from the vicinity areas of dumping sites were analyzed for various physico-chemical, heavy metals and microbiological parameters. It has been observed that leachate generation from dumping sites has contaminated the ground water quality of surrounding area and there is need for leachate collection and treatment to prevent further degradation of water resources. The chapter also provides details of water quality indexing from all the three cities of Chandigarh, Mohali and Panchkula which were performed using the two methods, OWQI and BIS 10500 method. Both Oregon water quality index and WQI as per BIS 10500 creates a score which helps to evaluate the water quality by combining the various water quality variables into a single number hence making it easier to categorize the water quality parameters. Multivariate analysis viz., Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were also carried out to understand the interrelationships of the results obtained. These statistical tools help in classification, modelling and interpretation of large data sets and allow the reduction of data in the form of extraction of data which will be helpful for the water quality assessment.

- The chapter seven presents details of Life Cycle Assessment of potential municipal solid waste management strategies in Tricity. The study analyses the impacts of different potential waste management alternatives for Tricity using LCA approach. The most feasible system being the one which produces least environmental impacts. LCA sensitivity analysis is also performed with the main aim to identify how the final results are influenced by uncertainties in the data and to calculate the results of LCA in order to assess its reliability. The sensitivity analysis identifies sensitive parameters and assesses whether a small change in an input parameter would induce a large change in the impact category.

- The chapter eight discusses the detailed summary of the results and conclusions derived from the study. The chapter also gives the recommendations for the improvement of existing waste management practices in Tricity and also mentions the future scope of the research.

CHAPTER-2

LITERATURE REVIEW

2.1 Review of Literature

The chapter reviews the detailed literature survey both in terms of theory and experimentation. A brief literature review conducted helps in providing knowledge for further innovative, safe and efficient design for MSW management.

The generation of waste dates back as soon as man started wandering the earth. Majority of human activities will ultimately lead to the generation of huge amount of waste due to irrational utilization of resources and energy. A study [131] concluded that there is a close relationship between human and nature. Man's commercial activities and eagerness to maximize the profits are responsible for damage caused to the environment. Every year 11.2 billion tons of solid wastes are collected worldwide [132]. The latest World Bank reports predicted the annual global solid waste management costs will increase from USD 205.4 billion to about USD 375.5 billion by 2025 [18, 31] . Waste generation is a very vital aspect to look at in order to have an effective solid waste management [93, 133]. The generation of waste varies considerably between countries, based on cultures, awareness among the public and management [134].

Low income areas normally have high population densities and lowest level of MSW services [96, 135]. It poses threat not only to the residents but also to the wider population as abundant volume of the waste generated worldwide is disposed in open dumps or landfill sites [136].

Generation of waste is directly correlated with the urbanization and economic development [8, 114]. Generally, the developed countries generate more waste than the developing countries but the management of the waste is a major concern for the developing countries [137,138, 89]. The generation of the waste is also associated with the economic status of the country. The Asian countries like Japan and Hong Kong who have higher gross domestic product (GDP) were stated to generate more waste as compared to developing countries like India and Nepal [59].

The rapid urban development has come up with serious environmental challenges concerning solid waste management. Solid wastes constitute a growing problem and have gained increased awareness over the recent years. Studies [139, 65] have defined solid waste as the third major pollution after air and water pollution. The problem of solid waste is not new only the magnitude of problem has increased over the time. The management processes involved in solid waste is a complex task which requires an appropriate organizational capacity and cooperation among numerous stakeholders in public and private sectors [140, 141].

Solid waste management has become one of the major concerns in environmental issues. This is particularly true for urban areas where population is rapidly growing leading to increase in generation of waste. A survey conducted by World Health Organization (WHO), 1999 stated that the quantity of MSW tends to vary from place to place and bears a rather consistent correlation with the average standard of living of a particular country, state, region or areas. In developing countries the problems associated with solid waste are more acute than in developed countries [142]. The overall waste management system worldwide is irrational with very little top to down planning [201].

Study conducted [143] mentioned that the urban solid waste management should not only be viewed from the perspective of collection and disposal but instead should be considered as an issue dealing directly with the rapid urbanization. A analysis of various literatures reveals that many different studies based on solid waste management have been undertaken even prior to 1970 [144] and the studies showed that the prime consideration in the earlier time was only with the quick waste removal and no attention was given towards the waste utilization [145]. The problems got complicated further with the growth in population and urbanization which added greatly to the volume of waste being generated and demanded for waste recovery and reclamation services in municipal areas [66]. The lack of financial resources and infrastructure to deal with the solid wastes will further lead to reduction of quality of services provisions [146, 13].

MSW management encompasses a wide variety of activities and practices which describes the unwanted residues and how to carefully eliminate them without causing much damage to the environment and saving the resources [147]. As per [148] the United Nations Millennium Development Goals (MDG's) and Agenda 21 of Rio Declaration on Environment confirms that the major concern for maintain the Earth's environment is the sound management of waste so as to attain sustainable development in all countries [17]. A study conducted [44] gave a review of the waste management practices and their potential impact on human health. The study discussed the waste generation and disposal options in the World, in the European Union (EU), in OEDC countries and China. The study concluded with the evidences of adverse health outcomes of the population living near the landfill sites, incinerators, composting facilities and nuclear installations.

The major environmental issue in developing countries is the identification of the waste streams [149, 150]. The approach of effective MSW management varies and should be compatible with the nature of the given society. A major part of the world today has been following the throw away culture and producing huge amounts of waste. Developments in the field of environmental measurement techniques have made it possible to track that demand on the earth's resources is not sustainable and should be addressed immediately [151]. With the realization that our resources are not infinite came the awareness that our waste offers economic opportunities which can be utilized [89, 61, 15].

Management of MSW has become a significant environmental problem as the amount of waste generated increases each year and makes it difficult to create solutions to tackle such a huge amount of waste generated. A study was undertaken [60] for the waste management strategy for Chihuahua. The study analysed and compared the characteristics of MSW composition for various different seasons and socio-economic groups and concluded that lowest income groups produced least amount of waste and also less waste was generated in winter seasons. Another such study [152] was conducted in Czestochowa city with the main aim to present and evaluate the amount of MSW directed to landfills or recovery, levels of recovery, water and material usage and checking the level of recyclable materials and compost.

The integrated solid waste management (ISWM) was introduced in 1995 to improve the earlier system that neglect unique characteristic of a given particular society, environment and economy [153]. European countries had applied various system assessment tools for creating sustainable development and environmental prosperity [83].

A comprehensive methodology is a prerequisite for improving various policies, rules, regulations and legal framework so as to attain a sustainable solid waste management. A method successfully utilized for identifying potential drawbacks in the existing MSW management system is the use of 'wasteaware' benchmark indicators which includes qualitative and quantitative indicators for the assessment [154, 155, 123, 11]. The quantitative indicators of 'wasteaware' benchmark indicators are part of the physical component and comprises of Public Health collection, Environmental controlled disposal and Resource Management including reuse, reduce and recycling (as percentages) whereas the qualitative indicators are part of governance covering user and provider inclusivity; financial sustainability; and the national policy framework and local institutions.

The adverse effects of waste can be minimized up to some extent by identifying strengths and deficiencies in the current management practices and taking appropriate action to improve those [35]. Strength, weakness, opportunities and Weakness (SWOT) analysis has emerged as an excellent tool for exploring the possibilities for initiating and implementing the municipal solid waste management. Strategies identified and formulated from SWOT analysis not only will lead to successful management of the waste as well as reduction in the waste.

A Research [59] gave various approaches for SWM should be compatible with the nature of a given society, and, in this regard, Asian countries are no exception. The systems are being oriented to concentrate on sustainability issues; mainly through the incorporation of 3R (reduce, reuse and recycle) technologies. However, degree and nature of improvements toward sustainability are varying and depend on the economic status of a country.

India being one of the developing countries of the world with 16 % of the world population and 2% of the total land area [11, 156] along with growth in population and industrialization is not immune to the harmful effects of SWM on its existing environmental conditions which are highly susceptible to deterioration. Since rapid urbanization is occurring in India, the problem of solid waste management is causing a great concern to our environment [93, 11, 123].

According to a survey conducted [24], the total waste generated by class I cities (population above 1, 00,000) alone is 32,450 tons per day. Seven of the twelve metropolitan cities, Kolkata, Mumbai, Delhi, Bangalore, Chennai, Ahmedabad and Hyderabad contributed maximum.

The current status of MSW management in Indian cities is reported in a study conducted by [32]. The study states the current status and challenges in MSW management in Indian cities and concluded that the setting up of decentralized solid waste processing units in cities and towns and development of formal recycling industry sector is the need of hour in developing countries like India. MSW generation is an issue of worldwide concern. Research performed by [9, 10], outlined the trends and challenges that will shape the waste management in metropolitan cities of India. Study established that if the progression of population and growth of percentage increases, per capita waste generation rate will increase proportionally.

The unsanitary techniques adopted for dumping of solid waste causes serious health concerns with significant environmental and social costs associated with it [157]. Open dumping of waste aids to the breeding of disease vectors such as insects, flies, rodents, cockroaches, rats and other pests. The poorly maintained disposal sites also aid to ground water contamination due to production of leachate [158].

Recent studies carried out have indicated that urban area of India is responsible for generation of 48 million tons of municipal solid waste rising to about 250 million tons solid waste by 2050 [8]. As such, municipalities of urban locations are responsible for the proper management of such huge amounts of wastes generated and the processes followed are often done in haphazard manner thereby reducing efficiency. The problem is further exacerbated due to additional reasons including poor land use and its reduced availability, lack of proper technical skills in handling such huge volumes of wastes, lack of adequate finances and its management, non-coordination between different authorities and lack of definite legislative policies [33, 34, 123]. This often leads to illegal dumping without any regard for the environmental standards [159].

The generation of waste has been showing increasing trend in proportion to the rise in population and urbanization [16, 160]. The environment is infested with various types of pollutants and this is one of the major problems in major cities of developing countries like India [161]. The effect of environmental pollution is not only in India but effect the whole world. An investigation and analyzation of the recycling potential of MSW in the Indian capital city of Delhi was performed [1]. It was found that an informal sector comprising waste recyclists and a hierarchy of recyclable dealers plays an important role in the management of solid waste.

The municipal services like water and sanitation, treatment and disposal of solid waste, drainage system etc. are not able to keep up the pace with the urban growth, which leads to the rise in pollution levels [162, 97, 48]. Domestic waste from urban areas without any roper planning is turning out to be a major problem [112].

A research carried out by [163, 164], reveals that the average organic content for urban MSW in Africa is around 55% and its degradation is the major contributor to the greenhouse gas emissions. Rapid growth of population over-whelms the capacity of municipalities to provide even the basic necessities.

The organic fraction present in the waste is produced in huge amount and is responsible for the unpleasant odor, the use of large areas of land for disposal of waste and often acts as source of ground water contamination [165,166].

The MSW from the Indian cities comprise about 40 to 60% of organic fraction which can be easily recycled as compost. In this context, studies have been carried out by utilizing few samples from the metropolitan cities like Delhi, Ahmadabad and Bangalore [11, 57]. The study results indicated that the compost characteristics were found to be suitable to be used as green compost. The Carbon: Nitrogen ratio of municipal solid waste compost was found to be 19 to 25 which were well within the required range of 20-40 [11]. The metal concentration of the municipal solid waste compost of Delhi was found to be on a higher side as compared to the other cities. It was found that there is a need for continuous monitoring of heavy metals for municipal solid waste so that quality could be assured and contamination could be prevented [11, 123].

Research surveys conducted [12, 18, 19] estimated that approximately 29,000 million liters/day of waste water is generated from class- I and class II towns but only 40% collection system exist through sewer lines. A large part of the uncollected and untreated waste water find its way either in the nearby surface water or remain accumulated on roads. This becomes the breeding ground for insects and mosquitoes and also a source of ground water contamination. In many urban as well as rural areas the source of drinking is ground water. Thus, a large population is at a risk of various water borne diseases.

Land filling of municipal solid waste is considered most economical and viable practice for waste management in many parts of world [76, 77]. Non-engineered landfills or open dumps are the final depositaries for the MSW and therefore has the potential to produce leachate containing many harmful organic and inorganic compounds. A study [167] stated that the leachate poses a significant threat to water sources. Thousands of other drinking water wells across the USA have already been shut down due to the contamination from landfills. An analysis of Landfill Leachate Generation investigated by [168] gave an understanding that design of the leachate collection system within the landfill and also of the leachate treatment plant depends on the estimated leachate quantity [11]. Landfill leachate shows significant temporal variability in terms of quantity and leachate composition. The study also presented comparative analyses of the implementation of different methodologies for landfill leachate generation for the particular landfill in the municipality of Centar Zupa.

A study conducted [169] on the status of ground water quality near the MSW disposal site in Kolkata, India and reported presence of high chlorides, hardness and dissolved solids in all the ground water samples implicating the presence of ions due to percolation of leachate.

Research [16] assessed the effect of leachate percolation on the ground water samples was analyzed from unlined landfill site in Delhi. It was found that high concentrations of various physical and chemical parameters as well as heavy metals in ground water indicate that ground water quality is being significantly affected by leachate percolation thus renders the associated aquifer unreliable for domestic water supply and other uses.

A research [38] in Dhapa solid waste dump site Kolkata determined that the leachate sample collected and analysed for different parameters in two seasons. The laboratory test results show prevalence of high concentration of TDS, $NH4^{+}$-N, Cl^{-} and some heavy metals such as Pb and Hg in all the leachate samples. The maximum concentration of heavy metals lead and mercury for water resources have exceeded their respective permissible limits recommended by Bureau of Indian Standards (BIS). The results recommend appropriate leachate treatment before discharging it to the surrounding environment.

A study [78] in one such open dump site of Nigeria, showed the presence of heavy metals and high amount physico-chemical parameters in leachate samples has the potential of being a source of environmental risk. Another similar study was conducted for identification of characteristics of leachate from MSW landfill site in Inbadan, Nigeria [4]. Variation in leachate characteristics was measured for dry and wet seasons. It was concluded that leachate generated caused serious problems by contaminating the nearby soil and ground water resources. Due to high cost involved the developing country like Nigeria is not able to address these severe harms.

In India, dumping of MSW on non-engineered land fill sites (or open dumpsites) accounts for more than 90% of disposal conditions [170, 79]. Even though, treatment processes like segregation, recycling, composting and incineration processes are often used, direct disposal on the landfill sites remain the most preferred way for disposal of solid waste [80, 91].

Further, environmental inequality studies show that such waste facilities are often disproportionally located in the most deprived regions or locations where minority groups reside [81], leading to the unequal pollutant exposure.

For attaining an effective and sustainable waste management strategy it is first necessary to identify the nature and composition of the waste [123]. For an effective waste management development of an insight into the impact of generation of waste, collection, transportation and disposal methods adopted by society on the environment and adoption of new methods for reducing the impacts is essential. Therefore, collection of reliable data regarding generation and characterization of MSW is the key to successful MSW management. Many such studies for the characterization of MSW have been reported worldwide [11, 171, 172, 123, 91, 58, 8]. All these studies have reported characteristic properties of MSW and the factors with which these characteristics values fluctuate. The physical and chemical characteristics of MSW vary with the social, demographic and economic make up.

One such research [112] revealed that the leachate contain high concentration of heavy metals. In addition, most of the heavy metals concentration in leachate is exceed the maximum permissible limit into the natural environment of materials hazardous to the aquatic environment. Rapid urbanization and population growth are largely responsible for very high increasing rate of solid waste in the urban areas, its proper management and recycling is major problems of Municipal Corporation.

A comparative research [173] in Chennai and Sri Lanka was directed to study the periodic monitoring of leachate quality at two large dump sites in Chennai, India and four smaller dump sites in Sri Lanka. It was concluded that with the help of computation of leachate pollution index a reliable data can be generated for evaluation of dumping sites. Not only the waste, but landfills as such constitute health hazards and environmental burden. The two main emission pathways for pollutants from landfill are leachate or gas. Organic waste biodegradation leads to production of landfill gases which contributes to the global warming. The main constituents of landfill gas are methane and carbon dioxide, both of which are greenhouse gases, with methane being over 20 times more intoxicating than carbon dioxide on a one hundred year scale [9, 116]. Degradation of organic fraction present in waste can also lead to landfill settlement, which, if uneven, can cause damage to landfill cover which leads to infiltration and leachate generation.

In landfills, along with the organic fraction of waste, inorganic waste is also present. An experimental study of landfill with mainly inorganic waste [174] revealed that in spite of heterogeneous mixture of waste, leaching mechanism could be defined accurately. In case of constituents like chlorides and potassium, that are easily dissolved, leaching phenomenon was controlled while for elements like copper and lead, it was governed by solubility. When most of the organic fraction of waste is degraded, the organic waste landfills behave in a similar way as inorganic ones [109]. One characteristic common in landfill sites is long stabilization time they require [175]. Stabilization implies to the conditions within the landfill has achieved a state of physical, chemical and biological immutability. Many studies have been done on this concept of landfill stabilization but none has concluded to the main causes of the extended periods of time required for organic fraction of the waste to stabilize. Certain possibilities although have been defined like the excessively high carbon to nitrogen ratio, anaerobic decomposition or presence of certain substances like cellulose which might be responsible for delaying the decomposition process.

The management of urban waste problem is getting more severe due to reasons like poor land use and infrastructure, weak technical and financial capacity, lack of enforcement of standards, poor coordination between the authorities and absence of political priorities [35]. Despite the legislations, waste is dumped unscientifically. Landfill gas emissions from the conventional solid waste management systems in developing countries contribute significantly towards the global climate change. Study undertaken by [96] stated that the awareness of environmental impacts has continued to increase and stakeholders are focusing on efficient waste management as a key target in environmental policies worldwide. Various strategies and policies have been taken up along with identification of the factors responsible for poor management of waste.

A brief overview of MSW management [176] presented that in major cities medium scale towns and small scale towns. The research work also presented some interesting results on MSW management of small scale towns and their neighboring villages and impact of solid waste on environment and human health.

Continuous entering of pollutants into the ground water system by the means of human activities and natural sources leads to the contamination. Solid waste from the industries is being dumped along with the MSW, and is subjected to reaction with percolating rain water and tends to enter the ground water system. This leads to mixing up of many unwanted impurities which contaminate ground water sources. The problem of pollution of ground water in several parts of country has become so acute that unless some major steps for control are taken, the resources may be damaged.

Unscientific dumping of solid wastes leads to several associated environmental hazards like air, soil and ground water pollution causing adverse public health impacts [82, 83, 57]. In particular, contamination of ground water by leachate generated from unlined landfill sites is highly predominant and is most prevalent in developing countries due to disposal of MSW in open landfills [2, 66, 86, 87]. The quality of ground water varies from place to place due to different reactions and processes acting on water. A number of ground water studies have been carried out to testify the effect of the MSW [177, 16] near the landfill sites.

Ground water contamination is irreversible i.e. once it is contaminated it is difficult to restore the original water quality of the aquifer [91]. Excessive mineralization of ground water degrades the quality of water producing objectionable taste, odor and excessive hardness. Although soil mantel through which water passes act as an adsorbent retaining large part of colloidal and soluble ions with its cation exchange capacity [62], but ground water is not completely free from the menace of chronic pollution. Therefore, it is always better to protect ground water in the first place rather than relying on technology to clean up contaminated water at later stage [92].

A study [178] investigated the effect of landfill on ground water quality system in Lahore, Pakistan. For investigation purposes 16 samples of ground water from various depths were collected and analysed. It was found that major part of samples was showing high value of arsenic. Dumping sites impacts are in result of changing ground water chemistry, waterborne diseases and other various environmental problems.

An investigation conducted [113] on evaluation of ground water contamination and its impact gave an insight that contamination of ground water is due to percolation of leachate from the dump site. Studies conducted within contaminated areas to determine the ground water use showed that higher percentage of lower and middle economic status residents of the area were using the ground water for drinking purposes. For many years the waste was disposed of in dumps with no liner or pollution controls [102], so the pollution of the surface and ground water resources are the most severe environmental hazard. The organic matter in the waste leads to the oxygen depletion of water sources. Many heavy metals and xenobiotic compounds are reported in ground water as well as leachate samples. Inorganic macro components include nutrients that can cause eutrophication, and a range of inorganic compounds commonly found in landfill leachate are chlorides and ammonia, which are toxic to many fresh water species [107].

The risk assessment of pollutants present in the leachate is a major environmental issue worldwide due to large number of unscientific disposal sites and importance of protecting the ground water. Moreover, there is lack of knowledge for environmental, eco-toxicological and toxicological characteristics of most contaminants contained in leachates. Knowledge about the characteristics of leachate and creating the risk assessment strategy are the need of the hour to correctly face the landfill issues and make future projections of long term impacts of landfill. Study [179] conducted in this context, proposed an integrated strategy to evaluate toxicity of leachate using chemical analysis, risk assessment and in vitro assays using hepatoma cells. Results from the study concluded ecological risks model have toxic effects on fish and rodents mainly due to ammonia and inorganic constituents present in leachate.

Landfill leachate has become a serious environmental concern because of many hazardous compounds so it becomes important to assess toxicity of the leachate along with the physico-chemical analysis. Similar studies [54, 55] were conducted for leachate samples from landfill sites in Delhi. The chemical and toxicological analysis of the leachate raised potential threat to ecological health including humans. Studies [170] have also reviewed the toxicity potential of harmful contaminant- polycyclic aromatic hydrocarbons (PAH’s) present in leachate on human health and remediation. PAH’s highly toxic and have carcinogenic properties.

The quality of ground water is often affected by the pollution particularly from MSW. Research [180] assessed the effect of MSW leachate on ground water quality. It was found that the ground water samples near to the landfill sites were found to be highly polluted making it evident that the leachate from the MSW dumping sites plays major role in deteriorating the quality of water. Due to rise in pollutional acitivities, cities and vilages both are getting affected in terms of human health as well as environment.

A study was conducted [89] to evaluate the ground water characteristics in Dehradun, India to estimate the suitability of ground water for drinking purposes. In the study, 12 water samples representing shallow ground water area were analysed. Hydro chemical faces were determined and water types were identified. Another such study conducted [53] carried out a field research of MSW dump site in Jaipur, India for assessing the ground water quality in and around the area. The results revealed that high concentration of fluoride; chloride and dissolved solids were found in ground water samples. All the parameters exceeded the permissible limits. It was concluded from the study that percolation of toxic elements from the MSW is responsible for the contamination of ground water.

Research showed [181] the ground water samples were collected from different depths from various bore wells near the MSW landfill sites and were analysed for various physical and chemical parameters. The trend of dispersion of each variable was demonstrated using GIS software. The study concluded that the ground water samples were alkaline in nature with presence of heavy metals and all the parameters have displayed values higher than the permissible limits as prescribed by World Health Organization. It was also concluded from the study that distance also affects the vulnerability of the samples. The ground water sources within 2 km radius of the landfill site were more affected due to percolation of leachate.

It has been studied [27] that the ground water and soil samples have shown presence of high levels of heavy metals like lead, chromium, copper and nickel. It was concluded from these studies that when several vegetables species were grown in such soils, they tend to get polluted with hydrocarbons and they can participate in degradation through the rhizosphere, part of the root which can favor the growth of several microorganisms.

Few studies [110] have also reported that leachate can be used in forests and grasslands depending upon the response of plants to leachate. Although, some studies [160] supported that it might not be suitable to use in agricultural fields as response of a plant species is dependent on various factors like type of plant species, source of leachate, tolerance of plant to various concentrations of leachate etc. It is necessary to determine the toxic effects of organic pollutants on agricultural crops to determine the suitability of leachate application in agricultural fields. A study [182] conducted to investigate the effect of landfill leachate on survival of chick pea. Different experiments were conducted with various leachate dilutions concentration to check effect on chick pea plant. Various parameters like germination shoot and root length and chlorophyll content were calculated. In the final results, it was observed that initially the plant responded well to the leachate concentration having high value of chemical oxygen demand but later on symptoms of stress become prominent and wilting appeared which might be due to the toxicity and high salt concentration in leachate.

Similar base of work reported [91], the effect of leachate concentration on the growth of legume and fate of nitrogen fixing bacteria. The results indicated the observable effect of soil on physico-chemistry, plant growth and nodulations.

Certain ground water protection policies are being developed which would hopefully lead to more sustainable development. Techniques are also available to clean up polluted or contaminated ground water sources, but are very expensive. India has a good infrastructure in core industries like metals, fertilizers, drugs and petroleum, industries like plastics, pesticides, detergents, fuels, solvents, paints, dyes and food additives, released effluents and emissions, polluting soil and water ecosystem. The disposal of solid and liquid wastes containing heavy metals like lead, nickel, chromium and mercury in land or water bodies, leads to heavy metal contamination of soil, water, plant and animal ecosystems.

Study [183] evaluated the geochemical implication of heavy metals on the ground water surrounding MSW dumpsite. In the study, ground water samples and leachate sample were collected around the dump site. The results revealed high concentration of lead; iron and manganese were present in ground water samples while concentrations of the other parameters were reportedly very high in leachate samples. Geoaccumulation factor showed that samples of ground water which were farther away from dump sites were less contaminated.

Research determined [184] the effect of heavy metal contamination in waste water irrigated soil and brought to conclusion that due to the use of waste water, the concentration of heavy metals like lead, chromium, nickel, mercury and cadmium has been found in soil. The study also highlighted that the concentration of zinc was higher and the chromium was minimum in both natural and impacted areas. It was concluded that increase of these heavy metals in soil is alarming and may also occur in agricultural crops being grown there which may cause some health hazards by entering in human body by means of food chain.

A technique of assessing the toxicity of landfill sites is given by the leachate pollution index (LPI) as it provides an overall pollution potential of a landfill site. A study undertaken [41], in Malaysia had shown the variability of parameters involved in LPI from the four landfills. It was concluded that landfill sites required immediate attention based on the results of LPI values to control environmental hazards. The values generated from LPI can be used as a means for assessing the pollution potential of the landfill sites. Study conducted [118-120], in Punjab, India determined that the leachate pollutant variables exceeded the permissible limits of disposal and depicted higher values of LPI.

A study [28, 29] determined the leachate characteristics and leachate pollution index from the landfill sites in Delhi, India and concluded that the awareness among the states about the benefits of integration of various technologies for MSW processing is lacking. This is necessary as different technological options are required for treating the different components of waste like composting, incineration, biomethanation etc.

A study [120] used aggregate indexing method to assess the ground water quality near the MSW dumping site. As the aggregate index was increasing as a function of the distance from the landfill site, the ground water quality improved as one move away from the landfill site. Aggregate index also decreases with increase in time. It may be due to the reason that with the passage of time the solid waste gets degraded and the waste constituents percolated down along with rain water thereby polluting the ground water sources. Hence, the authors advised some remedial measures to prevent further contamination of ground water in the vicinity of the landfill.

The quality of ground water is often affected by the pollution particularly due to MSW. Research conducted [185] to ascertain the effects caused due to leachate production on ground water quality of Nigeria revealed the presence of high amount of heavy metals, physico-chemical and bacteriological constituents. The study also concluded that contamination of ground water was more dependent on the proximity to the landfill sites.

A study [186] conducted for analyzing the water quality of Sasthamkotta Lake, Kerala in which important issues included decreasing water quality, alternation in biological productivity, and increase in nutrient concentrations and contaminants migration into the lake. The results from the analysis depicted that in post monsoon season the quality of lake decreases as compared to pre-monsoon as the migration of contaminants was more prominent. The quality of water can also be illustrated through a single index called water quality index (WQI). Study [187] employed WQI to assess the environmental quality in Kuwait. The study concluded that the water quality at most of the sites was within environmentally satisfactory condition but it dropped in summer season emphasizing the seasonal effects in water quality. Hence, the WQI is a highly effective tool which helps in assessing the quality of water in a simple way.

A study conducted [61] helped in evaluating the level of pollution in ground water by giving WQI. WQI is a simple and concise method useful for indicating impairment of water quality. Study concluded that majority of ground water samples belong to good water quality.

A study [62] conducted for determination of heavy metals in drinking water of district Patiala, Punjab. In the study, the ground water samples collected from 100 localities during one year period. It was observed in the study that nickel and aluminum levels were high in most of the samples whereas the concentration of other metals was comparatively low. It was concluded that high levels of nickel and aluminum in ground water samples were due to the anthropogenic sources like domestic sewage.

Research [36] reviewed the various water quality indices used for assessing the quality of water. As different national and international agencies involved in water quality assessment and pollution control defines water quality criteria for different uses of water considering different indicator parameters so there are numerous water quality indexing methods specific to any region or areas. It was concluded from the research that water quality varies according to type of use. There is a need for regular monitoring of water parameters.

Given the huge complexity issues and problems related to solid waste management across the countries various strategies have been proposed to minimize the environmental problems caused due to unscientific dumping of waste, problems caused by landfills and to optimize landfill management. Sustainability of waste management is a key to providing an effective service that satisfies the needs of the end users. The principles of sustainable solid waste management have been articulated through efforts of the World Bank’s involvement during the 1990’s with an inter-agency solid waste collaborative working group.

One pillar of sustainable solid waste management is strategic planning, and links to guidance provided. Another pillar is cost analysis of solid waste options, and links to the useful analytical tools provided. For financing, involvement of private sector has become a growing trend in solid waste management. Also, there are new funds for emissions reduction that supports global needs (Prototype Carbon Fund and Global Environmental Fund), and sample calculations for how to achieve and thus market such emission reductions are also provided. For successful development if any solid waste project, community participation in collection, community consultation on cost recovery, and public participation in setting and design of facilities is inherently essential to sustainability.

Waste can be treated in several ways. It can be composted, incinerated or landfilled. Until a decade ago, landfilling of the waste was very popular all over the countries. However, due to the environmental implications linked with landfilling different other methodologies are being considered for disposing waste in more environmental friendly ways.

The basic and foremost step towards attaining a sustainable waste management has been recognized as to reduce the use of materials and reusing them. Source reduction begins by reducing the amount of waste generated and reusing materials so as to prevent their entry in the waste stream. Material recovery (MRF) from waste in form of recycling or composting is an effective method for handling waste. The strength of MRF approach is its ability to intuitively organize material flows.

A study [112] stated that due to technical and economic limitation of recycling, most of MSW generated goes directly to the landfills especially in developing countries like India. It was also suggested in the study [106] that local authorities should start working together for promoting source separation. If this is achieved and recycling rate starts to increase then provisions must be made for handling non-recyclable waste.

Studies have revealed that as much as 95% of products environmental impact occurs even before it is discarded [71], most of it during the manufacturing processes. Along with recycling, methods like composting are also being followed up for attaining sustainable waste management. Composting of mixed waste results in a compost which is contaminated with many organic, inorganic and heavy metal impurities [177]. Many energy recovery methods have also been designed and explained which can be a better alternative to open dumping.

The research conducted [58] discovered that the efficiency of the recycling and composting is reduced due to absence of source separation. Lack of source separation moreover declines the aerobic and anaerobic processes. Anaerobic digestion is sensitive to the type of feed and thus biomethanation system gets easily spoiled due to presence of impurities. Waste is sometimes used as unfit word as nothing generated is accounted as waste. Every possible substance use and throw away comes back as new and different material. Materials discarded into the environment after use may come to only two possible ends. One is discharge into the environment and other is reuse or recycling and reclamation. Conditioning of organic waste can help in pollution abatement.

Study conducted [19] stated that landfills containing mechanically and biologically treated waste have improved leachate quality. Leachate concentrations of organic matter and ammonium are lower than from the MSW landfills where unsegregated and untreated waste was disposed. Landfill gas generation was also reduced significantly. However, some degradation potential is still left along with methane production. A common pre-treatment method given to waste is stabilization prior to landfilling.

A study [9] has described MSW as viscous material which showed timed dependent behavior. The continuous deposition of the MSW resulted into gas and leachate generation. Engineering properties of MSW of metropolitan center landfill like compressibility behavior and shear strength parameters were also determined. The changes in the mechanical behavior of MSW could be linked to the landfill gas and leachate generation. Physical properties of MSW like moisture content and organic content at varying ages were obtained.

Landfill leachate constitutes a major environmental hazard for surface and ground water [125]. Researchers have worked on landfill leachate treatment methods and one such study was undertaken [157] worked on solar distillation of landfill leachate. Solar distillation offers a promising alternative to currently used treatments methods. Recirculation of leachate from landfill was studied [27]. Leachate recirculation is gaining popularity as an alternative to conventional leachate systems. Research has shown that leachate recirculation through a landfill can offer operational advantages such as microbiological treatment of leachate, increased stabilization and volume reduction of leachate by evaporation. It appears to be feasible as well as economically viable method.

Electrical conductivity can be used to detect soil contamination by landfill leachate. Experimentation work on this was performed [121]. The electrical conductivity and complex permittivity for a natural clayey soil are measured before and after permeation with multiple ionic solutions that help in stimulating the composition of leachate from a MSW disposal site. The results showed that the experimental system provides reliable measurement of soil complex permittivity and of soil static electrical conductivity.

A study conducted [128, 94] stated that leachate tend to pass through soil and the movement of leachate with respect to depth and time were analysed. With the increase in waste generation, leachate released from landfills tends to percolate through unsaturated soil, polluting the ground water with organic and inorganic impurities. Therefore the estimation is necessary. The results provide guidelines for the design for new landfills with proper collection and treatment system.

Research has reported [95] that new type of landfills developed such as bioreactor landfills which make use of leachate air to encourage biodegrading inside the landfill. The study also reported that methane gas produced by the breakdown of organic waste in bioreactors can be used as an energy source. This methane is similar to the natural gas so can be used as fuel or to generate electricity.

Evaluating the performance of MSW system is a complex job. Life cycle assessment (LCA) is a methodical tool which helps in assessing the environmental acceptability of the MSW management options. LCA tool was used to study the MSW management in China [188]. The results showed that methane released from the landfilling was the primary pollutant contributing to the global warming. Study also suggested that material recovery and recycling will lead to less environmental impacts.

Technologies for waste management are ever improving and also the number of ways to treat the waste. It therefore becomes necessary to find one such method which gives most optimal results. For accomplishing the goal for efficacy of waste management system, a new metric method based on LCA is provided which helps in making comparisons and evaluating threats to environment. It is one of the micro level approaches which accounts for primary materials and energy requirements in specific products and services. A number of LCA models have been developed for the general assessment of the product or process. For a good LCA many important key parameters need to be understood for its successful implementation in solid waste management. Huge variations in results have been observed among various LCA models, although it has been that results from LCA models are consistent. Many studies have reported and identified the methodologies and technical assumptions used in various parts of selected waste LCA models. The modelling assumptions of waste management processes ranging from collection, transportation, intermediate facilities, recycling, thermal and biological treatments and landfilling are critical when comparing various waste LCA models.

The first comparision of the solid waste management LCA models was given by [189, 190]. Their comparison was based on a quantitative assessment and they attempted to run six scenarios. The results highlighted various discrepancies in LCA.

A study presented the life cycle based framework to optimize over multiple time stages the collection and treatment of all waste streams to curb the final disposal by minimizing cost or environmental impacts. The results show the utility of the multi-stage framework and the insights which can be gained from these frameworks [191].

Landfills are the common disposal methods employed in most of the countries. To evaluate the potential impacts due to these ineffective waste management practices, LCA methodology is applied. Such a methodology was applied to Bangalore [192]; LCA serves a decision making tool in selection of most suitable and environmentally friendly disposal options. The waste disposal methods such as open dumps, bioreactor landfills, landfills with and without gas recovery systems were assessed using LCA. The analysis was done in terms of material flow, energy flow and impacts of open dumping and landfilling on environment. It was concluded from the study that present scenario produced high environmental impacts, so methods like bioreactor landfill can be best method for a city like Bangalore as it produced least impacts. The life cycle cost analysis was also performed considering an average life of a landfill as 50 years. Cost analysis was done in terms for initial fixed costs and operation and maintenance costs.

An optimization model [193] was formed for integrated solid waste management in Mumbai, India. A linear programming model was developed to integrate different options and stakeholders involved in MSW management. Various economic and environmental cost associated with the management of MSW were considered for developing the model. The results from the study concluded that the best optimal solution is compost plants whereas sanitary landfills are indispensable. Segregation of waste will lead to optimization of MSW management.

A study performed in Macau [194] evaluated the current and potential patterns of MSW management with regard to the environmental impacts using LCA methodology. The results showed that the current waste management generates many environmental burdens thereby suggesting and providing useful data which will be helpful for better understanding of environmental pollution situation and put forward appropriate management policies.

Another study evaluated [188] the current and possible patterns of MSW management in regard to GHG's emissions using LCA approach in China. The results showed that with the combination of various integrated waste management scenario the GHG emissions can be lowered.

A study performed in Mumbai [195] evaluated the current and potential patterns of MSW management with regard to the environmental impacts using LCA methodology. The comparison between environmental impacts of different potential MSW management scenarios, the current waste management practices showed maximum environmental impacts. It was also concluded that there is no single MSW management scenario that performs best in all the impact categories.

The quantity and composition of waste was predicted using LCA methodology [51]. The input of LCA is considered as quantity and composition of MSW and energy whereas the output is taken as air emissions, water emission andenergy recovery. The results indicated that recycling has least environmental impacts than the incineration in initial years and as the years passes landfills produce more environmental impacts than the incinerators due to waste accumulation in landfills.

2.2 Summary of Literature Review

From the review of literature, it is investigated that solid waste management is one of the foremost responsibilities of both urban and rural communities. The fundamental objective of solid waste management programmes is to minimalize the contamination to the environment as well as utilizing the waste as resource. The targets of managing the waste can be achieved using the methods that can be afforded by communities over a long term period and with less risk to the individuals involved. Based upon the review of many literatures, it was concluded that the MSW was mainly disposed of in an unscientific manner by open dumping and hence causes many hazards linked to human health as well as environment. Rapid population growth over-whelms the capacity of most municipal authorities to provide the most basic services. MSW management is a technological issue that involves aspects such as institutional, social, legal, financial, coordinating and managing a large work force and collaborating with involved stakeholders as well as general public. The disposal of MSW is one of the most serious and controversial issues being faced by the governments in developing and developed nations. The purpose of the policies formed by the nations to curb the waste has been to promote more recycling and energy extraction of products and materials thereby decreasing landfilling and organic fraction not ending up in landfills at all. With the passage of time the constituents present in the waste tend to percolate into ground water. The waste placed in open dumping sites is either compacted with the help of compactors or is burned in the open place. The organic fraction in the waste undergoes various changes in the presence of available moisture and generates leachate. The contaminants from the leachate enter the food chain.

The summary of literature reviews reflect that indiscriminate dumping of MSW without any prior treatment or management must be stopped and remedial measures must be adopted to stop further contamination.

Therefore, the present study of MSW characterization and analysis in Tricity of Chandigarh, Mohali and Panchkula has been undertaken to understand the existing waste Management practices in Tricity and to assess the characteristics of MSW, leachate and ground water from the dumping sites and analyse the impacts of different potential MSW management scenarios in Tricity.

CHAPTER 3

OVERVIEW OF THE MUNICIPAL SOLID WASTE MANAGEMENT PRACTICES IN TRICITY

3.1 Introduction

Increased industrialization along with high economic growth has led to rapid urbanization leading to a production of a huge quantity of waste that is harmful for the existing environment. Municipal solid waste (MSW) management has converted a key issue due to the poor waste management practices which affect the health and amenities of the cities. The quantity and composition of MSW vary from place to place and is the reflection of the average standard of living [196,165, 16]. The annual waste generation has been showing increasing trend in proportion to the rise in population and urbanization [196]. Solid waste generation in Indian cities per capita varies from 200-870 g/day depending upon the population and economic potential of the city [5, 8, 14, 34, 59]. Generally, half of the generated MSW is not collected which leads to the reduction of the collection efficiency [11, 92]. The complications related with the MSW management are multifaceted due to the quantity of waste generated and diverse nature of the waste and a reduced amount of financial resources to the municipal authorities [94, 159]. The waste which remained uncollected is either retained in open areas or in streets and finally finds its way into drains contributing to flooding, breeding of insects, pests and rodents thereby spreading diseases. On other hand, the MSW collected is normally disposed in open dump sites or burned in open spaces leading to the contamination of environment [11, 93, 22].

In the above context, it is very important to ensure a safe and proper disposal of the generated MSW to maintain the serenity and efficiency of the city. Several guidelines and rules have been framed at both global and national levels to tackle the ever increasing problems related to MSW as it is the only sector where per capita contributes its fraction [57, 59, 10]. A systemic approach is prerequisite for improving the strategies, guidelines and permitted frameworks for achieving a sustainable MSW management in Asian countries. Attaining zero waste is not completely feasible but the impacts can be reduced to some extent by having an understanding of the existing waste management practices, identifying the factors responsible for poor waste management, creating awareness among the people about adverse impacts of improper waste management and taking appropriate actions to improve the waste management practices.

Keeping in sight this, the present study has been commenced to assess and review the existing MSW management practices in Tricity of Chandigarh, Mohali and Panchkula. The main objectives of the study were to analyze the present MSW management practices and identifying the factors responsible for inefficient management of MSW. A system analysis of the MSW generated in Tricity has been evaluated by the 'wasteaware' techniques to evaluate its performance.

3.2 Methodology

3.2.1 Study Area

Chandigarh, Mohali and Panchkula together are known as Tricities and located in Northern India. Chandigarh serves as the capital of two of the most important states and is bordered by satellite towns of Panchkula and Mohali without any actual physical demarcations. All the three cities have their own separate municipal corporations which govern the management of the MSW generated in their respective cities.

Chandigarh- City Profile

Chandigarh city was planned and designed by Le-Corbusier in 1957 and is located in northern part of India and is bordered by three states i.e. Punjab, Haryana and Himachal Pradesh. The city is located under the foothills of Shivalik Hills at a height of 365 meters above the sea level and spread over an area of 114 km^2. Chandigarh derives its name from religious temple "Chandi Mandir" which is situated in the vicinity of the city. The word 'Chandi' refers to deity- the goddess of power and 'garh' refers to a fort that is located beyond the temple, thus named as "Chandigarh". Chandigarh is also known as 'The City Beautiful'. It is one of the Union Territory of India and the capital of Punjab and Haryana and also and is enclosed by Haryana and Punjab state.

'Le Corbusier' was a French architect who designed the city, similar way to human body, with a noticeably defined head (the Capitol Complex, Sector 1), heart (the City Centre

Sector-17), lungs (the leisure valley, innumerable open spaces and sector greens), the intellect (the cultural and educational institutions), the circulatory system (the network of roads, the 7Vs) and the viscera (the Industrial Area). The idea of the city is grounded on four major purposes: living, working, care of the body, spirit and circulation. City is alienated into residential area, commercial complexes, slums, health facilities, capital complex, educational facilities, gardens, and on the basis of income group sectors and can be clearly demarcated into classes: High Income Group (HIG), Low Income Group (LIG) and Medium Income Group (MIG).

Almost all the sectors cover an area of almost 102 hectares. The inner roads usually link with the shopping areas located within the sector. Though educational, cultural and medical facilities are spread all over city, but, major institutions are located in Sectors 10, 11, 12, 14 and 26 mainly. The industrial area comprises of 2.35 km^2 and is located in the outskirts of the city so as to restrict pollution from these sources. Plantations of tree and landscaping have been an integral part of the master plan for the city. There are approximately 30 different varities of flowering and 22 species of evergreen trees planted along the roads, in parking areas, shopping complexes, residential areas and in the city parks making it green city.

Mohali

Sahibzada Ajit Singh (SAS) Nagar is a town in Punjab. It is generally known as Mohali which is a satellite town of Chandigarh. It is situated immediately to the south-west of the capital for the state of Punjab and Haryana in Chandigarh, which is also an administrative center for both the states of Punjab and Haryana. The town attracts large number of settlers and job seekers from neighboring states and population is expected to increase steadily.

Mohali and Chandigarh are contiguous areas with only the boundary between Punjab and Chandigarh dividing this area. The original plan of Mohali is in fact a mere extension of the road and an 800m x 1200m extension of the sector design system of Chandigarh without any unique planning. The plan of this town is based on a rectangular module called sectors or phases. Each sector spreads in an area of 2 km^2 and has been so planned that facilities like shopping complex, schools, hospitals, community centers, and marriage palaces, places of worship, play grounds and parks are available in each sector for its residents. The first 11 sectors in Mohali are popularly known as Phases. Early development was only till Phase VII.

The development of sectors and phases from Phase 8 onwards started in the late 1980s, and the city got its own bus stand in Phase 8 in the mid-1990s. Some sectors share both with Chandigarh and Sahibzada Ajit Singh Nagar like 48, 51, 52, 54 and 56 onwards all fall in Sahibzada Ajit Singh Nagar Region. The region has been targeted by an increasing number of IT companies, who look to capitalize on the rich investment opportunities the city offers. Like Chandigarh, Mohali is also defined on the basis of residential area, commercial complexes, slums, health facilities, capital complex, educational facilities, garden, and the basis of income group sectors.

Panchkula

Panchkula is the 17th district of Haryana state. It forms an integral part of Union Territory of Chandigarh and the city of Mohali. The word Panchkula is derived from the local word 'panch' and 'kula'. The city of 5 canals possibly refers to five irrigation canals that distribute water from the Ghaggar-Hakra River. It is approximately 4 km south-east of Chandigarh.

The new urban estate of Panchkula lies in the west of Chandigarh. The Chandigarh railway station is near to Chandigarh-Panchkula boundary and has an exit towards Panchkula. The township has been sub-divided into residential sectors, industrial sectors, parks and areas for regional recreation, major institutions, markets, and government and semi-government offices. It is divided into three phases. The Phase 1 is from sector 1 to 19 and industrial area and this is shaped like a large triangle with the railway line being on one side of the triangle and the Zirakpur-Kalka road being on another side. The Phase 2 includes sector 20 through 30 and has some sectors across the Zirakpur-Kalka road and many on both sides of the banks of Ghaggar River. The Phase 3 includes the newly broadcasted sectors beyond Ramgarh, to the east of the existing sectors. *Figure 3.1* shows the study areas of Chandigarh, Mohali and Panchkula.

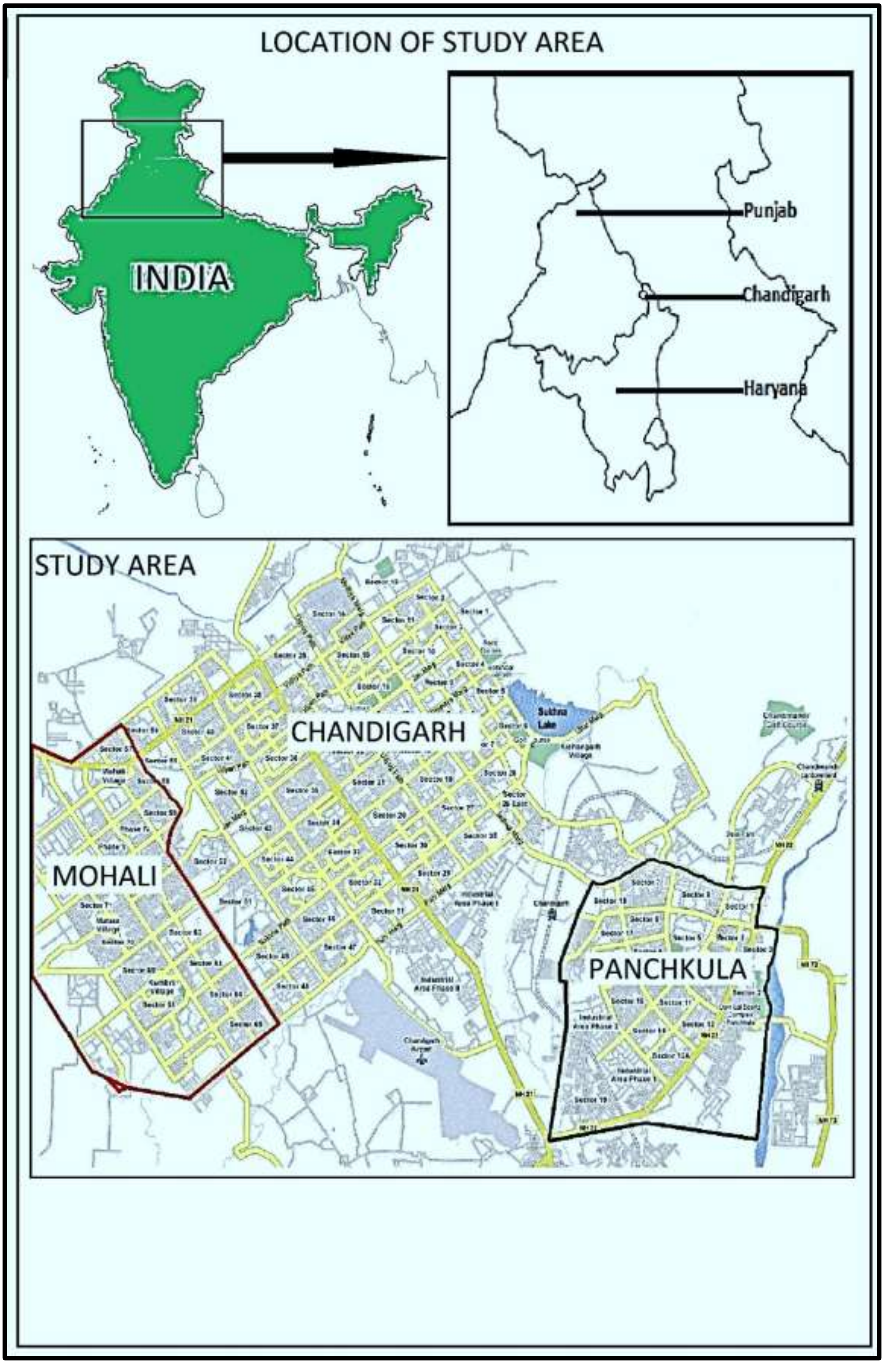


Figure 3.1 Location of study area

3.2.2 Geology

Tricity is situated in the foothills of the Shivalik hill ranges in the north which form a part of the fragile Himalayan ecosystem. It is occupied by Kandi (Bhabhar) in the north east, Sirowal (Tarai) and alluvial plains in the rest part. The subsurface formation comprises of beds of boulders, pebbles, gravel, sand, silt, clays and some kankar. The Tricity area is drained by seasonal rivulets viz. Sukhna Choe in the east, Patiala-Ki-Rao in the west and Ghaggar in the south-west. The basic geographic profile is given in *Table 3.1*.

Table 3.1: Geographic details of Tricity

	Chandigarh	Mohali	Panchkula
Area	114 km^2	1160 km^2	816 km^2
Longitude	76° 77' 94E	76°71'79E	76°86'06E
Latitude	30° 73' 33N	30°70'46N	30°69'42N
Altitude	350 meters	316 meters	365 meters
UTM Easting	669,256.85	664,513.73	667,585.95
UTM Northing	3,402,287.40	3,398,129.92	3,397,290.60
UTM Zone	43R	43R	43R

3.2.3 Economy and Population

Tricity is among the highest per capita income cities and is the richest city in India. It provides home to many local, national and multi-national corporations who look to capitalize on the rich investment opportunities all the three cities offer. At current the population of Chandigarh is 1.05 million as per 2011 census of which 97.25% constitutes urban population while rest 2.75% contributes to the rural population. Mohali has a population of 9, 86,147, of which 54.76% constitutes urban population and 45.24% rural population. Panchkula holds a population of 5, 61,293 as per census 2011 of which 55.81% contributes to the urban population and rest 44.19% adds to the rural population. The detailed demographics of Tricity are given in *Table 3.2*.

Table 3.2: Demographics and other details of the Tricity

	Chandigarh	Mohali	Panchkula
Total Population(2011 census)	1,054,686	9, 86,147	5, 61,293
Urban Population	1,025,682	5,40,014	3,13,258
Rural Population	29,004	44,6132	24,8035
Density of Population (km^2)	9,252	909	625
Literacy Rate (%)	86.43	83.80	81.9
Decennial Population Growth (%)	17.2	33.15	19.8

3.2.4 Rainfall and Climate

The climate of Tricity is characterized as subtropical experiencing hot summers and cold winters. All the three cities of Tricity experiences four main seasons i.e. Summer season; Rainy season, Post monsoon autumn and Winter Season. Months of May and June are the hottest months of the year with mean daily maximum and minimum temperatures about 37°C and 25° C, respectively. However, sometimes the maximum temperatures can rise up to 45-46°C. Month of July expreinces high intensity showers due to south-west monsoons and the weather is normally hot and humid at this time. In winters, January is the coldest month with the mean maximum and minimum temperatures of around 23°C and 3.6°C respectively. The variation in annual rainfall on year to year basis ranges from 700 mm to 1200 mm and the average rainfall of Tricity is 1100.7 mm.

3.2.5 Ground Water Prospects

The ground water in the Tricity take place under the unconfined water table situations in the upper aquifers which are largely formed of alluvium and semi-consolidated formations. Water holding formations are shale, clay and silt in the deeper aquifers and the groundwater occurs in semi-confined to confined conditions. The depth of water in the phreatic aquifers varies from 8.3 to 30.1 m below ground level. In most part of the Tricities the general slope of water table conforms to the topography of the area. Normally, the quality of water is good.

3.3 Existing Status of Municipal Solid Waste (MSW) Management in Tricity

The Municipal Corporations of Chandigarh, Mohali and Panchkula respectively are responsible for the overall management of the MSW which includes the collection of the waste from the households, storage of the waste, transportation of the waste to the final disposal sites. Apart from this various other organizations are also engaged in waste management related activities like Chandigarh Pollution Control Committee (CPCC) in Chandigarh, Punjab Pollution Control Committee (PPCC) in Mohali and Haryana Pollution Control Committee (HPCC) in Panchkula respectively are responsible for monitoring the compliance level of existing practices as MSW rules (Personal communication with the Municipal Corporation Employees of Chandigarh, Mohali and Panchkula). *Figure 3.2* demonstrates the existing waste management practices in Tricity.

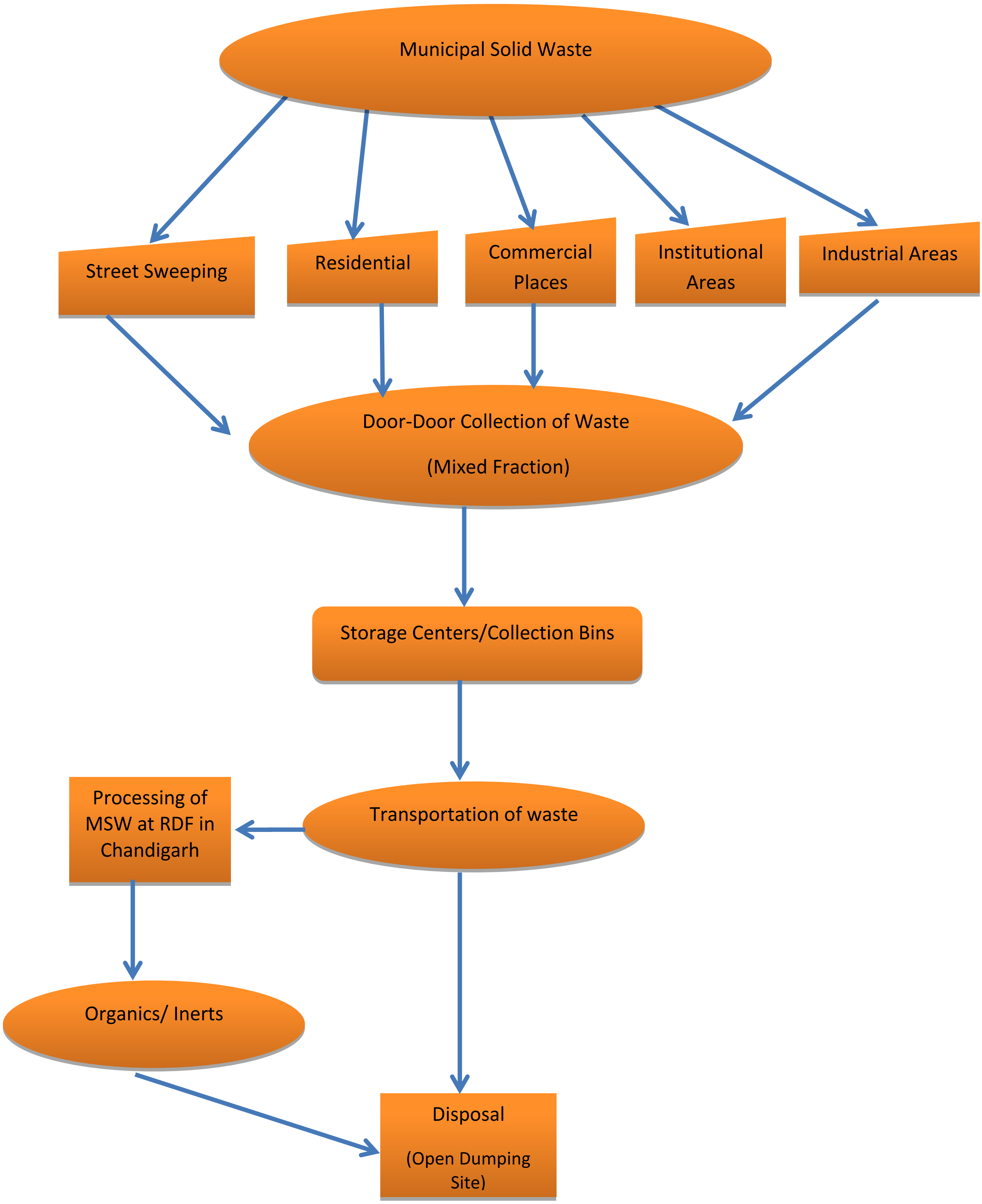


Figure 3.2: Existing Waste Management Practices Scheme in Tricity

3.4 'Wasteaware' Benchmark Indicators for Sustainable Waste Management in Tricity

SWM management is one of the most vital functions of a city's government as it is a key utility service on which the public health and the aesthetics are dependent [154, 155, 159]. The pollution levels are often defined by index systems [11]. For example, the amounts of water pollution or air pollution for cities are often defined by the water pollution index or air pollution index to judge the severity of pollution [11, 123, 154, 155]. It is often difficult to provide such a single index for pollution caused from solid waste because the SWM framework of any city is governed by physical components, functioning of governance and utilization of proper policies. Studies [154, 155, 11] have suggested that the efficiency of a city's SWM system can be used as substitute indicator of good governance. Appropriate benchmark indicators help a city to evaluate its own performance as regard to delivery of SWM services provided, information for decision making on priorities for the limited funds available for service improvements and monitor changes over time. A set of integrated solid waste management (ISWM) benchmark indicators were defined for waste systems by [154, 155], covering both physical and governance factors. These indicators are called the 'waste-aware' ISWM benchmark indicators, in order to reflect one of their primary purposes of raising stakeholder awareness of the state of the local SWM system. The aim of the 'Wasteaware' ISWM benchmark indicators is to use the existing data and not to carry out primary survey.

The ISWM framework distinguishes into physical components and the governance aspects. The physical components also called as the quantitative indicators include protection of public health which depends on a good waste collection service; environmental protection particularly during waste treatment and disposal; and resource value, the '3R's'- reduce, reuse, recycle [154, 155]. The detailed description with criterion of selection of 'waste-aware' ISWM benchmark indicators for physical components is shown in *Table 3.3,* plus three multi-attribute, composite indicators of the 'quality' of service provision for each component, as shown in *Table 3.4, 3.5* and *3.6.*

Table 3.3: Quantitative indicators for the physical components of SWM system

No.	Physical component	Indicator name and definition	Color coding				
			Low	Low/Medium	Medium	Medium/High	High
1.1	Public Health- waste collection	Waste Collection Coverage: % households who have access to a reliable waste collection service	0-49%	50-69%	70-89%	90-98%	99-100%
1.2		Waste Captured by the solid waste management and recycling system: % of waste generated that is collected and delivered to an official facility	0-49%	50-69%	70-89%	90-98%	99-100%
2	Environmental control - disposal	Controlled treatment or disposal: % of the total municipal solid waste destined for treatment or disposal which goes to either a state-of-the-art, engineered or 'controlled' treatment / disposal site	0-49%	50-74%	75-84%	85-94%	95-10%
3	Resource value - '3Rs' - Reduce, reuse, recycle	Recycling rate: % of total MSW generated that is Recycled. Includes materials recycling, organics, (composting, animal feed, Anaerobic digestion).	0-9%	10-24%	25-44%	45-64%	65% and over

[154, 155]

Table 3.4: Criteria used to assess Indicator 1C: Quality of the waste collection and street cleaning service

No.	Criterion	Description
1C.1	Appearance of waste collection points	Presence of accumulated waste around collection points/containers
1C.2	Effectiveness of street cleaning	Presence of litter and of overflowing litter bins
1C.3	Effectiveness of collection in low income districts	Presence of accumulated waste/illegal dumps/open burning
1C.4	Efficiency and effectiveness of waste transport	Appropriate public health and environmental controls of waste transport
1C.5	Appropriateness of service planning and monitoring	Appropriate service implementation, management and supervision in place
1C.6	Health and safety of collection workers	Use of appropriate personal protection equipment and supporting procedures

[154, 155]

Table 3.5: Criteria used to derive Indicator 2E: Degree of environmental protection in waste treatment and disposal

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

[154, 155]

Table 3.6: Criteria used to derive Indicator 3R: Quality of 3R's- reduce, reuse and recycle-provision

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

[154, 155]

The governance factors depicted as qualitative indicators include a well-functioning system [154, 155]. They have been identified as inclusivity, allowing stakeholders to contribute and benefit both as service users and service providers; financial sustainability, ensuring that solid waste management services and activities are cost-effective and affordable; and a base of sound institutions and pro-active policies. If adequate attention is not paid to these governance aspects, then any attempt to modernize SWM systems through technological improvements would fail [25,142, 154]. The detailed explanation of all the qualitative indicators is given in *Table 3.7, 3.8* and *3.9*.

Table 3.7: Criteria used to assess Indicators 4U and 4P: Degree of user and provider inclusivity

4U- Degree of user inclusivity			**4P-Degree of provider inclusivity**		
No.	**Criterion**	**Description**	**No.**	**Criterion**	**Description**
4U.1	Equity of service provision	Extent to which all citizens (users and potential users),irrespective of income level, receive SWM service.	**4P.1**	Legal framework	Degree to which laws are in place and implemented at national or local level.
4U.2	The right to be heard	If authorities have legal obligation to consult and involve citizens in decisions which affect them.	**4P.2**	Representation of private sector	Organizations in place which represent the private waste sector.
4U.3	Level of public involvement	Public involvement at appropriate stages of SWM decision making, planning and implementation.	**4P.3**	Role of informal and community sector	Evidence of recognition of the role of informal sectors within formal SWM systems.
4U.4	Public feedback	Existence and use of public feedback mechanisms on SWM systems.	**4P.4**	The balance of public and private sector in delivering services	Degree to which appropriate checks and balances are in place locally so that waste services are being delivered.
4U.5	Public education and awareness	Implementation of comprehensive and appropriate public education and awareness.	**4P.5**	Bid processes	Degree of transparency and accountability of bid process.
4U.6	Effectiveness in achieving behavior change	Changes habits and behavior of both public and business regarding SWM systems.			

Source: [154, 155]

Table 3.8: Criteria used to assess Indicator 5F: Degree of financial sustainability

No.	Criterion	Description
5F.1	Cost accounting	Extent to which SWM accounts reflect accurately the full costs of providing the service and relative cost of various activities within SWM system.
5F.2	Coverage of available budget	If the annual budget is adequate to cover all the costs of services.
5F.3	Local cost recovery from households	Percentage of the total households both using and paying for the services.
5F.4	Affordability of use charges	Procedures in place to support charges for those who can't afford to pay.
5F.5	Pricing of disposal	Degree to which the final disposal of waste at sites are charged at a rate that covers operational costs of disposal.
5F.6	Access to capital for investment	Adequate provisions for capital investments, to upgrade standards of waste disposal and to replace existing vehicles, equipments and sites at end of their life span.

[154, 155]

Table 3.9: Criteria to assess Indicators for sound institutions and proactive policies: 6N-National framework and 6L-Local institutions

6N- Adequacy of national framework for SWM			6L-Degree of local institution coherence		
No.	**Criterion**	**Description**	**No.**	**Criterion**	**Description**
6N.1	Legislation and regulations	If there is a comprehensive national law(s) in place to address solid waste management requirements.	**6L.1**	Organizational structure/ coherence	The degree to which all SWM responsibilities are concentrated into a different Agencies.
6N.2	Strategy/policy	If there is an approved and recent national strategy for SWM.	**6L.2**	Institutional capacity	Assessment of organizational strength and capacity of departments.
6N.3	Guidelines and implementation procedures	If proper and clear guidelines are provided for local authorities.	**6L.3**	City wide SWM strategy and plan	Any recent strategy or plan being implemented at city or reginal level for SWM.

6N.4	National institution responsible for SWM policy	If there is any single institution at national level which have all the responsibilities for SWM policies?	**6L.4**	Availability and quality of SWM data	Management information system which collects the data and monitor it.
6N.5	Regulatory control/enforcement	Any well-organized environmental regulatory agency been involved.	**6L.5**	Management, control and supervision of service delivery	Measure of strength of control of a city on the level of SWM services.
6N.6	Extended producer responsibility (EPR)	If any national or international companies involved who produce the packaging electronic and if they are recycled.	6L.6	Inter municipal corporation	Regulatory control at reginal or national level for waste collection and disposal operation.

[154, 155]

3.5 Matrix Method of Evaluation of MSW of Tricity

A simple quantification method has been proposed using the matrix methodology and has been computed for a better understanding of the system analysis approach carried out and explained in the upcoming sections. The proposed grading system used in the wasteaware benchmarks is low (L), Low/Medium (L/M), Medium (M), Medium /High (M/H) and High (H), a certain weightage has been assigned to each of these [155]. The assigned weights are (L=1, L/M=2, M=3, M/H=4, H=5). The parameters excluded for the study are the background information of the cities and the composition of the waste fraction; since they are not utilized in the grading process.

3.6 Results and Discussion

3.6.1 Assessment of MSW Management in Tricity

3.6.1.1 MSW Stakeholders and Budget Allocation

Public Private Partnerships (PPP) are becoming a norm in the management of solid waste. Literature reviews suggests that all of the major cities in India are now operating under a PPP mode for effective SMW systems [11, 197, 178, 151, 91, 123]. There exists such collaboration between Chandigarh Municipal Corporation and a private company functioning under the name of Green Tech Fuel Processing Plant [11, 123]. The company is responsible for complete processing of the MSW and it derives the refuse fuel from it which is then sold for commercial purposes. The company has no role in collection and transportation of MSW. However, till date no such PPP initiatives exist in Mohali and Panchkula Municipal Corporations. Due to lack of such collaborations there is a high negligence in management of MSW in both these satellite towns [11, 91, 123].

The total budget allocated for the financial year 2013-2014 to the Chandigarh, Mohali and Panchkula Municipal Corporations for management of solid waste generated was INR 5737.49 crores (US$9 million), INR 6.5 crores(US$1 million) and even less for Panchkula which was insufficient for maintaining the proper SWM system in all the three cities. In all the three cities, about 80% of the total SWM budget is allocated for salary of sweepers and rag pickers and only about 7-8% is allocated for collection purposes [11].

3.6.1.2 MSW Generation

Characteristics of solid waste are important for devising effective strategies including collection and disposal systems for waste management to prevent any harmful environmental impacts [11, 7, 48, 91, 93]. With increasing urbanization and changing lifestyle, Indian cities produce eight times more solid waste as was produced in 1947 [8, 10, 11, 16, 61, 82]. The major sources of MSW in Tricities Municipal Corporations areas are residential areas, commercial areas, offices and institutions. Chandigarh generates around 380 tons/day i.e. 0.40kg/capita/day while Mohali and Panchkula generates around 150 tons/day or about 0.267kg/capita/day respectively of MSW daily [11, 123].

The per capita generation of solid waste in India is comparatively less than the developed countries. For example, USA has the highest per capita generation rate of 2.58kg/day [18]. Similarly countries in the EU like Germany, France and UK, have higher per capita generation rates of 2.11kg/day, 1.92kg/day and 1.79kg/day respectively. In context of the developed countries in Asia, Japan and China have greater per capita generation rate of 1.71kg/day and 1.02kg/day. Amongst BRICS country, the per capita generation of MSW is less than other developed countries but is still significantly greater than India. For example, Russia has a per capita generation of 0.93 kg/day while Brazil has a generation rate of 1.03 kg/day per capita. The MSW generated from Chandigarh, Mohali and Panchkula mostly comprises of organic matter, inerts, paper, plastics and polythene, clothes, glass, leather waste [196].

3.6.1.3 MSW Collection Process

For an effective solid waste management system, the collection capacities have to be greater than or equal to the solid waste generation rates. However, in India collection capacity provided is often less than the actual waste generated which is a major drawback in proper implementation of solid waste management systems [2, 9, 174, 177]. In Tricity, the MSW collected (both organic and inorganic fraction) is normally stored in the common bins without any segregation [11]. Studies have been reported [144, 149] that 84% of the households in Kathmandu, Nepal store the MSW in commingled form without any segregation. Due to climatic factors like high temperature, humidity and also due to high organic fraction in solid waste, the collection of MSW is done regularly in Tricity as the waste gets decomposed rapidly [11, 123]. Different collection methods include house-to-house collection of the waste by using handcarts or tri-cycles and also collection of roadside waste by street sweeping. The remaining uncollected waste is often dumped on available vacant lands.

For a better SWM system, all the three cities of Chandigarh, Mohali and Panchkula are divided into 56, 114 and 30 sectors respectively [11]. Each sector is provided with 2-3 sweepers. Hand carts and tri-cycles with a broom are given to the sweepers to sweep the roads, lanes and collect the waste and load it to handcarts and transfer the same to the storage centers where the waste is stores till they are finally transported to the disposal sites. The hand carts provided have an average capacity of 2-3m^3 [11, 123]. This is similar to containerized handcarts used in Kolkata having carrying capacity of 160-200 litres [93] whereas in Delhi it varies from 1-4m^3 [7]. The collection efficiency of 90% is achieved in Chandigarh and around 70% and 60% is achieved in Mohali and Panchkula respectively which includes the registered households and slums [11].

The main reason for low collection efficiency in Mohali and Panchkula as compared to Chandigarh city is the lack of adequate manpower and not being educated about the hazards of the MSW [11, 123]. All the Municipal Corporations of respective cities of Chandigarh, Mohali and Panchkula aim at providing a daily collection routine but lack of proper trained manpower, insufficient bin capacity leads to overflowing bins and odor problems emanating from different sectors in these cities [11, 91]. Increasing the trained manpower and providing more MSW storage stations in all the three cities will help in increased collection efficiency thereby reducing the harmful effects due to accumulation of the harmful odor and gases. Further the available manpower should be motivated for working diligently [11, 123] as delaying in collection of MSW can prove harmful not only to the environment but also cause health hazards. *Figure 3.3* shows how the collection is being done in carts and transferred to the primary collection points in Chandigarh, Mohali and Panchkula respectively. The results are symbolized as (a) for Chandigarh, (b) for Mohali and (c) for Panchkula respectively.

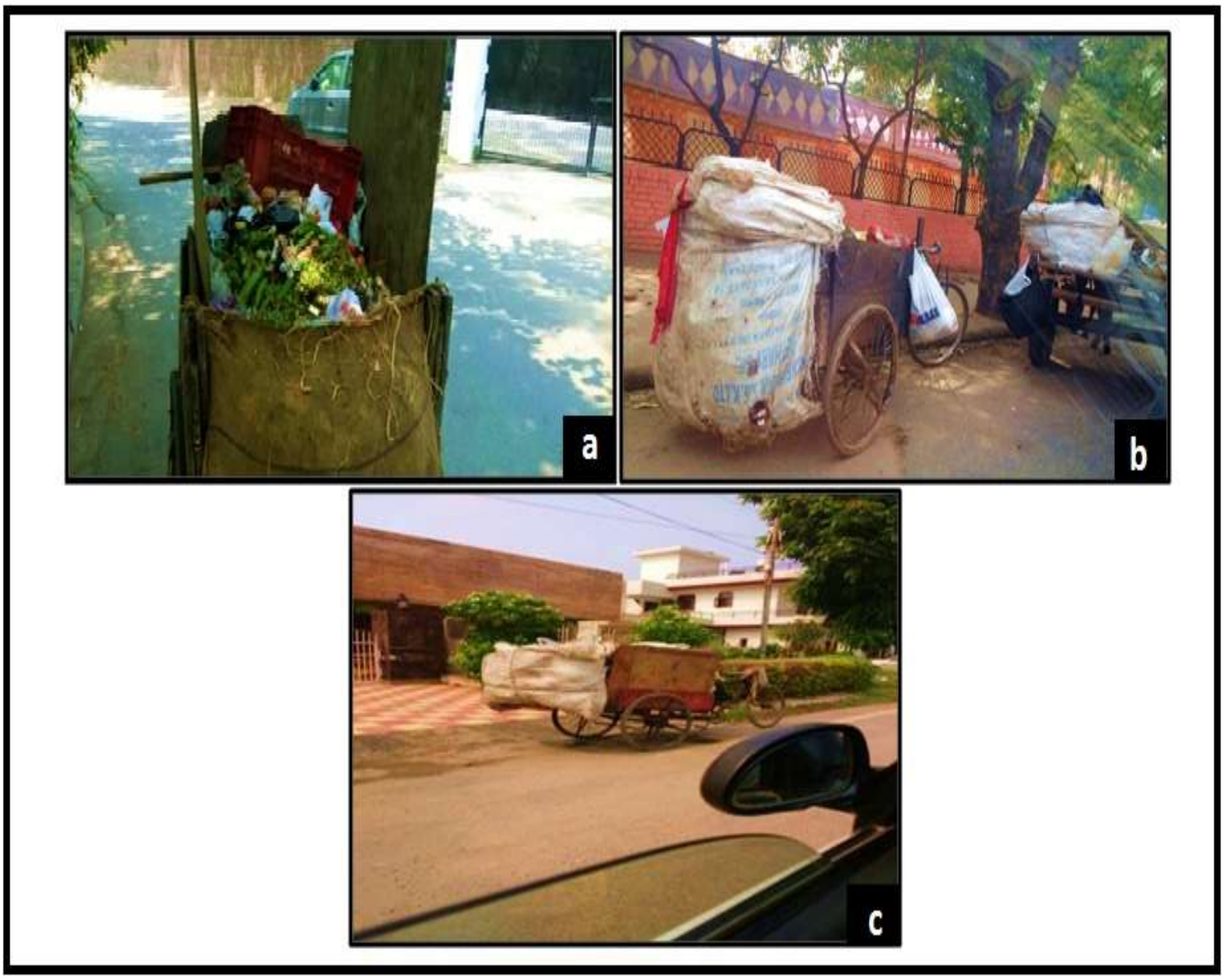


Figure 3.3: Collection of MSW in (a) Chandigarh, (b) Mohali and (c) Panchkula

3.6.1.4 MSW Storage Process

Chandigarh Municipal Corporation have set up various community Sehaj Safai Kendra's (SSK's) in 35 out of 56 sectors where the MSW after collection is stored primarily before getting transported to the disposal site [11]. These SSK's are like collection-cum-transfer stations built over an area of 60x40 sq.ft. For those sectors which do not have SSK's, wastes are collected and stored in SSK's of adjoining sectors [11]. These constructed buildings are provided with boundary wall also act as segregation platform with drinking and toilet facilities, storage room for rag pickers to take rest. Waste is brought to these community SSK's with the help of handcarts during primary collection and is emptied in storage containers [11, 123]. Segregation of waste is carried out by rag pickers and sweepers in informal way in these Kendra's. Trucks or dumpers can also enter these SSK's and pick up the waste from these storage sites to the disposal site. These SSK's act as transfer stations except that there is neither compaction unit nor any proper segregation unit.

Mohali Municipal Corporation has built temporary collection stations of waste from where it is transported to the disposal site by vehicles (trolleys, tractors etc.) but they are not available in every sector and are not well maintained in those sectors in which they are operational. Often, they are set up in an open field with no proper facilities [11, 91] of boundary walls or drinking and toilet facilities for sweepers and are often accessed by stray animals as possible food source. The boundaries of these storage stations are fenced by tin sheets (Personal interaction with sweepers and locals of Mohali, 2015). *Figure 3.4* shows the MSW storage stations in Chandigarh, Mohali and Panchkula respectively.

Figure 3.4: Storage Centers of MSW in (a) Chandigarh, (b) Mohali and (c) Panchkula

Unlike Chandigarh and Mohali; Panchkula has no storage stations in any of the sector of Panchkula where the solid waste collected from domestic households can be stored temporarily before being taken to the disposal site [11, 123]. The solid wastes collected by the sweepers from households are stored in the temporary bins located at different locations within the sectors [11]. These bins are placed at particular sites in each sector. Each sector has four bins. Not all the sectors have the facility of bins (Personal interaction with sweepers and locals of Panchkula, 2015). Further, the sweepers face enormous difficulty, as it is difficult for the sweepers to bring the handcarts to the bins every time since they are located haphazardly and in various undefined locations [11, 123]. For those sectors, not provided with bin collection facilities, sweepers themselves empty the handcarts full of waste to the disposal site [11]. This is one of the major drawbacks reducing the collection frequency of solid waste in Panchkula. To increase the collection efficiency, provision of proper storage stations with drinking and toilet facilities for sweepers should be made. Since, these waste storage stations also serve as the segregation platform [11, 91].

3.6.1.5 Transportation of MSW

Maximum budget of the Municipal Corporations of all the three cities of Chandigarh, Mohali and Panchkula is devoted for collection and transportation, which includes salaries of human resources, fuel, maintenance and procurement of vehicles [11, 198]. Therefore, it is essential to critically investigate actual manpower, vehicle load requirement and make a strategy either to increase funds available for waste management activities or find methods to improve efficiency of waste management by designing collection bins or optimize routes to save energy and fuel consumption [11]. Transportation implies conveyance from point of collection or storage stations to the point of final disposal sites [5, 9, 11]. The Municipal Corporations of Chandigarh, Mohali and Panchkula have been provided with total of 112, 17 and 25 conservancy vehicles respectively for transportation of MSW [11]. In Kolkata, on average 305 vehicles are used for transportation of MSW, where 60% of the vehicles are privately owned [16]. An overview of details of vehicles used for transportation of waste in Tricity is given in *Table 3.10* and *figure. 3.5* gives a view of MSW being transported to the disposal sites of Chandigarh, Mohali and Panchkula respectively. Mechanical street sweeping machines are also sometimes used in cleaning the streets and roads [11].

Table 3.10: Categories and Number of vehicles deployed for transportation in Tricity

Area	Type and number of vehicles
Chandigarh	Tractors trolleys (22), Dumper placers (52), Refuse collector compactors (4), Open trucks (3), Three wheelers (6), Front-end loaders (4) Tractor trolleys for horticulture wastes (20) JCB (1)
Mohali	Tippers (4), Tractor trolley (4), Tempo (5), Dumper placer (2), JCB(1) Loaders (1)
Panchkula	Tractor trolley (19) Dumper placer (5) JCB(1)

The routes used by drivers for transferring wastes are haphazard and depend upon the existing traffic of that particular day. MSW is transported in a very inefficient way in open trucks and many times waste tends to fly from these trucks which lead to spilling of waste on road sides [11]. Further, the wastes are neither cleaned nor given any treatment with sprays so as to avoid any contamination or spread of disease [11].

Figure 3.5: Transportation of MSW in (a) Chandigarh, (b) Mohali and (c) Panchkula

3.6.1.6 Disposal of MSW

Many studies [8, 33, 27, 57, 123, 11] described that numerous waste treatment technologies like composting, vermicomposting, incineration, biomethanation, palletization are being adopted in the country, but so far are to give progressive results as these are still being tested for their sustainability due to high level of variation in the waste fraction. In Tricity, as such no large scale treatment process is being functional.

Although, in Chandigarh city, a refuse derived fuel (RDF) plant is operational since 2008. The state-of-the-art European technology customized to Indian MSW (of high moisture content and varying calorific value) involves conversion of waste (mainly horticulture) into densely packed fluff/pallets free from any harmful by-products and effluents [198, 11]. This project is first of its kind in whole Northern India that produces refuse derived fuel from Municipal Solid Waste [11]. It is the first plant to have dryer and hot air generator (HAG) installed to process the waste [11]. The refuse-derived fuel (RDF) obtained from the plant has calorific value of 3100 Kcal/Kg and moisture content less than 15% (Jaypee Group, 2015). The plant has a processing capacity about 500 tons of garbage daily. With the help of this technology the volume of municipal solid waste gets substantially reduced. This plant is controversial since it started functioning. Waste received by the plant constitutes major fraction of organic material having high moisture content and less combustible fraction. Due to this only 15-20% of waste contributes to the production of RDF [11]. The remaining organic and inert fractions are dumped into dumping site. The processing cost of waste to produce RDF is much more as compared to the rate at which RDF is sold and hence it is not a cost-effective plant. Another major drawback the plant experiences is that the refuse derived fuel so generated is not getting appropriate buyers thereby incurring heavy financial losses.

Due to presence of high degradable fraction of waste, daily disposal of MSW is necessary as it could cause many hazards [34, 171]. There is only one designated dumping site in each of the cities of Chandigarh, Mohali and Panchkula respectively. These disposal sites are located on the outskirts of the respective cities [11]. However, in the past few years a large number of inhabitants have built their houses near to the dumping sites. The dumping site of Chandigarh city is situated in sector 38 near Dadu Majra labor colony. It is 30 years old open dump yard. The total area of the dumping ground is 45.11 acres, out of which 25 acres has been reclaimed by capping 17 acres and creating a land fill site on 8 acres [11]. The remaining 20 acres is being used for dumping the rejects or inert from the garbage processing plant and waste coming from sabzi mandies, apni mandies, big hotels, and villages under the

Chandigarh administration [11]. The dumping site of Mohali is located at Sector 74, Phase-8B. The dumping site covers an area of around 8 acres and is around 20 years old. The site used for dumping the municipal solid waste of Panchkula city is situated in sector 23 in Panchkula. The total area of dumping ground is 10 acres (Personal communication with Panchkula Municipal Corporation, 2015). This dumping ground is in use for the past 15 years. The dumping sites in all the three cities are open dumps and the practice of disposing of MSW is open dumping, the MSW unloaded on the site by vehicles is compacted with the help of bulldozers and covered with layer of soil or construction and demolition wastes [11]. After levelling the waste, a bacterial solution is sprayed on the MSW to prevent foul smell and breeding of flies and insects. Fogging of the dumping sites is also being done on weekly basis. *Figure 3.6* shows the map depicting the site and actual dumping sites of Chandigarh, Mohali and Panchkula respectively.

Figure 3.6: Map depicting site and actual dumping site of MSW disposal in (a) Chandigarh, (b) Mohali and (c) Panchkula

With the exception of the mentioned methods, no further treatment of MSW is being provided at the sites. All the three dumping sites have no provision of leachate and landfill gas collection systems. Besides, they are unlined and there are possible chances of contamination of aquifer in surrounding areas due to percolation of leachate in the sub soil, which prerequisites monitoring the ground water quality in routine [11]. Looking into the environmental implications of the dumping sites of Chandigarh, Mohali and Panchkula, the Municipal Corporation of the respective cities must initiate the conversion of the dumping sites into the sanitary landfills and its restorations.

3.6.2 Existing Problems in MSW system and possible solutions for Tricity

3.6.2.1 Source separation

Source separation of the waste leads to reduced loads on the landfills. *Figure 3.7* shows the suggested source separation using different color coding for different fractions of the waste. Similar proposals have been suggested for Chandigarh city [35, 160]. There must be a facility for proper compaction of waste given that major portion of waste is biodegradable in comparison to other proportions of the waste [11]. Hence, composting or other economic bioprocesses can be one of the treatment technologies to be followed effectively. Further, separation of kitchen and yard waste from the remaining waste can lead to composting under natural conditions which can be carried out efficiently and economically which will lead to reduction in large quantities of waste and transportation will become easier [11]. Chandigarh Municipal Corporation in partnership with Bhabha Atomic Research Centre (BARC) has planned to set up two biomethanation plants to process hotel, vegetable and mixed waste. Likewise, the Municipalities in Mohali and Panchkula should also undertake setting up of biomethanation systems. With the installation of these plants, the Municipal Corporations in Tricity will be able to process the organic waste generated from the vegetable market and hotels and methane gas so generated will be utilized to generate electricity [11].

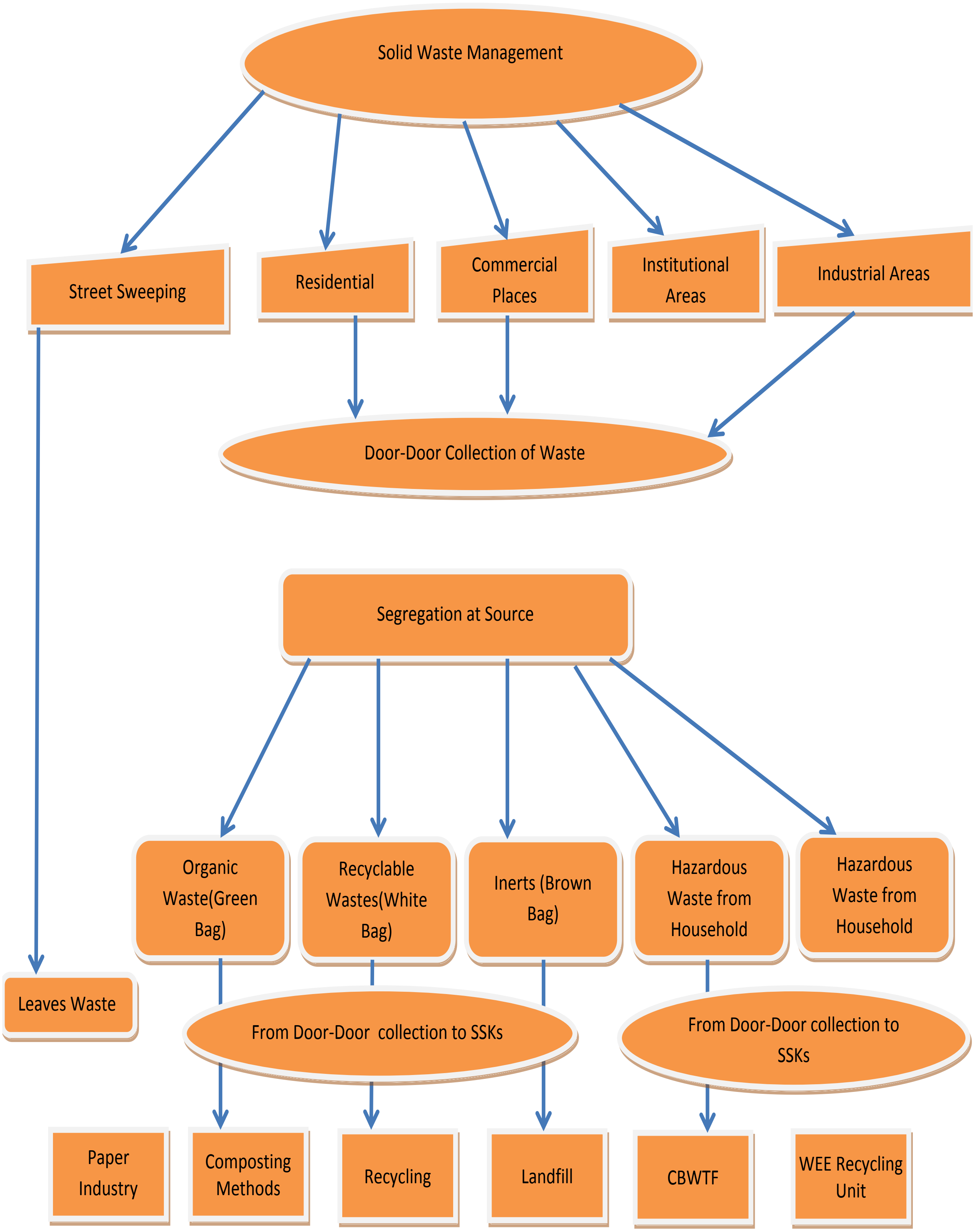


Figure 3.7: Proposed Waste Management Scheme for Tricity

3.6.2.2 Littering by residents after collection

Even though the sweeping and collection of waste is often done regularly in Tricity, residents cause littering of the waste which poses serious problems [11]. The households particularly from the slums, low income areas and local shopkeepers frequently throw waste on the streets and roads and any available open spaces causing excessive littering and clogging of drainage systems in Tricity [11]. Instead of disposing of waste in the garbage bins provided, they litter the waste in open.

To curb this problem, the Municipal Corporations of all the three cities should strictly specify and notify about the timings of the waste collection so as to avoid the problem of littering [11]. Big containers or bins should be placed outside shops so that the waste is disposedofin those bins and penalize the offenders with heavy fine and punishment. The lack of an adequate policy and regulatory framework further compounds the problem. Legal actions must be taken against the individuals or the industrial units who are found guilty. The Municipal Corporations in Chandigarh, Mohali and Panchkula respectively should also campaign aggressively for more awareness and education about maintaining cleanliness in public areas [11]. Municipal Corporations in Tricity should also re-organize allotment of budgets to prioritize upgrade of waste infrastructure and services.

3.6.2.3 Poor Conditions of Collection Containers and Areas around them

It has been witnessed that about 60% of the primary collection and storage of the waste is done using open storage enclosures. The conditions of these open containers are very unhygienic in most of the collection points in Tricity [11]. Foul smell and odor, breeding of flies and other disease causing vectors is common site at these sites. It is suggested that these open containers should be completely eliminated or must be replaced with closed containers and handcarts with adequate spacing to hold waste. If open containers are to be continued with for collection of wastes they should be regularly cleaned, disinfected and should be replaced after certain years of service [11]. Another important suggestion is using proper volume storage containers to be sufficient enough to cater to the entire waste generation for that particular location. This will not cause an overflow and will prevent poor conditions around the collection container.

3.6.2.4 Distribution of Labor and Resources

Sweepers or sanitation workers are allotted to different sectors on the basis of population. In Chandigarh, for 56 sectors, about 10-15 sweepers are assigned to each sector whereas in Mohali with 114 sectors and Panchkula 30 sectors, about 2-3 sweepers are assigned to each sector [11]. For collection of waste from each of these sectors in Tricity, handcarts have been provided operated by a team of two persons [11]. Workers and handcarts are allocated based on population, commercial activities and vehicle road kilometers in various sectors in Tricity [11]. It has been envisioned to use rag pickers supervised by certain NGO's for improving the collection frequency. The rag pickers must be motivated to work which can be beneficial to both sides. On one hand, it will help in separating out the biodegradable and recyclable waste which would help in improving the efficiency of MSW collection and recovery and on the other hand would also provide job opportunities for the informal waste collectors [11].

Recycling and reclamation of waste are now strongly promoted for conservation of resources and prevention of environmental degradation. However, no recovery or recycling facilities occur in all the three cities of Chandigarh, Mohali and Panchkula respectively [11]. Hence, it is proposed that there should be an introduction of formal recycling unit where there should be proper and formal recycling of waste so as to derive all the benefits associated with waste recycling. Presently, in Chandigarh and Panchkula, there exist some local informal recyclers involved in recycling process and these informal recyclers mainly comprise of unorganized and unrecognized establishments and are not monitored by the government and hence do not contribute to the economy [11]. Interestingly, even the informal recycling is not carried out in Mohali.

3.6.2.5 Poor Working Conditions

The sanitation workers and sweepers, who collect and transfer the waste, work under unhygienic conditions. Most of them generally suffer from parasitic diseases like jaundice, diarrhea and trachoma [2, 178, 151, 11]. Local bodies and NGO's should conduct seminars making sweepers and rag pickers aware of the health hazards associated with such types of waste. The sanitation workers, sweepers and rag pickers should be made familiar with the proper procedures and methods followed during collection and segregation of the waste as they play an important role in maintaining the health and hygiene within the cities and this job personally exposes them to a variety of risk factors [11]. These conditions can't be totally prevented but the use of containerized handcarts and use of mechanical equipments could help in lesser direct contact of wastes with sanitation workers. In this context, the sweepers and sanitation workers should be provided with protective gear (like surgical gloves) to reduce direct contact with solid waste [11]. The sweepers should be advised to regularly undergo medical checkup. It is also advised that residents should be encouraged to use different containers for disposing of different type of waste which will reduce multiple handling and poor productivity.

3.6.2.6 Inadequate Maintenance and Replacement of Worn-out collection vehicles

Most of the vehicles used for transporting the waste to the disposal sites in Chandigarh, Mohali and Panchkula are obsolete [11]. Use of such vehicles increase operation and maintenance costs and reduces the transfer efficiency and also adds up to the air and noise pollution [11]. Proper maintenance of disposal vehicles must be done. An additional set of vehicles must be kept for emergency requirements too. Further, the vehicles must meet Bharat Stage IV standards, which are currently applicable to all vehicles in India.

3.6.2.7 Collection and Transfer System

The collection and transfer system in all the three cities is carried out in an unsystematic manner without following any organized approach. This leads to highly reduced efficiency. There exists no appropriate collection route and is left upon the drivers to decide and every vehicle collects the solid waste along its route until maximum capacity of the vehicle is reached [11]. Since the routes are not properly designed for avoiding traffic, reducing travel times, vehicles often travel extra distance or spend more time at same route leading to more fuel consumption and increasing operating costs. Hence, the present approach is neither cost-effective nor resourceful. It is suggested that vehicles equipped with GPS technology that can be utilized for deciding proper routes should be implemented for economic and efficient collection of waste [11]. Further, proper scheduling of collection of wastes from different sectors in Chandigarh, Mohali and Panchkula should be optimized so as to avoid unnecessary delays and additional time for collection of waste on the designated routes. This will also lead to use of effective utilization of existing manpower and resources.

3.6.2.8 Disposal Method

The waste collected from all the three cities, Chandigarh, Mohali and Panchkula respectively, are dumped directly at the open dumping sites under unhygienic conditions. Once the wastes are dumped in these open sites, they are covered with the *malba* or soil and leveled with bulldozers [11]. No lining system exists in the dumping sites to avoid leakage of leachate from the waste so as to prevent the contamination of the soil and ground water sources in the nearby vicinity. This leads to uncontrolled leaching and thereby contamination of the ground water. Such uncontrolled leachate percolation poses tremendous health hazards from toxic metals. Also, there exists no proper security at the dumping sites of Tricity, which leads to uncontrolled entry of rag pickers, stray animals which further worsens the conditions [11]. It is suggested that proper-engineered landfills with proper leachate collection and extraction systems will help in minimizing the ground water contamination. In this context, the Municipal Corporations of Chandigarh, Mohali and Panchkula have proposed engineered landfill sites and all the municipalities are acquiring different landfill sites which would be made secured landfills [11, 123].

3.6.3 ‘Wasteaware’ Benchmark Indicators for Sustainable Waste Management

Using the procedure described by [154, 155] for generating the ‘wasteaware’ benchmark indicators, the same was generated for Chandigarh, Mohali and Panchkula and has been presented in *Table 3.11*. The generated benchmark of Chandigarh, Mohali and Panchkula has been compared with benchmarks of Surat (tier-II city in India) and Lahore (comparative city in Pakistan) as reported by [11, 154, 155].

It is observed from the *Table 3.11* that all these cities experience similar nature of solid wastes generated with the highest proportion of organic waste. It is observed that Lahore city which has almost eight times the population of Chandigarh almost generates twice the amount of waste per capita due to higher population density [11]. Interestingly, this is also observed for Mohali city which has a higher population generate lower waste per capita than Panchkula city which has a lower population.

Table 3.11: Comparison of Wasteaware parameters for Chandigarh, Mohali and Panchkula compared with other tier –II cities of India and Asia.

No.	Category	Indicator	Chandigarh City Results	Mohali City Results	Panchkula City Results	Surat City Results	Lahore City Results
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	$1,420	$1,420	$1,420	$1,420	$1,140
B2	Population of the City	Total Population of the City	1,055,450	9,86,147	5,61,293	4,600,000	8,160,000
B3	Waste Generation	MSW Generation (tons/year)	13,5050	37,595	54,750	45,6250	1,916,000
W1	Waste per Capita	MSW per capita (kg per year)	128	38.12	97.54	119	219
W2	Waste Composition	3 key fractions – as % wt. of total waste generated					
W2.1	Organic	Organics (food and green wastes)	52%	55%	-	54%	65%
W2.2	Paper	Paper	6%	5%	-	8%	2%
W2.3	Plastics	Plastics	7%	4%	-	10%	12%
1.1	Public health – Waste collection	Waste collection coverage	90%(M/H)	90%(M/H)	60%(L/M)	95%(M/H)	77%(M)
1C		Quality of waste collection service	90%(M/H)	75%(M)	60%(L/M)	95%(M/H)	58% (M)
2	Environmental	Controlled	30%(L)	30%(L)	30%(L)	55%(L/M)	8%(L)

	control – waste treatment and disposal	treatment and disposal					
2E		Degree of environmental protection in waste treatment and disposal	L (0%)	L (0%)	L (0%)	L/M (37%)	L/M (37%)
3	3Rs – reduce, reuse and recycling	Recycling rate	0% (L)	0% (L)	0% (L)	30% (L)	35% (M)
3R		Quality of 3Rs provision	L (17%)	L (10%)	L (12%)	L/M (29%)	L (17%)
Governance Factors							
4U	User inclusivity	User inclusivity	M (75%)	M (75%)	M (74%)	M (80%)	L/M (37%)
4P	Provider inclusivity	Degree of provider inclusivity	M (78%)	M (76%)	M (75%)	M (82%)	L/M (50%)
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	L/M (60%)	L/M (60%)	L/M (60%)	L/M (60%)	L/M (29%)
6L		Degree of institutional coherence	M (75%)	M (75%)	M (75%)	M (77%)	M/H (62%)

Further, comparison of the '*wasteaware*' benchmarks parameters for Chandigarh, Mohali, Panchkula, Surat and Lahore displays that Chandigarh, Mohali and Surat have very good collection efficiencies [11] as compared to Panchkula and Lahore which showed 'low-medium' and 'medium' index on wasteaware benchmark indicators respectively. The major difference between Chandigarh, Mohali, Panchkula, Surat and Lahore is in the disposal methods and in the efficiency of *3R method*, whereas Surat scores a 'Low/Medium' index for environmental controlled waste treatment and disposal method as reported earlier [11, 154, 155], Chandigarh, Mohali and Panchkula scores 'Low' index. This is because the disposal sites are unsanitary landfill in nature. Though, EM and bacterial solution and leveling of waste are done, these are not proper engineering solutions to handle the hazards arising from solid waste. Further, there is no lining provided at the landfill site to prevent the percolation of leachate in groundwater thereby contributing to environmental hazard [11].

Further, Surat and Lahore scores a 'Low/Medium' index for efficiency of*3R* methodology (reduce, reuse and recycle) as reported in earlier studies [154, 155, 11], however Chandigarh, Mohali, Panchkula scores 'Low' index in the same category as no recycling facilities exists in these cities. *Figure 3.8* presents the radar diagrams of Chandigarh, Mohali and Panchkula and *Figure 3.9* presents the comparative radar diagram for Chandigarh, Mohali, Panchkula, Surat and Lahore.

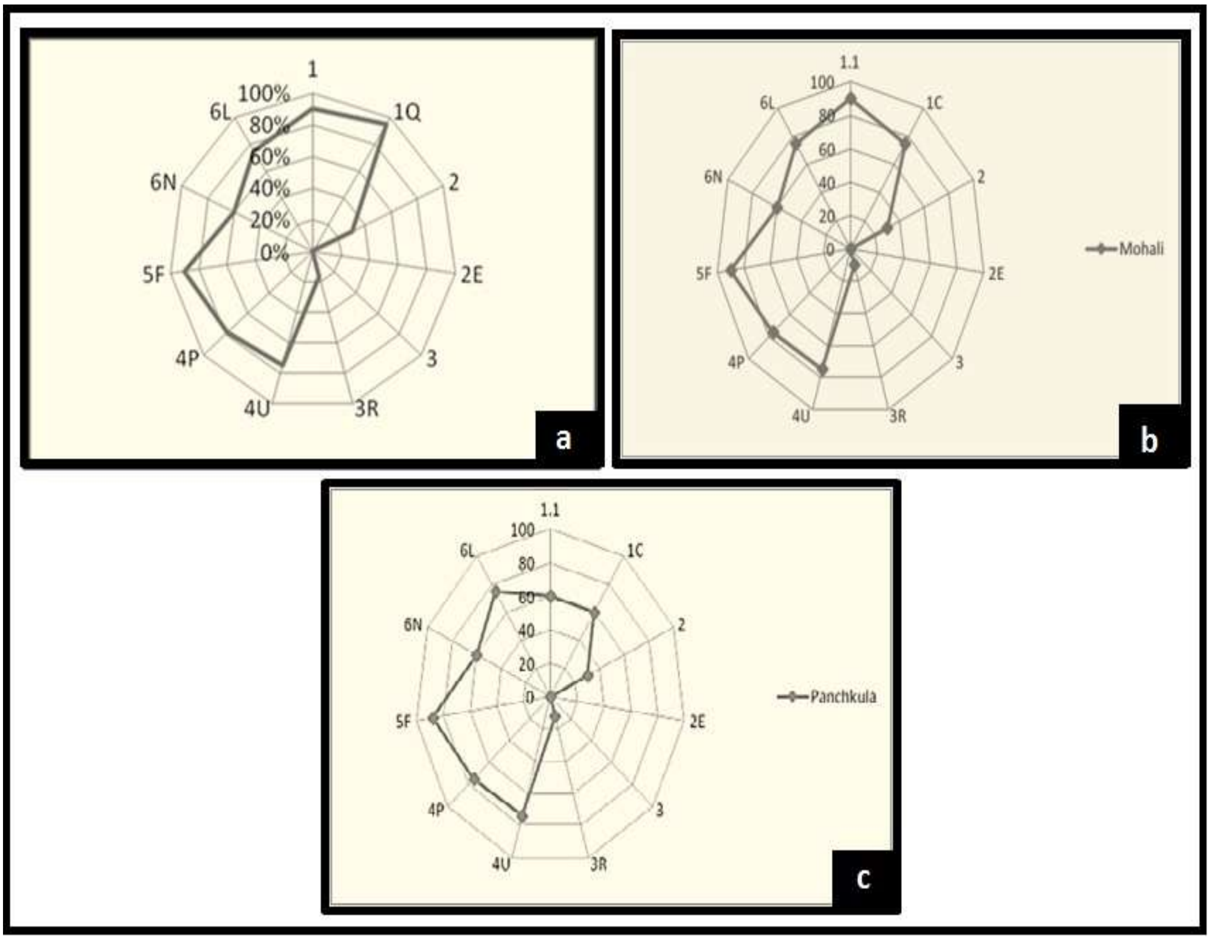


Figure 3.8: Radar Illustration representing the Wasteaware ISWM benchmark indicators for (a) Chandigarh; (b) Mohali and (c) Panchkula

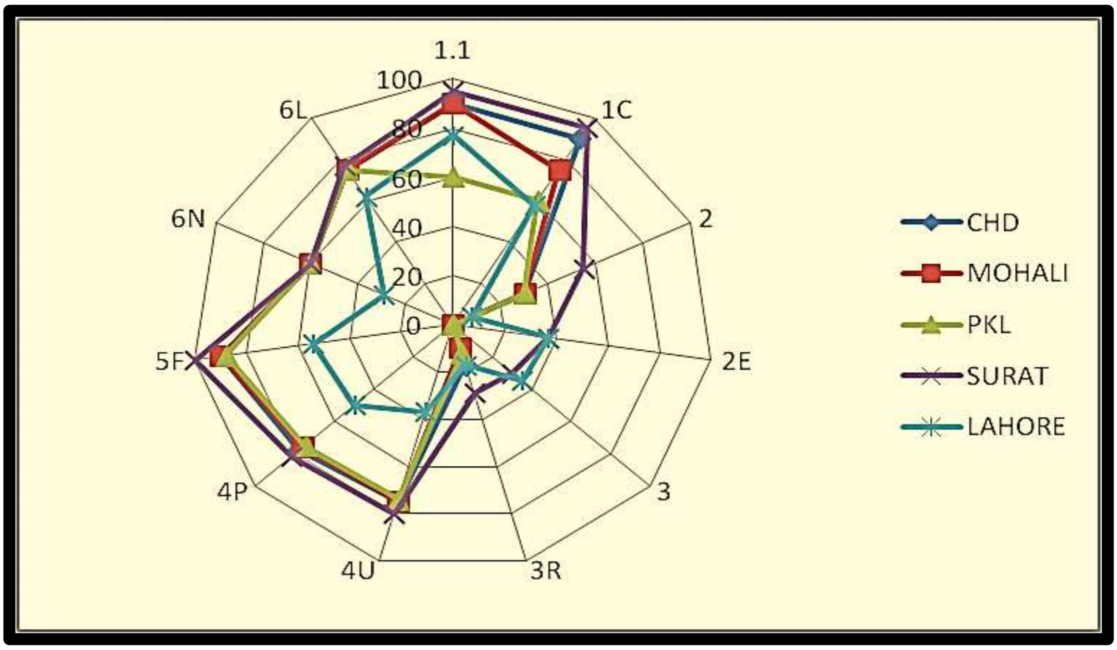


Figure 3.9: The comparative radar diagram for Chandigarh, Mohali, Panchkula, Surat and Lahore.

3.6.4 Quantification of Indicators using Matrix Method of Evaluation

Using the methodology of matrix method as mentioned earlier in section 3.5, the weights were assigned for the respective indicators and have been presented in *Table 3.12*. The final scores obtained using the matrix methodology has been summarized in *Table 3.13*.

Table 3.12: Weightage Assignment for evaluation using matrix method

No.	Category	Indicator	Chandigarh City Results	Mohali City Results	Panchkula City Results	Surat City Results	Lahore City Results
Quantitative Indicators (Public Health, Environmental Control, 3R)							
1.1	Public health – Waste collection	Waste collection coverage	90%(M/H) (4)	90%(M/H) (4)	60%(L/M) (2)	95%(M/H) (4)	77%(M) (3)
1C		Quality of waste collection service	90%(M/H) (4)	75%(M) (3)	60%(L/M) (2)	95%(M/H) (4)	58% (M) (3)
2	Environmental control – waste treatment and disposal	Controlled treatment and disposal	30%(L) (1)	30%(L) (1)	30%(L) (1)	55%(L/M) (2)	8%(L) (1)
2E		Degree of environmental protection in waste treatment and disposal	L (0%) (1)	L (0%) (1)	L (0%) (1)	L/M (37%) (2)	L/M (37%) (2)
3	3Rs – reduce, reuse and recycling	Recycling rate	0% (L) (1)	0% (L) (1)	0% (L) (1)	30% (L) (1)	35% (M) (2)
3R		Quality of 3Rs provision	L (17%) (1)	L (10%) (1)	L (12%) (1)	L/M (29%) (2)	L (17%) (1)

Qualitative Indicators (Governance Factors)							
4U	User inclusivity	User inclusivity	M (75%) (3)	M (75%) (3)	M (74%) (3)	M (80%) (3)	L/M (37%) (2)
4P	Provider inclusivity	Degree of provider inclusivity	M (78%) (3)	M (76%) (3)	M (75%) (3)	M (82%) (3)	L/M (50%) (2)
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	L/M (60%) (2)	L/M (60%) (2)	L/M (60%) (2)	L/M (60%) (2)	L/M (29%) (1)
6L		Degree of institutional coherence	M (75%) (3)	M (75%) (3)	M (75%) (3)	M (77%) (3)	M/H (62%) (4)

The matrix method for evaluation showed the best possible results for Surat city with an overall score of 52%, being classified as L/M category. Qualitative and Quantitative parameters for Suratwere almost of equal score (Quantitative parameters = 50%, Qualitative parameters = 55%). In contrast, the quantitative parameters were significantly less than the qualitative parameters for Chandigarh, Mohali and Panchkula. The overall classification of the three cities was in the low categories [11]. Interestingly, governance factors for all the Indian cities were equal with 55% of weightage. The main difference between categorization of scores between Surat and Chandigarh, Mohali and Panchkula is primarily due to increased scores for Surat cities for better environmental control facilities (2 and 2E) and recycling facilities (3, 3R). Interestingly, no recycling facilities exist for Chandigarh, Mohali and Panchkula [11].

Table 3.13: Summary of scores obtained using matrix method

No.	Category	Indicator	Chandigarh City Results	Mohali City Results	Panchkula City Results	Surat City Results	Lahore City Results
Quantitative Indicators (Public Health, Environmental Control, 3R)							
1.1	Public health – Waste collection	Waste collection coverage	4	4	2	4	3
1C		Quality of waste collection service	4	3	2	4	3
2	Environmental control – waste treatment and disposal	Controlled treatment and disposal	1	1	1	2	1
2E		Degree of environmental protection in waste treatment and disposal	1	1	1	2	2
3	3Rs – reduce, reuse and recycling	Recycling rate	1	1	1	1	2
3R		Quality of 3Rs provision	1	1	1	2	1
Total Score (Quantitative Indicators)			12	11	08	15	12
Maximum Score			30	30	30	30	30
Weightage (%)			**40**	**37**	**27**	**50**	**40**

Qualitative Indicators (Governance Factors)							
4U	User inclusivity	User inclusivity	3	3	3	3	2
4P	Provider inclusivity	Degree of provider inclusivity	3	3	3	3	2
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	2	2	2	2	1
6L		Degree of institutional coherence	3	3	3	3	4
Total Score (Qualitative Indicators)			11	11	11	11	9
Maximum Score			20	20	20	20	20
Weightage (%)			**55**	**55**	**55**	**55**	**45**
Total Score (Overall)			12+11 = 23	11+11 = 22	08+11 = 19	15+11 = 26	12+09 =21
Total Maximum Score			30+20 =50	30+20 =50	30+20 =50	30+20 =50	30+20 =50
Overall Weightage (%)			**46**	**44**	**38**	**52**	**42**

3.6.5 MSW Processing and Minimization

Recycling Possibilities

The system analysis of the waste generated showed the absence of recycling facilities in Chandigarh, Mohali and Panchkula [35, 11]. This is a great setback to proper management of MSW generated in these cities. To enable to have an operational recycling facility, proper segregation of waste should be carried out for the collected wastes generated from these three cities. The municipalities of Chandigarh, Mohali and Panchkula should encourage this practice by utilization of rag pickers under the supervision of a local NGO [11]. Similar practices have been followed in in Delhi [11, 14, 32, 193, 192]. A combined recycling unit could be set up to serve in all the three cities of Chandigarh, Mohali and Panchkula.

Major infrastructural requirements for optimizing recycling activities are stakeholder infrastructure, cognitive infrastructure and recycling infrastructure. Stakeholder infrastructure involves the decision-making capabilities of concerned stakeholders (government, contractors, and consumers) as their decision highly influences the results of the recycling period. Cognitive infrastructure depends upon the willingness of the consumers and general public to go for recycling process and in turn use reuse the recycled products so manufactured. An unwillingness to recycle products and reuse of such goods may have severe detrimental effects on the recycling process. Recycling infrastructure deals with the actual daily processes involved in the recycling process. This includes existing infrastructure for collection, transportation, processing etc. Available resources for these processes can significantly affect the overall efficiency of the recycling process.

Recycling is one of the best methods that could be implemented successfully in Tricity. There exists an ample potential of recycling in all the three cities of Chandigarh, Mohali and Panchkula, primarily because the MSW generated in these cities consist of high fractions of recyclables (plastics, paper and glass). Unfortunately no dedicated recycling facilities are available in any of these cities [11]. A plastic recycling plant for Tricity will cost about INR 35-40 lakhs ($52000 - $60000). A similar plastic recycling plant was set up in Kozhikode (MSW generation rate of 250 TPD) in 2013 at a cost of INR 62 lakhs ($93000) was closed after sometime due to dispute between contractor and the state government. Latest reports suggest it will soon become operational again. A paper recycling plant of 1 lakh tons capacity would cost around INR 200 crores ($30000000). A recycling plant of such capacity is already in operation in Coimbatore in India. One of the major advantages of the waste recycling is that a substantial amount of revenue can be generated which can be utilized for treatment cost of MSW. Recycling facilities provide tangible financial benefits from recycling of certain products and thereby also increase the lifespan of the landfill sites.

3.7 Recent Improvement and Interventions taken by Municipal Corporations of Tricity

The Government of India has launched a *"Swachh Bharat Abhiyan"*- "*Clean India Mission*" in 2014 for making efforts towards substantial improvement in public health and thereby ultimately contributes to the national economy.

As a part of this movement and also with increasing quantity of solid waste, the Municipal Corporations of Chandigarh, Mohali and Panchkula have introduced many new resolutions for better solid waste management [11]. This includes introduction of more number of garbage bins of appropriate capacity in different sectors. Further, all the three municipalities have sanctioned buying of more dumpers, trucks and containers for the upcoming financial year for effective collection and disposal of solid waste. Municipal Corporations of Chandigarh, Mohali and Panchkula are focusing on overall development of integrated solid waste management to effectively manage essential activities starting from segregation and storage of waste at the sources, implementation of public-private collaboration which will work towards the better and efficient integrated solid waste management [11]. The development of an integrated system will optimize better utilization of solid waste generated by recycling, RDF, composting etc. As mentioned earlier purchase of new dumping sites fitted with proper lining systems to prevent leachate percolation and appropriate gas collection are already in process for all the three municipalities [11]. This will prevent contamination of groundwater in the nearby vicinities of the three cities.

3.8 Summary and Discussion

The study helped in understanding the existing waste management practices in Chandigarh, Mohali and Panchkula and identifying the factors responsible for the inefficient management of solid waste. It is observed that despite adopting various methods for efficient management of waste, there are many short-comings in the system. The study has also suggested remedial measures to overcome some of the drawbacks including proper maintenance of collection vehicles, upgrading to new vehicles, installing adequate number of bins and bin capacity depending on the population of different sectors in all the three municipalities and proper design of collection routes to increase the efficiency. Further, recruitment and training of additional sanitary workers should be carried out to increase collection efficiency. Under the *Clean India Initiative* both the municipalities of the satellite towns are in advanced talks to purchase new landfill sites which will have proper lining system to minimize leachate percolation and avoid any groundwater contamination. The wasteaware benchmark indicators for Chandigarh, Mohali and Panchkula show very poor performance in environmentally controlled waste treatment, disposal method of waste and the *3R* methodology. Further, this study can be taken as a baseline for planning new policies/rules for effective MSW management system in Chandigarh, Mohali and Panchkula.

CHAPTER 4

CHARACTERIZATION OF MUNICIPAL SOLID WASTE IN TRICITY

4.1 Introduction

India's economy is expected to rise to 38% by the year 2026 [123, 199, 91, 27] and as such the volume of the MSW generated is expected to increase manifold times [123, 5, 8, 44, 31]. In India, the per capita generation of solid waste varies from 0.15 kg in rural locations to 0.45 kg in urban areas [35, 71, 123]. Proper management of MSW is a complex process which has been further affected due to reduced budgetary provisions available to municipal authorities [44, 45, 46, 57, 91, 123]. A systemic approach is required to improve various policies, rules, regulations and legal frameworks so as to achieve sustainable solid waste management in the Asian countries [59, 11, 123]. An effective waste management system utilizes data including quantity, quality and composition of waste (from different socio-economic groups) for determining an effective solid waste management system [123]. As such, these parameters depends on number of varied factors like living standards, seasonal variations, food habits, source of generation and socio-economic conditions of the area [43, 10, 44, 60, 96, 49, 35,123, 171]. As such, the characterization studies help in determining the existing deficiencies in the MSW management system practices and can help in identifying appropriate steps to minimize the existing deficiencies in the MSW management process [35, 123].

For a sustainable waste management strategy it is first necessary to identify the nature and composition of the waste [49, 50, 58, 60, 61, 123]. In India, it has been reported that the organic fraction of MSW varies between 35 to 60% in different parts of country [8]. The organic material includes paper, plastics, yard waste, food waste, wood, textiles and disposable diapers [65, 200, 201, 123, 50, 7, 158, 123]. The organic matter in MSW in developing countries like India is much higher than that in the waste in developed countries [33, 49, 50]. India has a potential of producing about 4.3 millions of compost each year [58, 123], but poor solid waste management practices and low quality of compost production causes huge constraints in exploring such large amount of plant nutrients which in turn can be helpful in increasing crop productivity [123, 171]. The environmentally sound facilities for the treatment and disposal of MSW are in great shortage and rag picking is one activity that is feared to be causing steep decrease in the calorific value of the waste due to implicit recycling activity [123]. Presently, lack of data as well as information regarding the generation, amount and nature of MSW creates hurdle in developing an integrated MSW management plan. Majority of the studies reported for India are primarily based on Metropolitan and Tier-I cities. Very limited studies have been reported for characterization of municipal solid wastes in Tier-II cities of India which are often the state capitals or designated industrial hubs with a population of about 1 million [123].

In this context, the present study focuses on characterization of MSW from Tricities of Chandigarh (CHD), Mohali (MOH) and Panchkula (PKL), top tier-II cities in Northern India. The main objectives of the study were to analyze the physical and chemical characteristics of MSW in all the three cities, for assessing suitable waste processing technologies, to understand present waste management and identifying factors responsible for inefficient waste management in these cities and to suggest suitable remedial measures.

4.2 Methodology

4.2.1 Materials and Methods

The sampling procedures followed in the study were as per the guidelines described in ASTM-D5231-92 (ASTM, 2004a, b, c; 2006a; 2008). MSW samples from all the three cities were collected from vehicles unloading waste from commercial, institutional and household waste at dumping sites [123]. In accordance with the method, vehicles were identified from the designated regions reaching the dumping sites were selected arbitrarily throughout each day of the 10 days sampling period to have an illustrative waste stream. Sampling of waste from all the three cities was done for five groups including commercial (comm.), Low Income group (LIG), Middle Income group (MIG), High Income group (HIG) and Institution (Inst.) as shown in *figure 4.1*.

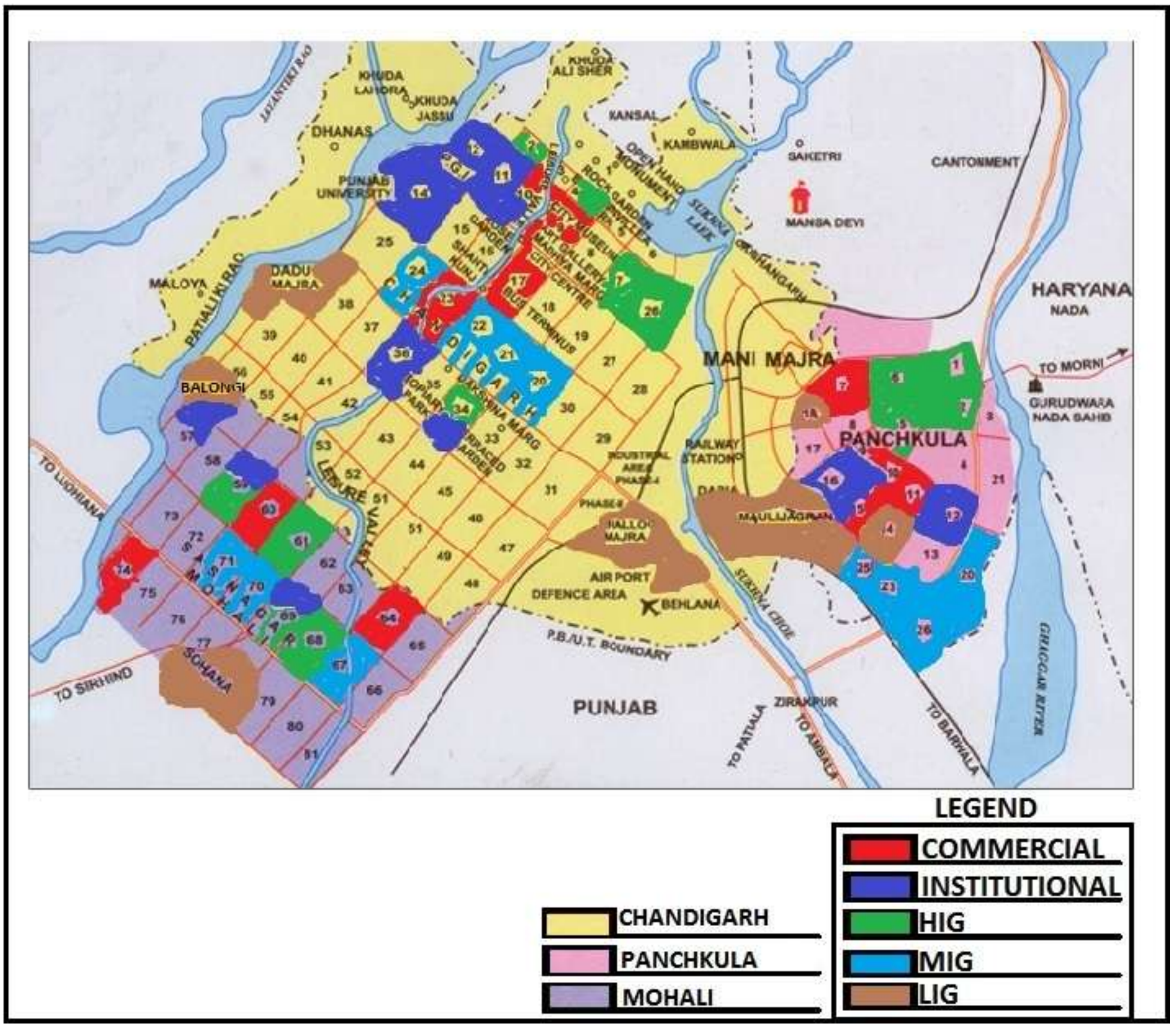


Figure 4.1: Detail of different income group areas in Tricity

In particular, majority of the characterization studies are utilized including different socioeconomic groups using High Income Group (HIG), Low Income Group (LIG), and Medium Income Group (MIG). However, in this study we have incorporated two more categories including institutional and commercial [123]. This is because over the period of time it has been observed in the Tricity area that there has been rapid growth of MSW generated from institutional (universities, colleges, coaching centers) with about 10% in Chandigarh, 6% in Mohali and 6% in Panchkula and commercial (shopping complexes, malls and restaurants, local markets) and are now responsible for accounting for about 10% in Chandigarh and 7% each in Mohali and Panchkula of the total MSW generated in the Tricity region [123]. The samples were collected using quartile method to understand the waste composition [3]. All the contents in the vehicles were emptied on a plastic sheet for preventing mixing of soil or any beneath water; 1000 kg of the waste samples unloaded from the vehicles was then reduced to 100 kg in second iteration. Segregation of the waste sample was done manually with the help of workers and rag pickers [123].

4.2.2 Characterization of MSW in Tricity

An overview of composition of MSW in Indian cities is shown in *Table 4.1*. To plan an effective waste management system, information regarding quantity and composition of waste is necessary as they both are influenced by a number of factors like standard of living, seasons, food habits of people, source of generation and socio-economic conditions of an area [35, 56, 123].

Table 4.1: MSW Composition in Indian cities

City	Paper*	Textile*	Leather*	Plastic*	Metals*	Glass*	Ash*	Organic Matter*	Moisture Content*
Ahmadabad	6.0	1.0	-	3.0	-	-	50.0	41.0	32.0
Bengaluru	8.0	5.0	-	6.0	3.0	6.0	27.0	52.0	35.0
Bhopal	10.0	5.0	2.0	2.0	-	1.0	35.0	52.0	43.0
Mumbai	12.0	4.6	0.4	2.0	-	0.2	44.0	62.0	54.0
Delhi	6.8	5.6	0.6	1.5	2.9	1.7	51.5	54.0	50.0
Hyderabad	7.0	1.7	-	1.3	-	-	5.0.0	51.0	50.0
Jaipur	6.0	2.0	-	1.0	-	2.0	47.0	45.0	40.0
Lucknow	4.0	2.0	-	4.0	1.0	-	50.0	49.0	60.0
Ludhiana	3.0	6.0	-	5.0	2.0	-	50.0	45.0	50.0
Pune	5.0	-	-	5.0	-	10.0	15.0	55.0	40.0
Surat	4.0	5.0	-	3.0	-	3.0	45.0	40.0	30.0
Kolkata	10.0	5.5	0.5	1.7	0.4	1.6	50.0	51.0	46.0
Puducherry	11.0	4.0	-	2.0	0.2	1.5	26.0	50.0	54.0

[12];*Values in %

Physical Characterization

Determination of the physical composition of MSW is highly important as it helps in ascertaining the suitable technology for implementation of an effective waste management system [3, 6, 123]. The samples collected were analyzed on wet weight basis (without any prior drying of waste samples for removal of moisture) and segregated into their components. Segregation of the waste helps in properly disposing the vast amount of waste [123]. The segregated component includes paper, polythene/plastic, clothes/textiles, organics/vegetables/horticulture, rubber/leather, glass, other mixed constituents like clothing, toys and sanitary items metals and inert. Inert wastes are generally defined as those wastes which are non-reactive chemically and cannot be degraded biologically by microbes. In present study, the inert materials present in the MSW characterization for all the three cities were gravel, sand and stones [123]. The reason for inert component in the MSW for the

Tricity region is primarily due to construction of buildings which are collected via street sweepings and disposed of at the MSW dumpsite.

Each component of the waste was weighed separately to know the percentage contribution to the waste. Moisture content of the waste was immediately analyzed in the laboratory as delaying can alter the characteristic properties of waste and thereafter sample preparations were done for chemical characteristics [123].

Chemical Characterization

The proximate and ultimate analysis of the MSW was also performed to determine the fraction of crustal elements and ash content of the MSW as physical characterization provides information only regarding the main component fraction present in MSW [3, 6, 123, 202]. Sample preparation was done as per BIS-IS: 9234 and ASTM-D5231-92 [123, 203-206]. Various analyzed parameters include moisture content, volatile matter, ash content, fixed carbon and elemental analysis (C, H, N, S and O). The gross calorific value was determined using bomb calorimeter (Model 6200 Spectronics) in the laboratory.

Moisture Content

The moisture content of the sample was determined by heating a known weight of waste (as received) in an oven at temperature of 105°C until constant weight was obtained [3,6]. The values of moisture content were calculated using the formula below:

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

Ash Content

Ash content was estimated by heating the sample at 750°C in muffle furnace for [3, 6]1 hour, until the waste is completely converted to ash and was calculated as:

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

Volatile Matter

Volatile matter was analyzed by heating the samples in a covered crucible at a temperature of 950°C for seven minutes [3, 6]. The loss in weight was recorded and volatile matter was calculated using the formula below:

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

Calorific Value

Gross Calorific Value (GCV) of the waste samples was analyzed with the help of Bomb Calorimeter. A pellet of known weight was prepared and fired in a bomb cell. The rise in temperature of water in the calorimeter was detected and GCV [3, 6] was calculated using the following equation:

$$\text{GCV (Kcal/kg)} = \frac{(\text{Rise in temperature of sample} \times \text{Water equivalent})}{\text{Weight of the sample}}$$

Fixed Carbon

Fixed carbon is the amount of combustible residue that is left after the volatile matter is removed [3, 6]. The value of fixed carbon can also be calculated using the following formula:

$$\text{Fixed Carbon (\%)} = 100(\%) - \text{Moisture (\%)} - \text{Ash (\%)} - \text{Volatile Matter (\%)}$$

Elemental Analysis

For elemental analysis, the samples were oven dried at 75°C and grinded into smaller particles, pulverized and sieved through 2mm and 1mm sieves [3, 6]. The elements C, H, N, S and O were then determined using Organic Elemental Analyzer (Model-Flash 2000).

4.3 Results and Discussion

4.3.1 Physical Characterization

Physical characterization plays an important role in characterization of waste stream, results of which indicate fraction of organics, inert and recyclables present in the MSW which help in determining the treatment procedures for MSW [123]. The results of physical characterization of MSW from Chandigarh, Mohali and Panchkula are presented in *Table 4.2*. The Miscellaneous waste generally includes waste like thermocol, coconut, straw/hay, foam and dry leaves.

Density of MSW plays an important role in deciding various processes of the waste handling starting from collection of the waste to its storage as well as transportation of the waste. It was observed that due to higher percentage of compostable and inert fractions the bulk density of wastes from all the three cities was high [123]. The density of the waste of Chandigarh, Mohali and Panchkula was reported to be 500.8 kg/m^3, 465 kg/$m^3$and 432 kg/m^3 respectively [123]. It was observed that the major fraction of the MSW from the various socio-economic groups of the three cities of Chandigarh, Mohali and Panchkula includes organic material ranging from 24.1 to 59% of the total MSW followed by inert with composition ranging from approximately 22 to 33% [123].

The biodegradables comprise mainly fruits and vegetables generated from diverse socio-economic groups of the three cities. The MSW collected from the LIG areas contained maximum organic fraction for all the three cities [123]. The results are similar to other reported literature wherein it has been stated that with decrease in socio-economic status on area, organic fraction of the waste increases [5, 8]. Other studies have also showed that developing nations generate organic waste as a major fraction [35, 161, 123, 16, 25]. A study conducted to analyze the MSW generation in developing countries like Nepal, Pakistan, Bangladesh and Sri Lanka concluded that these countries have high percentage of organic matter (40-70%) with high moisture content, which makes them unsuitable for incineration [25].

The high content of inert fraction in the Tricity region is predominantly due to continuous unrestrained practice of combining street sweeping waste and construction and demolition waste with MSW [123]. The presence of inert increases the density and decreases the calorific value of the refuse [171, 123]. Similar characterization studies performed in Jalandhar city reported that the MSW contained approximately 21 to 33% of inert [123, 171], which is almost similar to the percentage of inert contained in the MSW from the Tricities [123]. Another case study in Pune city indicates the presence of around 26% inert matter in the MSW [199]. Few studies conducted in the metropolitan cities like Delhi, Bangalore and Ahmedabad have also specified that MSW contained approximately 27–55% of inert fractions [16, 161, 123].

The inorganic fraction in the Tricity region primarily consists of paper, plastic, cardboard, polythene, rubber, leather, metals and glass [123]. The physical characterization results show that the inorganic fraction of the Municipal Solid Waste in Chandigarh, Mohali and Panchkula (Tricity) were found to be 17.4, 15.1 and 15.7% respectively [123]. Chief contributions of the inorganic fractions for the Tricity regions were of plastics (7.3% Chandigarh, 6.6% Mohali and 7.06% Panchkula), paper (6.1% Chandigarh, 5.3% Mohali and

5.4% Panchkula). The quantities of the metals as well as rubber and leather were less in waste owing to the informal recycling and segregation of the waste by the waste handlers before it reaches the dumping ground [11, 123]. It was observed from the results that major fractions of inorganics were generated from commercial, institutional and HIG areas suggesting the use of more packaged and disposable products in these sectors [123]. Further examination of the characterization results showed that, the highest value of inorganics was observed for Chandigarh city, it being more commercialized and developed in comparison to Mohali and Panchkula. *Figure 4.2 (a, b and c)* presents the average of the percentage of various physical components of various socio-economic groups in Chandigarh, Mohali and Panchkula respectively.

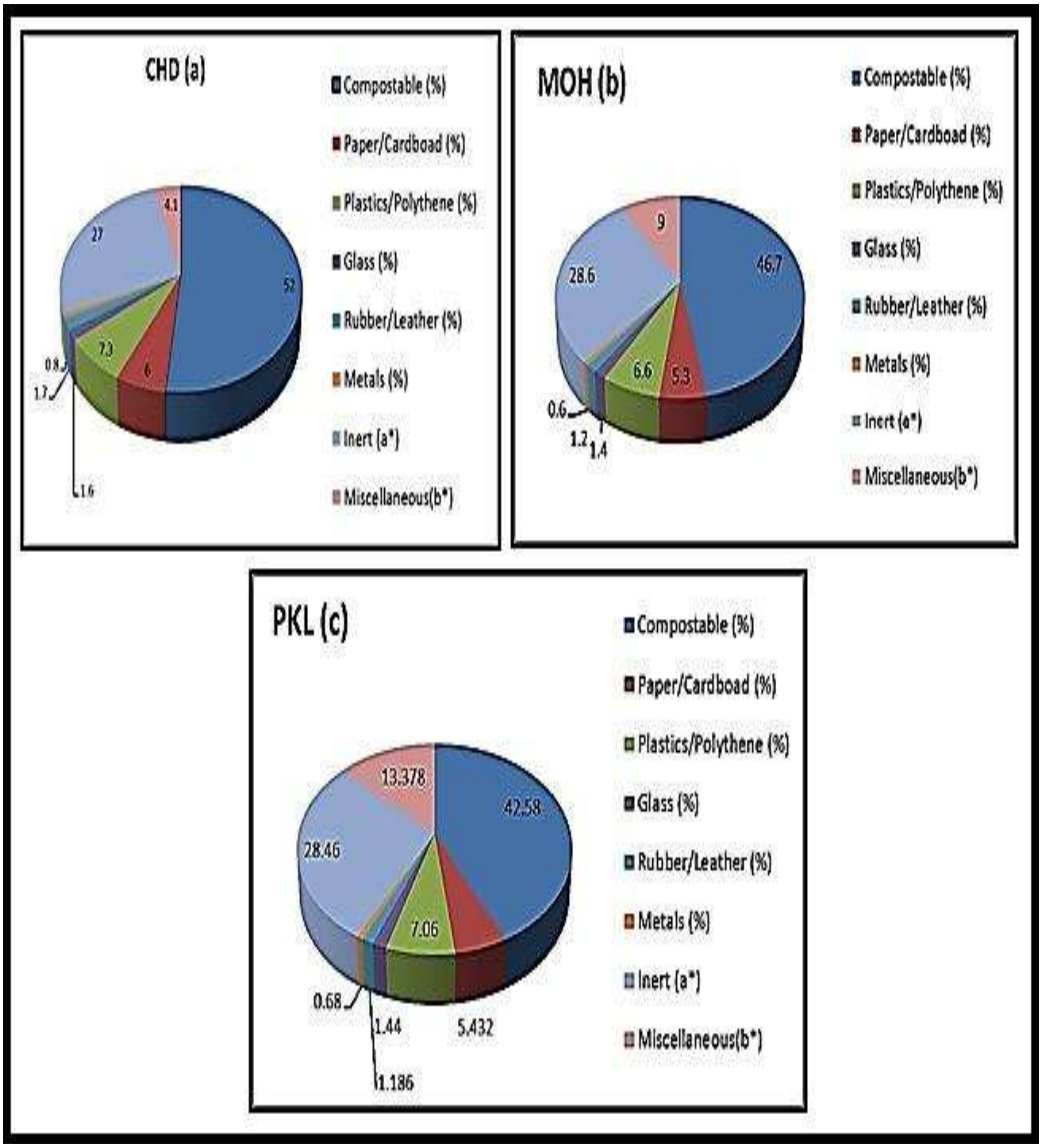


Figure 4.2: Physical Composition of (a) Chandigarh; (b) Mohali and (c) Panchkula respectively

Table 4.2: Physical Characteristics of the MSW in three cities of Chandigarh (CHD), Mohali (MOH) and Panchkula (PKL)

Components	Commercial (%)			HIG (%)			MIG (%)		
	CHD	MOH	PKL	CHD	MOH	PKL	CHD	MOH	PKL
Density (Kg/m^3)	580±4.1	480±7.6	390±5.7	490±8.7	395±2.9	380±2.1	500±2.4	430±8.7	490±6.1
Compostable*	56.4±4.46	52.6±2.88	49.4±3.56	48.9±3.67	46±6.1	38.8±3.2	59±4.6	53.9±2.56	49.1±8.2
Paper/Cardboard*	4.2±1.8	2.5±1.9	3.5±1.9	7.0±2.1	7.8±1.8	7.3±0.7	5.2±0.77	4.5±2.98	5.2±3.3
Plastics/polythene*	6.6±1.88	7.3±3.44	6.4±2.8	8.2±6.7	8.0±1.44	8.5±2.9	6.2±1.1	5.7±1.7	5.9±0.77
Glass*	0.4±1.1	0.2±1.61	0.8±1.09	1.8±0.6	1.9±4.10	1.22±1.8	1.4±2.1	1.0±2	1.4±0.45
Rubber/leather*	0.6±1.72	0.1±0.16	0.2±0.17	2±5.23	1.9±0.03	1.7±1.2	0.5±6.1	0.7±0.04	0.53±2
Metals*	0.2±0.34	1.0±1.78	0.6±1.1	0.1±0.03	0.1±1.6	0.5±1.7	0.1±0.3	0.1±0.03	0.2±0.1
Inert [a]*	28.5±9.2	29.4±4.66	29±9.66	29±2.3	30.1±9.6	30.8±5.7	22±1.7	25±1.58	25.2±4.3
Miscellaneous [b]*	3.5±1.6	7.6±1.56	10.1±5.84	3±2.87	4.2±3.89	11.7±3.3	5.6±1.56	9.3±5.29	12.5±7.4
Total	100	100	100	100	100	100	100	100	100
Components	LIG (%)			Institutional (%)			Average		
	CHD	MOH	PKL	CHD	MOH	PKL	CHD	MOH	PKL
Density (Kg/m^3)	550±8.7	550±8.8	487±7.8	384±2.99	470±4.6	410±7.6	500.8	465	432
Compostable*	58.1±2.9	54.9±1.4	51.5±3.4	35.6±2.1	26.4±2.76	24.1±3.34	52	46.7	42.6
Paper/Cardboard*	5.1±3.8	4.6±2.9	3.8±1.40	8.6±2.4	7.4±1.7	7.3±6.8	6.0	5.3	5.43
Plastics/polythene*	5.1±1.16	4.7±0.2	4.6±1.80	10.6±3.9	9.4±8.9	9.9±7.2	7.3	6.6	7.06

Glass*	0.1±1.4	0.4±3.1	0.1±1.68	4.3±2.75	3.9±0.23	3.7±1.5	1.6	1.4	1.44
Rubber/leather*	0.9±1.56	0.5±0.02	0.4±1	4.5±0.45	3.2±0.23	3.1±0.01	1.7	1.2	1.186
Metals*	1±0.02	0.1±1.7	0.1±0.01	2.7±0.01	2.0±1.3	2.0±0.4	0.8	0.6	0.68
Inert [a]*	28.7±1.34	32.2±7	33±6.1	26.9±5.62	26.3±7.9	24.3±6.6	27.0	28.6	28.46
Miscellaneous [b]*	1±3.3	2.6±1.7	7±5.9	7.6±6.6	21.3±2.19	25.6±4.57	4.1	9	13.378
Total	100	100	100	100	100	100	100	100	100

Number in parentheses is standard deviation

HIG high income group, MIG medium income group, LIG low income group

*Values in percentage (%)

[a]*Includes waste from building construction, gravel, sand and stones

[b]* Includes waste like thermocol, coconut, straw/hay, foam and dry leaves

4.3.2 Chemical Characterization

The physical characterization of the MSW provides information regarding the main fraction of the waste stream, however; only the physical characterization of the MSW is not adequate as chemical characterization helps in deciding the future course of treatment processes by giving the percentage of crustal elements present in MSW [123]. It is essential to carry out the ultimate and proximate analysis for selection of suitable technology for future treatment processes. The results of proximate and ultimate analysis of the MSW of Chandigarh, Mohali and Panchkula are given in *Table 4.3*.

4.3.2.1 Moisture Content

Wet moisture content of the MSW for Chandigarh, Mohali and Panchkula were observed to be in range of 42-59%, 34-57.7% and 35-44% respectively [123]. It has been earlier reported that the moisture content for Asian countries varies between 17 and 65% [8, 31, 34, 16] and the moisture content observed from the Tricity region was well within the limits as observed for Asian countries [123]. Studies conducted in Delhi and Ahmedabad also show the moisture content in the MSW lies in the range 24-9% [123, 25]. The moisture content plays an important role in understanding the nature of the waste as high moisture content indicates presence of higher fraction of organic and putrescible materials [6]. Moisture content was highest in LIG areas of all the three cities indicating presence of higher fractions of vegetables and other putrescible constituents [123].

4.3.2.2 Ash Content

Ash is defined as the residue which remains after combustion [3, 6]. The ash content of the MSW of the three cities was observed to be high due to large amount of inert material in waste samples [123]. The combined average ash content of low income group from all the three cities was reported to be 27.7% (25.94% in Chandigarh, and 27.51% in Mohali and 29.9% in Panchkula). Such findings had also been observed for a study carried out in Delhi wherein ash content of 21.8% was reported from LIG area [7].

4.3.2.3 Volatile Matter

Volatile matter is the material which is remained after the waste is subjected to a temperature of 950°C for seven minutes [3, 6]. Average volatile matter of the three cities was observed to be 23.7%. Such results had also been observed for a study carried out in Kolkata where volatile matter of 38.53% was reported in MSW [123].

4.3.2.4 Calorific Value

The knowledge of calorific value of MSW is necessary for designing the energy recovery from the MSW. MSW characteristic studies conducted in metropolitan cities of Delhi and Mumbai [8, 15] indicated the approximate calorific values for these cities as 4498 kcal/kg and 7477 kcal/kg, respectively. The calorific value of the MSW of Chandigarh, Mohali and Panchkula was found to be significantly high in HIG (2508 kcal/kg in CHD, 2208 kcal/kg in MOH and 1500 kcal/kg in PKL) followed by the commercial area (2200 kcal/kg in CHD, 2186 kcal/kg in MOH and 2218 kcal/kg in PKL) and lowest in LIG (1008 kcal/kg in CHD, 1005 kcal/kg in MOH and 1123 kcal/kg in PKL). This is primarily due to the presence of higher combustible fractions of waste in HIG and commercial sector in comparison to LIG wherein more organic fraction and higher moisture content was observed [123].

4.3.2.5 Fixed Carbon

Fixed carbon represents the portion of combustible matter that must be burned in the solid state rather than as gas or vapor [3, 6]. The average fixed carbon in the MSW samples of all the three cities was reported to be 3.40%.

4.3.2.6 Elemental Composition

The elemental composition analysis indicated higher average concentration of C (34.18% in CHD, 33.8% in MOH and 31.9% in PKL) followed by O (11.41% in CHD, 10.2% in MOH and 11.1% in PKL), H (4.42% in CHD, 4.2% in both MOH and PKL) and N (1.35% in CHD, 1.53% in MOH and 1.1% in PKL). The C/N ratio varies from 22.9 to 28, 19 to 25.9 and 24.6 to 29 for Chandigarh, Mohali and Panchkula respectively [123]. The reported literature mentions that C/N ratio for Asian countries varies from 17 to 52% [8, 34, 35, 123]. The importance of the elemental composition of the waste helps in determining the type and hence treatment potential of the waste components and also helps in developing stoichiometric equations to compute gaseous byproducts for treatment of MSW [15, 123]. *Figure 4.3 (a, b and c)* represents the average proximate analysis (Moisture content, volatile matter, ash content and fixed carbon) and *Figure 4.4* GCV (gross calorific value) of all the socio-economic groups of Chandigarh, Mohali and Panchkula respectively while *Figure 4.5 (a, b and c)* presents the ultimate analysisof all the socio-economic groups of Chandigarh, Mohali and Panchkula respectively.

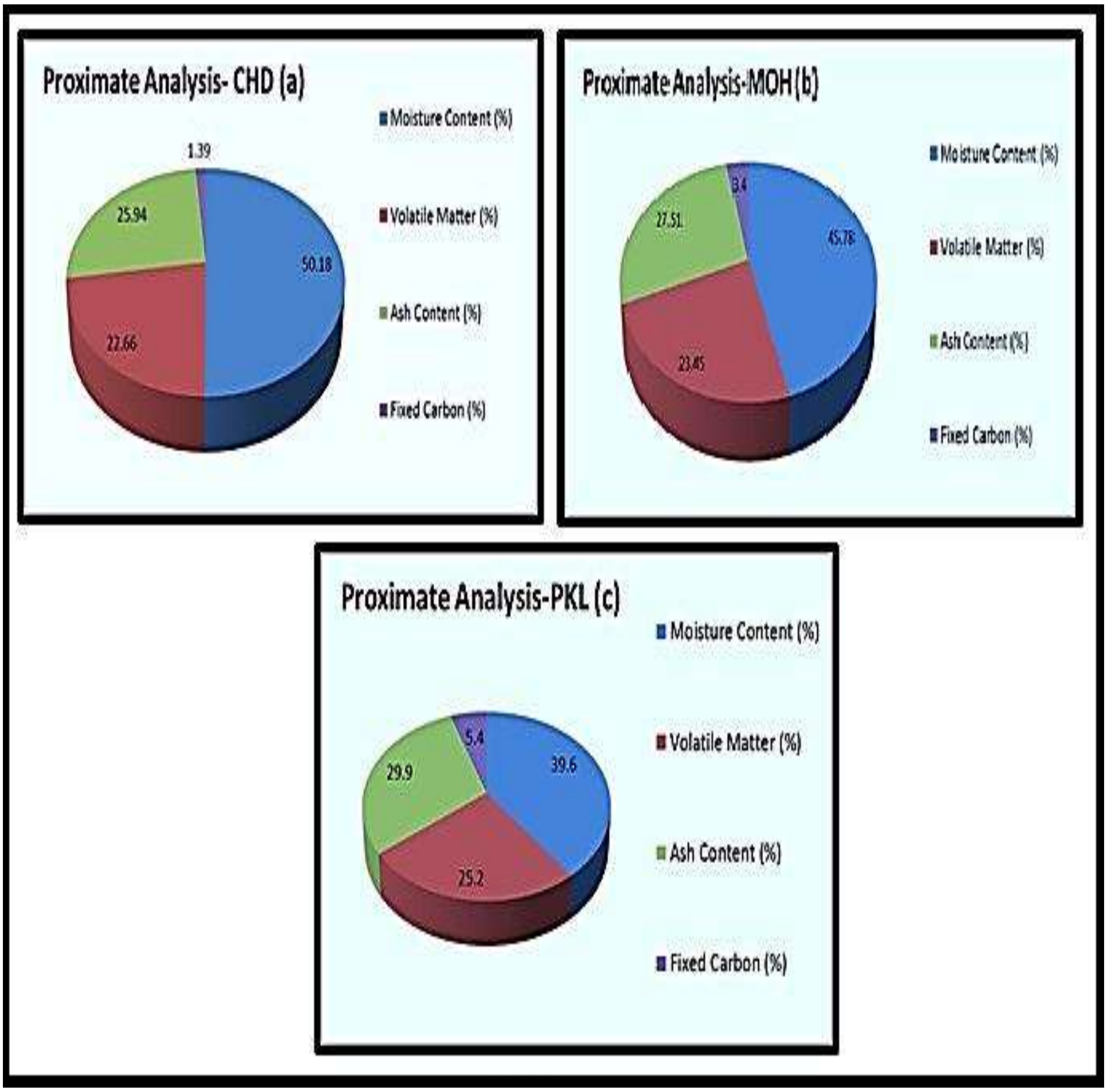


Figure 4.3: Average Proximate Analysis of MSW for (a) Chandigarh, (b) Mohali, (c) Panchkula

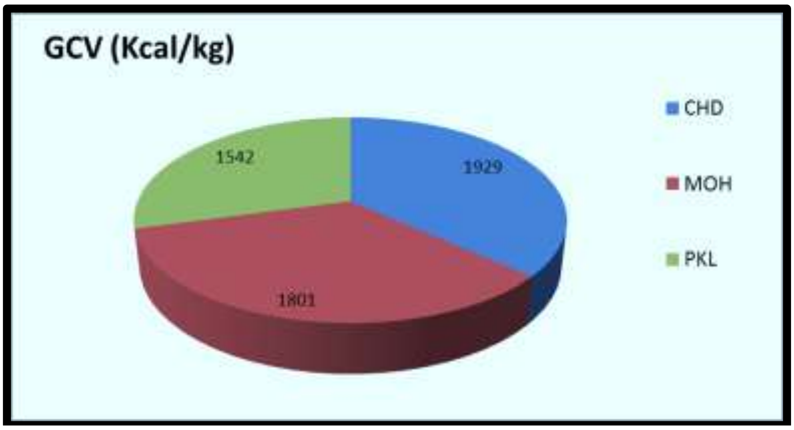


Figure 4.4: Average Gross Calorific Values of MSW for Chandigarh, Mohali and Panchkula

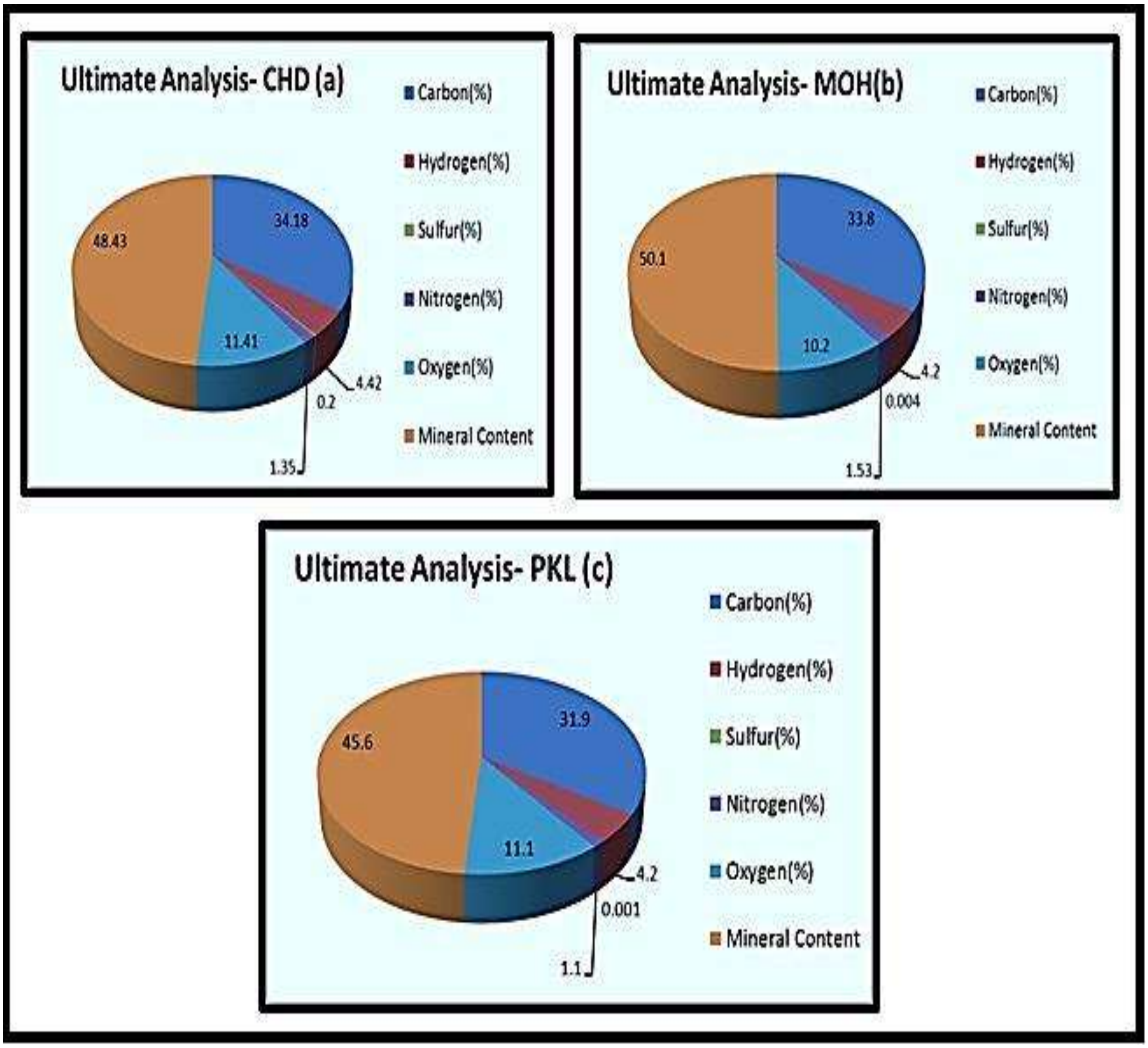


Figure 4.5: Average Ultimate Analysis of MSW for (a) Chandigarh, (b) Mohali and (c) Panchkula respectively

Table 4.3: Chemical Characteristics of the MSW in three cities of Chandigarh (CHD), Mohali (MOH) and Panchkula (PKL)

Components	Commercial (%)			HIG (%)			MIG (%)		
	CHD	MOH	PKL	CHD	MOH	PKL	CHD	MOH	PKL
Proximate Analysis									
Moisture Content*	59±7.8	49±5.66	44±5.2	49±3.9	44.6±2.1	37±1.76	42±2.44	43.6±7.1	38±1.77
Volatile Matter*	17.7±4.5	21±4.54	21.6±5	25.8±3.2	28.65±2.3	28.21±2.2	28±7.65	25.1±6.4	25.9±4.06
Ash Content*	22.4±5.7	28.8±4.1	30.2±4.8	24.7±6.56	24.95±4	29±6.1	26.4±6.70	28.5±7	28.8±4.98
Fixed Carbon*	1.0±4	1.99±0.1	4.2±3.8	0.8±6	1.82±7.12	5.79±1.66	3.67±0.76	2.8±5.23	7.3±0.6
Gross Calorific Value (GCV)[a*]	2200±41.8	2186±128.6	2218±324	2508±145	2208±206	1500±291.5	1729±160.2	1421±96.1	1540±116
Ultimate Analysis									
Carbon*	33.6±2.03	30±30.2	29.8±2.30	37±3.61	36.01±4.18	35.3±4.32	34.4±6	32.9±5.45	32.19±2.32
Hydrogen*	3.90±1.45	4.56±1.34	4.2±2.2	4.6±2.98	4.08±1.76	3.40±1.66	6.6±2.67	4.9±6.52	5V2
Sulfur*	1.0±0.001	0.001±0.1	ND	ND	ND	ND	ND	ND	ND
Nitrogen*	1.2±1.76	1.4±1.45	1.06±0.001	1.4±1.66	1.39±0.12	1.2±0.08	1.5±6.3	1.48±2.30	1.2±1.11
Oxygen*	12.6±6.43	12.9±6.22	14.2±7.87	12.5±8	10±2.61	10.01±1.58	6.9±3.4	5.8±5.45	6.2±2.33
Mineral Content	47.7	51.2	51.7	44.5	48.5	50.09	50.6	54.9	55.4
C/N ratio	28	21.4	28.1	26.4	25.9	29	22.9	22.2	26
Components	**LIG (%)**			**Institutional (%)**			**Average**		

	CHD	MOH	PKL	CHD	MOH	PKL	CHD	MOH	PKL
Proximate Analysis									
Moisture Content*	58.9±8.2	57.7±9.26	44±6.71	42.01±6.66	34±5.21	35±7	50.18	45.78	39.6
Volatile Matter*	17±2	17.6±6.1	25±5	24.8±4.10	24.9±2.5	25.3±4.65	22.66	23.45	25.2
Ash Content*	23.3±4	21.6±6.1	26.2±7.8	32.9±3.4	33.7±7.5	35.3±8.5	25.94	27.51	29.9
Fixed Carbon*	1.0±1.89	3.1±5.6	5.7±5	0.5±6.59	7.6±4.56	4.4±7.4	1.39	3.4	5.4
Gross Calorific Value (GCV)a*	1008±56.8	1005±88	1123±138	2200±459	2185±233	1329±132	1929	1801	1542
Ultimate Analysis									
Carbon*	32.9±8.9	34.55±7	32±8.5	33±2.13	35.9±0.66	30±2.56	34.18	33.8	31.9
Hydrogen*	3.9±1.77	4.0±6.12	4.56±2.34	3.10±1.77	3.78±1.43	4.09±1.23	4.42	4.2	4.2
Sulfur*	ND	0.001±0.008	0.001±0.01	ND	ND	ND	0.2	0.004	0.001
Nitrogen*	1.35±0.67	1.49±1.34	1.3±2.66	1.3±2.45	1.89±3.91	1.08±7	1.35	1.53	1.1
Oxygen*	14.1±6.43	13.3±4.21	14±6.41	10.99±2.56	9.06±0.04	11.2±1.12	11.41	10.2	11.1
Mineral Content	47.7	46.9	48.1	51.6	49.3	53.1	48.43	50.1	45.6
C/N ratio	24.3	23.1	24.6	25.3	19	28.2	25.3	22.1	27.1

Number in parentheses is standard deviation

HIG high income group MIG medium income group LIG low income group

*Values in percentage (%)

a* GCV Gross Calorific Value (Kcal/kg)

4.3.3 Proposed Alternatives to Existing Waste Processing Techniques based on Characterization Analysis

There seems to be a dire need for the development of an integrated MSW management facility for Chandigarh, Mohali and Panchkula cities based on the characterization results. The unified waste management facility must be in compliance with the Solid Waste Management Rules, 2016 [72]. Based on the characterization results analysis carried out for the Tricity region, the following suitable alternatives are suggested.

Source Segregation

The physical characterization of the three cities indicates that MSW contains more than 55% of the organic fraction and around 34% inert fraction [123]. As such, the process of source segregation of wastes should be immediately implemented. In particular, mixed fraction of waste reduces the overall energy content of MSW. Segregation of the combustible material at source would also help the RDF plant in Chandigarh city to generate better quality and quantity of fuel [91, 123]. The street sweepings and the waste from construction activities must be strictly prohibited from getting mixed with the MSW. Separate containers or color coded containers need to be kept at the collection centers as well as in households which will further help in source segregation of the waste (segregation at source). The characterization of waste also indicated that the density of the wastes was in the range of 500.8 kg/m^3, 465 kg/m^3 and 432 kg/m^{3}for Chandigarh, Mohali and Panchkula citiesrespectively [123]. In this context, for an effective management system the capacity of the bins and containers must be evaluated on the basis of population, waste generation rates as well as density of waste within the different sectors of the Tricity regions [123]. The vehicles used for transportation of the waste from three cities must have a storage facility for the waste during rainy seasons to prevent rainwater from entering the waste.

Recycling and Recovery

Recycling and recovery of waste is strongly promoted for conservation of resources and prevention of environmental degradation. The percentage of plastic recovery is approximately 40% in India which is much higher than many developed nations having only 10-15% of the recycling rate [49, 50, 51, 123, 171]. Unfortunately, there exists no formal recycling or recovery facilities in Tricity areas [123]. Hence, it is proposed that there should be an introduction of formal recycling unit so as to derive all the benefits associated with the recycling process [123, 200].

Biomethanation Plant

The appropriate waste processing techniques for Chandigarh, Mohali and Panchkula cities must be implied depending upon the quantity and quality of the waste generated, economy and engendered environmental impacts [123]. Based on the MSW characterization of the three cities, the study revealed that installation of bio-methanation plant (serving the entire Tricity region) for the organic waste should be recognized.

Composting

A single technology cannot lead to the complete managementof the waste. The household or community side composting should be encouraged, as it would reduce the dumping ground burden. Numerous studies [71, 43, 44, 48, 60] have recommended that composting or even vermi-composting can play a vital role in organic waste management. The physical characterization of the MSW from the three cities in Chandigarh, Mohali and Panchkula showed that more than 55% of the waste stream was organic and are dumped directly in an unscientific manner in open dumping grounds [91, 123]. In this context, composting is a suitable method for application in the three cities. Composting is the finest method of disposal of urban solid waste, using it on the land as organic fertilizer since it transforms the organic matter into more stable form and also lessens the waste mass and volume elated to the landfills [44, 48]. The microbial based aerobic process is usually considered as environmentally thorough technique for conversion of organic waste into organic fertilizer or soil conditioner [48, 123]. Standards for composting as mentioned under the Solid Wastes Management Rules [72] contemplate waste segregation as an essential criterion for effective composting but this is not implied in many municipalities [58, 60]. However, in Chandigarh city few informal sectors and certain NGO's are practicing composting process in schools and colleges [11, 123].

4.4 Summary and Discussion

Management of solid waste is not a stand-alone system. Prediction of MSW generation plays a vital role in MSW management. Characterization of the waste from the Tricity region denotes that the physical characterization of the MSW from Chandigarh, Mohali and Panchkula indicateshigh percentage of organic matter (50%) and inert fraction (29%) in the waste stream of various socio-economic groups. The MSW collected from the LIG containsmaximum organic matter. Presence of inert along with the MSW must be controlled as it spoils the processing of biodegradables as well as recyclable materials. Chemical characterization of the waste from the three cities also specified higher ash content (27.7%) due to presence of high value of inert. Public–private collaboration in the functioning of a refuse derived fuel (RDF) plant gives a light edge to these cities over other similar Tier-II cities. Based on the MSW characterization from Chandigarh, Mohali and Panchkula, it is suggested that a single existent technology like RDF cannot lead to a complete management of waste, but there is a need to adopt integrated technologies for the treatment of different fractions of waste, and hence for these cities a combination of composting, vermicomposting and bio-methanation plant, would help in achieving a better solid waste management system.

CHAPTER 5

CHARACTERIZATION OF LEACHATE AND ASSESSMENT OF ITS TOXICITY POTENTIAL

5.1 Introduction

Land filling of MSW is considered most economical and viable practice for waste management in many parts of world. In India about 95% of the waste is dumped in the unlined systems and subsequently the solid waste has a potential impact on all phases of environment leading to the serious environmental problems [13, 46, 207, 165]. This process of disposal results in the generation of a complex liquid effluent, commonly known as leachate, due to excess rainwater percolation through layers of waste. Leachate generated from the decomposition of waste in a landfill can migrate to the neighboring sources, thereby polluting ground water and surface water bodies in the vicinity area and therefore making them unsuitable for domestic and other purposes [16, 20, 35, 71, 112, 208]. Many studies have reported [19, 97, 107, 108, 109] that landfills sites have the potential to generate leachate for many years even after their closure and have tendency to pollute the environment. Therefore, leachate is recognized as an important environmental problem, and its risk assessment and management is thereby considered essential.

The composition of the leachate varies considerably among landfills depending on factors like age of landfill, hydrogeology, amount of rainfall as well as composition and amount of waste and decomposition of waste. Leachate consists of cocktail of harmful pollutants including organic (chemical oxygen demand, biological oxygen demand, ammonia compounds); inorganic (calcium, magnesium, iron, chloride, sulphate etc.); carcinogens like heavy metals (cadmium, chromium, zinc, nickel, lead, copper) and recalcitrant making it potential source of pollution [30,31, 97, 140]. The impact of leachate on surface and ground water has been reported by a number of researchers [75, 76, 77]. Geophysical studies [100, 101, 102,103, 105, 156] of MSW studied the movement of leachate plume and reported that the leachate plume from the landfill migrates towards the aquifer leading to its contamination. Previous studies have reported presence of hazardous organic compounds like aromatics, chlorinated aliphatic, phenols, phthalates and pesticides in leachate [16, 97, 99, 183, 111].

Presence of different heavy metals including lead, copper chromium and iron have also been reported in studies [2, 52, 80, 81, 107, 110] which have indicated towards the contamination of the ground water due to percolation of the contaminated leachate. Apart from these major groups of contaminants, other chemicals may also be present in leachate in large amounts [114, 116]. Hence, illustrating that leachate causes toxic effects to biological organisms as well as environment [110, 117].

The constraint of using the physico-chemical analyses alone is that the harmful compounds which are present in low concentration below the detection limit of the instrument remain unidentified and hence often their potential biological effects are underestimated. Therefore, toxicological or Eco- toxicological analysis are gaining importance as knowledge of physico-chemical components along with the toxic potential of leachate not only helps in assessing the risk but also make projections on its long term impact and possible adverse effect on environment as well as humans [30, 107,127, 128, 52, 111]. In Indian scenario, where majority of landfills are unengineered, a very few studies [41, 117, 52, 111,121] have combined both physico-chemical and toxicological analyses of leachate for proper risk assessment. Many studies focused on the leachate toxicity on different organisms, such as aquatic crustaceans [122, 124, 125], fish species [30, 107, 127], human peripheral blood lymphocytes [145, 124, 107], mice blood cells and other organs [16, 92, 117, 173] but a very few studies have focused on using the in vitro bioassay using mammalian cell lines [55, 110]. In vitro mammalian cells are a suitable option as they are readily available, simple, sensitive as well as cost-effective [107, 110]. Some of the cell lines used for toxicological analysis are HepG2 (Human heptocarcinoma) cell lines, human neuronal cell lines such as SH-SY5Y neuroblastoma cells, Neuro-2a cells and LA-N-2 series [55, 54, 110, 209].

Another system used to classify the toxicity potential of leachate is Leachate Pollution Index (LPI), which gives an immediate assessment regarding remedial measures to be carried out at a landfill site [38, 41, 62, 66-68, 90]. The LPI index is based on assigning a single number ranging from 5 to 100 [61-68, 41, 90] like a grade which expresses the overall contamination due to leachate. Higher the value of the LPI greater is the toxicity and contamination potential of the leachate.

In the above context, the present study has been undertaken in Tricity. As already described in chapter 3 and 4, MSW generated in Chandigarh, Mohali and Panchkula are dumped in open dumping sites with no provision of leachate collection and treatment facility, hence the leachate generated has the tendency to percolate downwards in the subsoil and can pose threat to ground water. Keeping in view this fact and given the lack of studies evaluating the risk posed by leachate, the present study was planned to evaluate the effect of leachate from open dump sites of Chandigarh, Mohali and Panchkula by both physico-chemical analysis and in vitro toxicity assays using Neuro-2a cell lines. A risk assessment study on health impact was carried out to estimate the potential carcinogenic health risks due to contaminated ground water. The impact of leachate percolation on ground water quality was also determined using LPI methodology.

5.2 Materials and Methods

5.2.1 Collection of Leachate Samples

To determine the leachate characteristics and pollution potential of the MSW dumping sites at Chandigarh, Mohali and Panchkula, a monitoring campaign for collection of leachate samples from the dumping sites were carried out in the months of May-June, 2015 (S1); September-October, 2015 (S2) and February-March, 2016 (S3). As the dumping sites are open dumps so therefore no leachate collection facility is available at the dump sites, therefore, the samples of leachate were collected randomly in and around the waste piles and mixed thoroughly to get a representative samples and denoted as CL, ML and PL for Chandigarh leachate, Mohali leachate and Panchkula leachate, respectively. *Figure 5.1* shows the map of Tricity along with the open dump sites. The leachate samples were collected from three different points within all three MSW dumping sites in glass and plastic bottles cleaned and pre-soaked in 1M nitric acid (HNO_3) for 24 hours. The samples for heavy metal analysis were preserved by adding few drops of concentrated H_2SO_4 in the glass bottles [202]. A total of eighty one samples (n=27 for each dumping site) of leachate were collected from each of the three MSW disposal sites for the three sampling period and were analysed. Samples were collected in plastic bottles (thoroughly cleaned) and glass bottles (autoclaved to remove any contamination). The collected leachate samples were transported to laboratory and stored in refrigerator at 4^oC temperature till complete analysis [202].

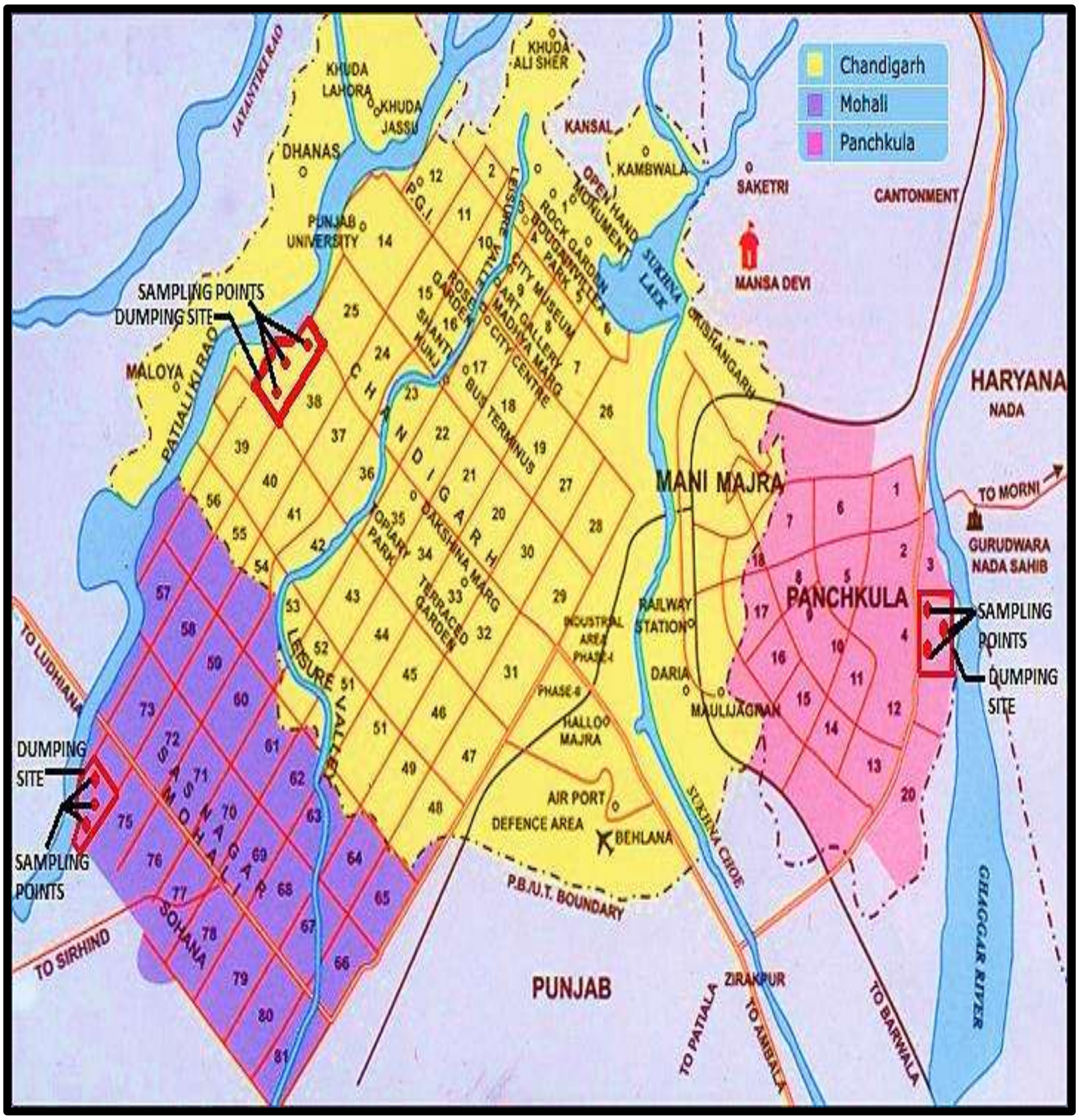


Figure 5.1: Location of dumping sites in Chandigarh, Mohali and Panchkula respectively

5.2.2 Analysis

Leachate samples were analysed for physico-chemical, heavy metals, microbiological parameters and toxicological assays as per standard APHA and BIS methods [202, 210, 211]. All the samples were analysed for physico-chemical parameters like pH, total alkalinity (TA), chemical oxygen demand (COD), biological oxygen demand (BOD), , total hardness (TH), chloride (Cl^-), electrical conductivity (EC), total dissolved solids (TDS), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), calcium (Ca^{+2}), magnesium (Mg^{2+}), ammonical nitrogen (NH_3-N), fluoride (F^-), nitrate (NO_3^-), sodium (Na^+) and potassium (K^+) and heavy metals i.e. copper (Cu), chromium (Cr), lead (Pb), zinc (Zn), nickel (Ni) and cadmium (Cd). The valuation of pH, EC and TDS was done with pH meter and conductivity meter respectively. COD was estimated using reflux titrimetry method. Ca^{2+}, Mg^{2+}, Cl^-, TA, TH were examined by titration methods. PO_4^{3-} , NH_3-N, NO_3^-, and SO_4^{2-} were analysed by spectrophotometer while Na^+ and K^+ by flame photometry. Heavy metals were analysed using atomic absorption spectroscopy. Microbiological analysis was performed using most probable number (MPN) method [202]. The results obtained were compared with standards for disposal of leachate in inland surface water, public sewers and land disposal as specified by the Municipal Solid Waste Management and Handling Rules, 2016 [72]. For the toxicological analysis of the leachate samples, extraction of the organic contaminants (quantitative and qualitative) was done by using GC-MS analysis and the cytotoxic effects of leachate were analyzed by preparing cell culture and giving various treatments on cell lines. The brief procedure for analysis is described in subsequent sections. The analytical method for various parameters is given in *Table 5.1*.

Table 5.1: Analytical methods of the parameters

Parameters	**Analytical Methods**
Temperature	Thermometer
pH	pH meter
Electrical Conductivity	Conductivity meter
Biochemical Oxygen Demand (BOD)	Winkler Titration
Chemical Oxygen Demand(COD)	Reflux Titrimetry
TH,Ca^{2+},Mag^{2+},TA,Cl^-, TSS	Titrimetry
PO_4^{3-} , NH_3-N, NO_3^-, and SO_4^2	Spectrophotometry
Heavy Metals	Atomic Absorption Spectrophotometry
Na^+, K^+	Flame Photometer
Total Coliforms	Most Probable Number (MPN) Test
Organic Contaminants	Gas Chromatography-Mass Spectrometry

5.2.2.1 Physico-chemical Parameters

Temperature

Temperature is measured in degree Celsius, using thermometer in the field. The temperature was analysed in the field straightaway after collection of the samples with the help of thermometer and readings were noted.

Color

Presence of color in samples indicates the level of contamination.

Odor

Odor in samples specifies the presence of pollutants in the samples.

pH

pH is the negative logarithm of hydrogen ion concentration and is denoted as:

$$pH = -\log (H+) \text{ or } pH = \log 1/ (H+)$$

It is frequently used for detection of the acidity or alkalinity of a solution. The values of pH scales ranges from 0-14. In distilled water $[H^+]$ equals $[OH^-]$ giving value of 7, representing the neutral value of pH while the values ranging between 0-7 postulates the acidic nature of the solution while the higher values are in the range of 7-14 and indicates the alkalinity of a solution. pH was analysed in the field itself directly after the collection of the samples. pH meter was already standardized in laboratory before scheduleding for the sampling by dipping the electrode in buffer solution of known pH values i.e. 4.0, 7.0 and 9.2. The values were adjusted using the control knob, till the meter read the accurate value for pH of buffer solution. After the collection of the leachate samples, pH meter was immersed in each sample and interpretation was noted.

Electrical Conductivity (EC)

Electrical conductivity denotes the overall concentration of soluble salts or the ionized constituents which are present in a given solution. Higher the concentration of dissolved salts, higher is the electrical conductivity of a particular solution. EC was noted in the field using the conductivity meter. After the collection of samples, electrode was immersed in the samples to know the conductivity. Reading was recorded in µS/cm.

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) is the quantity of dissolved ions usually various types of minerals, compounds and metals in a given volume of solution and are expressed as mg/l. it can be analysed by evaporating the sample and weighing the residual solids. Another way to approximately determine TDS is by using the values of EC by United States Salinity Laboratory Staff (1954) formula:

$$\text{TDS} = 0.64 \times \text{EC}$$

Total Hardness (TH)

Total hardness is the results of the collective outcome of calcium and magnesium ions. Total hardness is normally known as the capability of a solution to precipitate soap. Hard water forms a curd like material when it comes in contact with soap and can also lead to skin irritation. The hardness of a solution can be categorized in four groups as given in *Table 5.2*.

Table 5.2: Classification of Total Hardness values

S.No	Values of TH (mg/l)	Category
1.	0-60	Very Soft
2.	61-120	Moderately Hard
3.	121-180	Hard
4.	>181	Very Hard

It was estimated by means of titration method. A pinch of Eriochrome Black T (EBT) dye was added to known volume of the samples with the 1 to 2 ml of buffer solution. The sample solution change to wine red color which is then is titrated with 0.01M EDTA (Ethylene diamine tetra acetic acid) till the solution turns blue depicting the end point. TH can be calculated using the formula:

$$\text{Total Hardness (mg/l)} = \frac{(\text{S} - \text{B}) \times (\text{M}) \times (\text{M.W}) \times (1000)}{\text{Volume of sample taken (ml)}}$$

S= Volume of EDTA consumed for sample (ml)

B=Volume of EDTA consumed for blank (ml)

M= Molarity of standardized EDTA solution

M.W= Molecular weight of calcium

Calcium (Ca^{+2})

Calcium is present in the form of calcium, calcite and dolomite. The chief sources of calcium in a solution comprises rain water, dissolution of evaporate deposits, weathering of calcium silicate minerals. Calcium is broadly used in pharmaceutical industries, fertilizers, de-icing the salts and is also measured as one of the crucial elements in plants and animals for nutrition, bones, shells and formation of structures in plants. Water mixed with carbon dioxide acts as the weathering agent for calcite resulting in formation of calcium ions. Occurence of calcium is mainly owed to the leaching of secondary minerals. The reactions involved are expressed as:

$$H_2O + CO_2 \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

$$CaCO_3 + H^+ \longrightarrow Ca^{2+} + HCO_3^-$$

Calcium was determined in samples by titrimetric methods using EDTA as a titrant. To the known volume of samples, 2 ml of NaOH (IN) solution and 0.1-0.2 g of EBT indicator were added. The samples were then titrated with standard EDTA (0.01M) solution, with continuous stirring till the end point is reached.

$$\text{Calcium(mg/l)} = \frac{(S - B) \times (M) \times (M.W) \times (1000)}{\text{Volume of sample taken (ml)}}$$

S= Volume of EDTA consumed for sample (ml)

B= Volume of EDTA consumed for blank (ml)

M= Molarity of standardized EDTA solution

M.W= Molecular weight of calcium

Magnesium (Mg^{2+})

Magnesium occurs usually in the form of minerals like magnesite and dolomite. It is mostly used as drying agent and also in alloys refractories, fertilizers, flash photography, pharmaceuticals and food. It is a chief element required in chlorophyll and red blood cells of plants and animals respectively. It can be calculated using the following formula:

Magnesium as equivalent of mg $CaCO_3$=

[Total Hardness (as $CaCO_3$ mg/l) – Calcium (as $CaCO_3$ mg/l)]

Magnesium as Mg^{2+}= [(Magnesium as equivalent of mg $CaCO_3$) × 0.243 mg/l]

Total Alkalinity (TA)

Alkalinity is the amount of a combined property of a solution and is mainly function of carbonates and bicarbonates.

TA was analysed by titrimetry method, where to a known volume of sample, 3-4 drops of phenolphthalein indicator were added. If the sample turned to pink, it was titrated again with standard N/50 sulfuric acid (H_2S0_4) till the pink color vanishes which indicated the absence of phenolphthalein alkalinity and now one drop of methyl orange was added to the titrated mixture and again re-titrated with standard N/50 sulfuric acid (H_2S0_4) until the color changes from yellow to orange-red. The volume of titrant used is noted and values of alkalinity are calculated using the equations:

$$\text{Phenolphthalein Alkalinity(mg/l)} = \frac{\text{A} \times 1000}{\text{Volume of sample taken (ml)}}$$

$$\text{Methylorange Alkalinity or Total Alkalinity(mg/l)} = \frac{\text{B} \times 1000}{\text{Volume of sample taken (ml)}}$$

A= Volume of standard acid used for phenolphthalein alkalinity (ml)
B= Volume of standard acid used for methyl-orange alkalinity (ml)

Chloride (Cl^-)

Chloride ion (Cl^-) is one of the key anions in water and waste water. The presence of chloride concentration in a solution is due to the weathering of rocks, domestic waste etc. The agricultural, domestic and industrial waste waters have high concentrations of chloride due to occurrence of sodium chloride. Chlorides impart salinity factor to the water.

Argentometric titration method was used to estimate the chloride concentration in the samples. To the known volume of samples, 1 ml of potassium chromate (K_2CrO_4) indicator was added whichwas then titrated with silver nitrate (0.0141 N $AgNO_3$) solution. The end point was observed with the color change to wine red and readings were noted.

$$\text{Chloride(mg/l)} = \frac{(\text{A} - \text{B}) \times (\text{N}) \times 35.5 \times (1000)}{\text{Volume of sample taken (ml)}}$$

A= Volume of $AgNO_3$ consumed for sample (ml)
B= Volume of $AgNO_3$ consumed for blank (ml)
N= Normality of $AgNO_3$ solution

Sodium (Na^+)

Sodium is the sixth most richly existing element and is found in huge quantities in the natural waters. It occurs in the form of silicates and salt deposits in natural water. The concentration of sodium varies depending on the geological and hydrological conditions. It is mostly used in fertilizers, caustic soda, preservatives and water treatment chemicals. It is determined using Flame Photometry method. For performing the experiment the standard sodium chloride solutions were prepared. The flame of the instrument was adjusted and the prepared standard solutions were placed and atomizer inlet tube was immersed in the solution. When the solution is atomized into the flame, the element sector was set for sodium ion. After the standardization of the instrument, the samples were analysed and readings were recorded directly in mg/l.

Potassium (K^+)

Potassium is a vital element for plant and human nutrition and is present in abundance. It is richly found in sedimentary rocks and in minerals like feldspar and mica. The compounds of potassium are used in fertilizers, soft drinks, baking powder, pigments and electroplating industry. In drinking water, potassium is found in low concentration as compared to sodium while in waste water like leachate samples both are found in high concentrations. It is determined by flame photometry by preparing standard solutions of potassium chloride (KCl) and samples were aspirated under controlled conditions and readings were recorded directly in mg/l.

Flame Photometer works on the principle that the compounds of alkali and alkaline earth metals can be dissociated thermally in the presence of flame and some of the atoms produced will be further excited to a higher level and when these atoms return to the ground state, they emit radiations which lies mainly in the visible region of the spectrum. Each element will emit radiation at a wavelength specific for that element. It is a controlled flame test with the intensity of the flame colour quantified by the photoelectric circuit.

Fluoride (F^-)

Fluoride is most common element that does not occur in elemental state due to its high reactivity. In solutions it is commonly seen as fluoride ion (F^-). It has unique chemical characteristics and is the highest electronegative element among all the elements of the periodic table. Fluoride is naturally present in ground water in different concentrations.

Fluoride is one of the essential elements for human beings as trace amount of F is essentially required for bones and teeth and prevent dental carries. On the other hand, its concentration in solutions above the desirable limits can cause fluorosis.

SPADNS-Zirconyl method is used to estimate the concentration of fluoride in samples. To the known volume of samples, acid SPADNS-Zirconyl reagent was added and the absorbance was noted at 570 nm using spectrophotometer. The results were expressed in mg/l.

Sulphate (SO_4^{2-})

Sulphate is stable and oxidised form of sulphur which is highly soluble in water. The natural sources of sulphate include pyrite, gypsum and sedimentary rocks. Sulphur is widely used for commercial and industrial purposes mainly in the manufacturing of many chemicals, soaps, paper, glass, insecticides, fungicides and other several activities like pulp, mining, leather processing and sewage treatment industries. High concentration of sulphates in solutions can be result of oxidation, precipitation of rocks and various anthropogenic activities.

Sulphate was determined using spectrophotometry. To the known volume of the samples, 10 ml of conditioning reagent (composed of magnesium chloride, sodium acetate, potassium nitrate, acetate and distilled water) , a spoonful of barium sulphate ($BaSO_4$) were added. Sulphate ion precipitated in acetic acid medium with barium sulphate to form barium chloride. The absorbance of the solution was noted at 420 nm. The concentration of sulphate for samples was calculated and results were expressed in mg/l.

Phosphate (PO_4^{3-})

Phosphate is an essential element required for the growth of plants and animals. It occurs naturally in the form of element phosphorous and is found in many phosphate minerals. The concentration of phosphate in potable water is generally low due to less solubility of most inorganic compounds. It is extensively used in fertilizers, detergents and insecticides. Excess of phosphate can lead to eutrophication.

Phosphate was analysed using spectrophotometry. To the samples, few drops of phenolphthalein indicator were added followed by addition of reducing agent (mixture of stannous chloride and ammonium molybedate). The absorbance of the solution was noted at 690 nm. The concentration of the samples was calculated after noting down the absorbance and then comparing with calibration curve. The values were expressed in mg/l.

Nitrate (NO_3^-)

Naturally the concentration of nitrates is low, in water, but due to anthropogenic factors like run-off from agricultural fields, animal feedlots, sewage and septic systems contribute to increase in concentrations of nitrate in solutions. Various nitrogenous compounds are used to increase the yield of crops which gets rapidly converted to highly soluble nitrate form.

Nitrate was determined using spectrophotometry. To the known volume of samples, 1 ml of 1N hydrochloric acid (HCl) was added and the absorbance of the samples was read at the wavelength of 220 nm. The concentration results were expressed in mg/l.

Ammonical Nitrogen (NH_3-N)

Ammonical Nitrogen is a very important parameter for fresh and waste waters as it is the indicator of nitrogenous matter and organic contamination. The main sources of ammonical nitrogen include ammonia produced from the breakdown of plants and animals, application of ammonia based fertilizers in the agricultural fields, domestic waste and industrial processes.

Ammonical Nitrogen was analysed spectrophotometrically by Nessler's method. To a known volume of sample, 0.5 ml rochella salt solution was added followed by addition of 1 ml Nessler's reagent. After 10 minutes absorbance was noted at wavelength of 420 nm using spectrophotometer. The results were expressed in mg/l.

Spectrophotometer is a technique to calculate the ability of a substance to absorb light by measuring the intensity of light as a beam of light passes through the sample solution. The simple principle of the instrument is that every compound absorbs or transmits the light over a certain range of wavelength. It contains two devices; a spectrometer and a photometer. Spectrometer produces and measures light while a photometer indicates the photoelectric detector which measures the intensity of light.

Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand (COD) is the quantity that can be oxidized in the presence of a strong chemical oxidizing agent. For the drinking water samples COD should be absent.

For determining the COD, refluxing of samples was done with known amount of potassium dichromate ($K_2Cr_2O_7$) (0.25N) in the presence of sulphuric acid (H_2SO_4) with silver sulphate

($AgSO_4$) for two hours at 125°C. The excess of unreduced dichromate remained after the reaction was again titrated with Ferrous Ammonium Sulphate (FAS) (0.1N strength). The amount of dichromate used is proportional to the oxygen required for oxidizing the oxidizable organic matter. The value of COD was calculated using the formula:

$$\mathrm{COD(mg/l)} = \frac{(\mathrm{B} - \mathrm{S}) \times (\mathrm{N}) \times 8 \times (1000)}{\text{Volume of sample taken (ml)}}$$

B= Volume of FAS required for blank

S= Volume of FAS required for sample

N= Normality of FAS

Biochemical Oxygen Demand (BOD)

The Biochemical Oxygen Demand (BOD) is a chemical procedure for the determination of the amount of dissolved oxygen needed to break the organic materials present in a solution at a certain temperature over a specific period of time. Drinking water has a BOD of 1mg/l. To a known volume of sample, 2 ml of each manganese sulphate ($MnSO_4.H_20$) and alkali-iodide-azide and sulfuric acid is added and after that the solution is titrated against sodium thiosulphate. The value of BOD was calculated using the formula:

$$\mathrm{BOD(mg/l)} = \frac{(\mathrm{DO} - \mathrm{D5} - \mathrm{BC}) \times \text{Volume of diluted sample}}{\text{Volume of sample taken (ml)}}$$

DO= Initial dissolved oxygen of the sample

D5= Dissolved oxygen after 5 days

BC= Blank correction

5.2.2.2 Heavy Metals

Heavy metals are the non-degradable metals that get accumulated in nature and are toxic in nature. The contamination of water due to heavy metals is one of the serious threats as even a small concentration could lead to severe ill effects. Even though, few studies [16, 35] have stated that heavy metals like copper (Cu), zinc (Zn) are essentially required in low concentration for human beings but at higher concentrations they may cause toxicological effects. Various natural and anthropogenic sources of these heavy metals include erosion from minerals and ores, waste disposal, industrial effluents etc. Exposure to these metals may occur through many routes like inhalation and ingestion and may lead to damage of liver, bone disorders, kidneys, nervous system and genetic disorders.

Heavy metals were analyzed using Atomic Absorption Spectroscopy (AAS). AAS is based on the principle that when a beam of electromagnetic radiation is passed through a solution, the radiation is either absorbed or transmitted depending on the wavelength of the radiation.

Cadmium (Cd)

Cadmium is one of the most important pollutants in soil, air and water. The chief anthropogenic sources of cadmium include batteries, paints, metal alloys, burning of fossil fuels and smelting. Naturally, it occurs in the zinc ores and has a chemical similarity to zinc.

Zinc (Zn)

Zinc is the fourth most abundant intercellular metal. It is one of the essential trace metals which are required for the growth of living beings. The natural sources of zinc include combustion of fossil fuels, volcanic eruptions and forest fires. Zinc is commonly used in fertilizers, fungicides, pigments, automobile industries, domestic waste or sewage, batteries and alloys like brass and bronze.

Copper (Cu)

Copper is a transition metal and exist in cupric (Cu^{2+}) and cuprous (Cu^{+}) forms. The main sources of copper include mining industries (paper, foundries etc.), and run-off from agricultural and domestic waste. It is essentially required as the trace element for the human beings mainly for various enzymatic activities. Copper is widely used in roofing, electrical wirings, various alloys and utensils.

Chromium (Cr)

Chromium is a metallic element which is commonly used in pigments, leather tannings, steel and welding industries. In natural form, it occurs in the combined form with other metals mainly iron. Numerous salts are formed using chromium and most commonly used are sodium and potassium chromates and dichromates. It occurs commonly in two forms trivalent Cr (III) and hexavalent Cr (VI) where trivalent is non-toxic and hexavalent is highly toxic.

Lead (Pb)

Lead is one of the most toxic element that ranks 36th in the order of abundance in the earth's crust. The common sources of lead are dyes, paints, pigments, production of ferrous and non-ferrous materials, soldering activities and batteries. Plumbing pipes are considered as the major contributor of lead in the tap water due to corrosion of pipes and thereby leading to leaching of metals in drinking water. Lead is used mainly in acid batteries that accounts for 40% of all lead consumed in all the industrial applications worldwide. The other major use of lead is in pesticides, insecticides, fungicides, mines and alloys.

Nickel (Ni)

Nickel occurs naturally in the form of various metals like garnierite, nockelferous, pyrrohite and limonite. It is 24th most abundantly available metal on earth crust. Naturally, in the ground water nickel is present below 0.1 mg/l. Nickel is used in alloys, magnets, protective coatings and batteries. It is also one of the essentially needed trace metals for human body.

5.2.2.3 Microbiological Analysis

The coliforms are the gram-negative, aerobic to anaerobic facultative rod shaped bacteria which ferment lactose to acid and gas. The presence of coliforms in the drinking water may cause water borne diseases like typhoid, cholera, jaundice and diarrhoea and can lead to infections involving skins, eyes, ears and throat [16, 161].

For the estimation of total coliforms, Most Probable Number (MPN) method was used which involved inoculating the samples to several dilutions in a medium (MacConkey broth) of different strengths. The samples were incubated for 48 hours and the presence of total coliforms was observed by the change of color due to the production of acid and gas. Based on the number of coliforms, the samples can be categorized into four main classes as shown in *Table 5.3*. Ideally, in drinking water there should be no coliform bacteria as their presence makes it unfit for human consumption. Total coliforms were calculated as per McCrady's table as given in *Table 5.4*.

Table 5.3: Classification based upon coliform count

Class	Grading	Coliform Count (No./100ml) (MPN)
Class 1	Excellent	0
Class 2	Satisfactory	1-3
Class 3	Suspicious	4-9
Class 4	Unsatisfactory	>10

Table 5.4: McCrady's Statistical Table*
(*Most Probable Number (MPN) values/100 ml of sample, for a set of tests of one 50ml, Five 10ml and five 1 ml volumes),

S.No	1×50 ml	5×10 ml	5×1ml	MPN/100 ml	S.No	1×50 ml	5×10 ml	5×1ml	MPN/100 ml
1.	0	0	0	<1	22.	1	2	1	7
2.	0	0	1	1	23.	1	2	2	10
3.	0	1	2	2	24.	1	2	3	12
4.	0	1	0	1	25.	1	3	0	8
5.	0	1	1	2	26.	1	3	1	11
6.	0	2	2	3	27.	1	3	2	14
7.	0	2	0	2	28.	1	3	3	18
8.	0	2	1	3	29.	1	3	4	21
9.	0	3	2	4	30.	1	4	0	13
10.	0	3	0	3	31.	1	4	1	17
11.	0	4	1	5	32.	1	4	2	22
12.	0	0	0	5	33.	1	4	3	28
13.	1	0	0	1	34.	1	4	4	35
14.	1	0	1	3	35	1	4	5	43
15.	1	0	2	4	36.	1	5	0	24
16.	1	1	3	6	37.	1	5	1	35
17.	1	1	0	3	38.	1	5	2	54
18.	1	1	1	5	39.	1	5	3	92
19.	1	1	2	7	40.	1	5	4	161
20.	1	1	3	9	41.	1	5	5	>180
21.	1	2	0	5					

[202]

5.2.2.4 Toxicological Assays

The toxicological analysis was divided in two methodologies viz., firstly, extraction of organic compounds was done using GC-MS analysis. This extraction was further sub-divided as qualitative analysis which showed the presence of various organic contaminants and quantitative analysis which gave the occurrence of numerous polycyclic aromatic hydrocarbons (PAH's). This helped in human risk assessment methodology employed to evaluate the potential adverse effects of PAH's. Secondly, the cytotoxic effects of leachate samples were observed on cell lines.

Extraction of Organic Contaminants

The occurrence of organic contaminants in the environment has recently become a great cause of concern for the Environmental Protection Agencies around the world. These compounds are continuously introduced into the environment and are found at trace or ultra-trace concentrations (µg/l or ng/l), but, can severely impact quality of drinking water and human health [184]. Major concern about the presence of organic contaminants in the environment involve endocrine disruption, development of bacterial resistance to antibiotics, carcinogenic activities and uncertain human risks to long term chronic exposure at trace levels. Classical Liquid phase extraction with a separating funnel was used for the extraction of organic compounds from the leachate samples.For this, 100 ml of 1:1 *v/v* dichloromethane (DCM) and acetone was added to 250 ml of leachate samples [9,10]. The extraction process was repeated thrice. The extracted fraction was filtered through Whatman No.54 filter paper and then collected and evaporated using a vacuum rotator evaporator and then finally dissolved in 1 ml of DCM as the crude organic extract for Gas Chromatography-Mass Spectrography (GC-MS) analysis. The analysis was done using the Agilent GC-MS SP1 7890-0501 plus fitted out with capillary column Rtx-5 (dimensions: 0.25 µm film thickness, 0.25 mm internal diameter, 30 m length). 1 µl of the extract was analyzed by GC-MS at various conditions- initial temperature 70°C for 1 minute and temperature was increased from 70-310°C at a rate of 22°C min^{-1}. Detection was carried in scan mode for qualitative screening as well as in selective ion mode (SIM) for quantification of polycyclic aromatic hydrocarbons (PAH's). Identification of compounds in scan mode was based on the comparison of their mass spectra with the inbuilt standard mass spectra library system (NIST-05 and Wiley-8) of GC-MS. The PAH's were detected using SIM mode based on unique identifier ions chosen for each target compound.

Human Risk Assessment

The presence of halogenated aliphatic and aromatic compounds, PAH's, phthalate esters and other emerging contaminants like drugs, plasticizers, fire resistant objects, disinfectants, insecticides, fungicides, fumigants, fragrances and heavy metals in leachate samples leads to the leachate toxicity. Many compounds present are toxic, estrogenic and carcinogenic to both terrestrial and aquatic organisms. Hence, the understanding of the leachate composition for risk assessment with possible adverse effects on human health along with finding a suitable option to treat leachate effectively before being discharged into the environment is of utmost importance [54, 55, 110]. The risk assessments of pollutants from the landfills have become a major environmental issue and many steps have been taken by reviewing and evaluating the risks due to percolation of the leachate in ground water [184]. In order to estimate possible adverse effects on humans, we hypothesized an accidental leachate spillage resulting in 1:100 dilution of leachate percolating into ground water [179, 55, 54, 110] as shown in *Figure 5.2*.

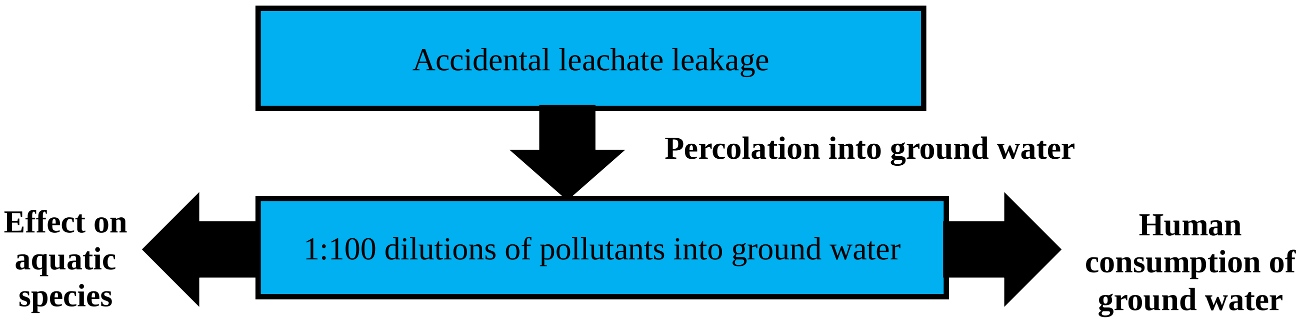


Figure 5.2: Flowchart of proposed hypothesis for risk assessment

All the compounds in the leachate will be subjected to dilution as the leachate mixes with the ground water. Similar hypothesis with the same dilution factor has been previously proposed in few studies [52, 55, 54, 110, 179]. For each carcinogenic PAH quantified, Chronic Daily Intake (CDI) (mg kg^{-1} day^{-1}) and Cancer Risk (CR) were calculated according to [179, 212] and using the following formulas:

$$\mathrm{CDI} = [\mathrm{Cwater} \times \mathrm{WI} \times \mathrm{ED} \times \mathrm{EF}) / (\mathrm{BW} \times \mathrm{AT})] \qquad (5.1)$$

C_{water}= pollutant's concentration in water (mg/l)

WI= water intake (2 l/day); ED= exposure duration (30 years);

EF=exposure frequency (365 days per year); BW=body weight (70 kg -adult)

AT= exposure average time (70 years -lifetime)

$$\mathrm{CR} = \mathrm{CDI} \times \mathrm{SF} \qquad (5.2)$$

SF=slope factor (kg day mg^{-1}) represents the chemical's carcinogenic potency for a unit dose; and its value for PAH's 7.30 [212].

As per the standard ATSDR, 2009, the threshold values of cancer risk is $CR<10^{-6}$ were deemed negligible for human risk assessment [213].

Cytotoxic Effect of Leachate

Cytotoxicity of leachate samples was evaluated using 3-(4, 5- dimethylthiazol-2-yl)-2, 5-diphenyl tetrazolium bromide (MTT) bioassay using Neuro-2a cell lines. MTT assay is a sensitive, quantitative and reliable colorimetric assay that measures viability, proliferation and activation of cells. Measurement of cell viability and proliferation forms the base for various in vitro assays. In MTT assay, the reduction of tetrazolium salts is widely recognized method to examine cell proliferation. The yellow tetrazolium MTT is reduced to purple formazan and can be quantified by spectrophotometric means. Neuro-2a cells are obtained from brain tissue of a mouse and act as suitable host [214]. The cell lines act as a suitable transfection host which makes them suitable for neurotoxicity as well for toxicological assessments. These cells exhibit neuronal and amoeboid stem cell morphology making them uniquely useful for scientific studies.

Cell Culture and Treatments

Neuro-2a cell lines were maintained in Dulbecco's Modified Eagle's Medium (DMEM) supplemented with 10% fetal bovine serum, 1% antibiotic antimycotic solution in 5% CO_2 at 37°C (Ghosh et al., 2014a, and b; Das et al., 2012; Tsarpali and Dailianis, 2012). The test samples for toxicity assays were prepared after the removal of bacterial biomass by centrifugation followed by filter sterilization using 0.22µm syringe filter. In MTT assay, 50µm benzo(a)pyrene (BaP) (positive control), 0.5% *v/v* Milli-Q (negative control) and test samples were added to the cell culture in different dilutions [9, 10, 54, 55, 110, 62, 179, 127 212].

Cell Viability

The number of viable cells was determined by measuring the conversion of the tetrazolium salt MTT into formazan [110]. The cells were seeded at 1×10^6 cells mole per litres (mL^{-1}) in 96-well plates and treated with 0.5% *v/v*Milli-Q, 50 µm BaP and different doses of test samples (5%, 10%, 15% and 20% *v/v*) after 90% of cells became adherent. All the experiments were carried out in triplicates. After 24 h of treatment, medium was removed and replaced with fresh medium containing MTT at a final concentration of 0.5 mg mL^{-1} and further incubated for 2 h and then the solubilization medium (DMSO) was added into each well and again incubated for 1h for proper solubilization at room temperature. Absorbance was now read at 570 nm and the half maximal effective concentration (EC_{50}) values were calculated [10,179].

5.2.3 Leachate Pollution Index

The leachate pollution index (LPI) is a tool for quantifying the pollution potential of leachate at the landfill sites. The pollution potential of leachate is generally given by an index formulated using Rand Corporation Delphi Technique [33-34, 67-68]. Delphi method is an organized communication technique which enables the formation of a group judgement [29]. LPI signifies the level of pollution concentration of a landfill. The indexing method leads to computation of a single value which varies from **5** (*best value*) to **100** (*worst value*), which expresses the overall pollution potential due to leachate contamination in form of an increasing scale index wherein higher values indicate higher levels of pollution leading to environmental degradation [118-120, 33-34, 67-68]. The minimum value of 5 units of leachate pollution ensures that LPI value does not results to zero even if some of the pollutants do not show any pollution [61, 62]. With the help of LPI index, landfills can be ranked as per leachate contamination potential [33-34, 67-68]. Landfill age also plays an important role in the leachate characteristics and hence affects the value of LPI [33-34, 61, 62, 67-68].

The procedure for calculating the LPI for a given landfill site at a given time involves the following three steps:

Determination of pollutants in the leachate: Leachate from the landfill was analysed to estimate the concentrations of major ions and heavy metals. LPI would be descriptive of the pollution potential of leachate analysed for a particular landfill site. A total of 18 variables are generally utilized for calculation of LPI [33-34, 67-68]. These variables include pH, TDS, BOD, COD, TKN, Ammonia nitrogen, Total iron, Copper, Nickel, Zinc, Lead, Chromium, Mercury, Arsenic, phenolic compounds, Chlorides, Cyanide and Total coliform bacteria.

Calculating sub-index values: To calculate the LPI, sub-index value (p_i) is quantified from the sub-index curves for all the pollutant variables [33-34, 67-68]. All the 18 parameters were assigned particular weights based on the significance level of individual pollutants as per study previously undertaken [33-34, 67-68, 41]. The 'p_i' values are obtained by locating the concentration of the leachate pollutant on the horizontal axis of the sub-index curve for that pollutant and noting the leachate pollution sub-index score where it intersects the curve [33-34, 67-68].

Aggregation of sub-index values: The calculated 'p_i' value for all the parameters are multiplied with the respective weights (w_i) assigned to each parameter [33, 34]. The weighted sum of all the parameters represents the overall leachate pollution index. The averaged sub-index (p_i) curves for all the pollutants were drawn to establish the relation between the leachate pollution and concentration of the parameter [33, 34, 118, 119, 120]. The various possible aggregation functions were evaluated by [33, 34, 38] to select best possible aggregation function. The LPI is calculated using the equation:

$$LPI = \sum_{i=1}^{n} wipi \tag{5.3}$$

Where: LPI= the weighted additive leachate pollution index,

w_i= the weight for the i^{th} pollutant variable,

p_i= the sub-index value of the i^{th} leachate pollutant variable,

n= number of leachate pollutant variables used in calculating LPI

$$\sum_{i=1}^{n} wi = 1 \tag{5.4}$$

If the data for all the leachate pollutant variables is not available then LPI can be calculated using the following equation:

$$LPI = \sum_{i=1}^{m} wipi \div \sum wi \tag{5.5}$$

Where: m= number of leachate pollutant variables when data is available ($m<18, \sum wi < 1$)

5.3 Results and Discussion

5.3.1 Leachate Characteristics

The physical, chemical and biological characteristic of the leachate samples collected during all the three samplings from the dumping sites of Chandigarh, Mohali and Panchkula are summarized in *Table 5.5*. The concentrations of tested parameters including pH, TDS, COD, BOD, chlorides, NH_3-N, Cu and Ni exceeded the permissible limits for all the three dumpsites for the entire monitoring campaign as specified by the Municipal Solid Waste Management and Handling Rules, 2016 [72] for discharge of leachate samples in inland surface waters, public sewers and land disposal.

The temperature of the leachate samples collected during all the three samplings from the dumping ground of Chandigarh, Mohali and Panchkula varies from 16.7°C to 25.6°C. All the leachate samples from Chandigarh, Mohali and Panchkula during all the three samplings were found to be strongly colored- dark brown to black and were characterized by unpleasant odor signifying presence of high amount of contamination.

Landfill sites are often classified on the basis of the pH of the leachate generated from such sites. Reported literature mentions that the variation of pH from leachate generated from landfill ranges from 4.5 to 9 [28, 29, 41] with younger landfills being classified as having pH of leachate generated from them less than 6.5 while a matured landfill has a pH greater than 7.5 [119-120, 36]. This is primarily because in the initial stages of the landfill the leachate generated has an increased concentration of Volatile Fatty Acids (VFA) resulting lower pH values of about $\leq$6.5 while in older landfill sites these VFA are converted to methane and carbon dioxide thereby resulting in a more alkaline nature of the leachate characteristics (pH > 7.5) [80, 91]. For our study locations, the average pH of the leachate samples from all the three dumping sites over the entire monitoring campaign varied from 9.2 for Chandigarh and 8.9 for Mohali and Panchkulaindicating highly alkaline nature and that all the three dumping sites were in methanogenic phase and can be classified as '*old or matured*' landfill sites. The average pH values of Chandigarh, Mohali and Panchkula, respectively, over the three monitoring campaigns is presented in *figure 5.3*.

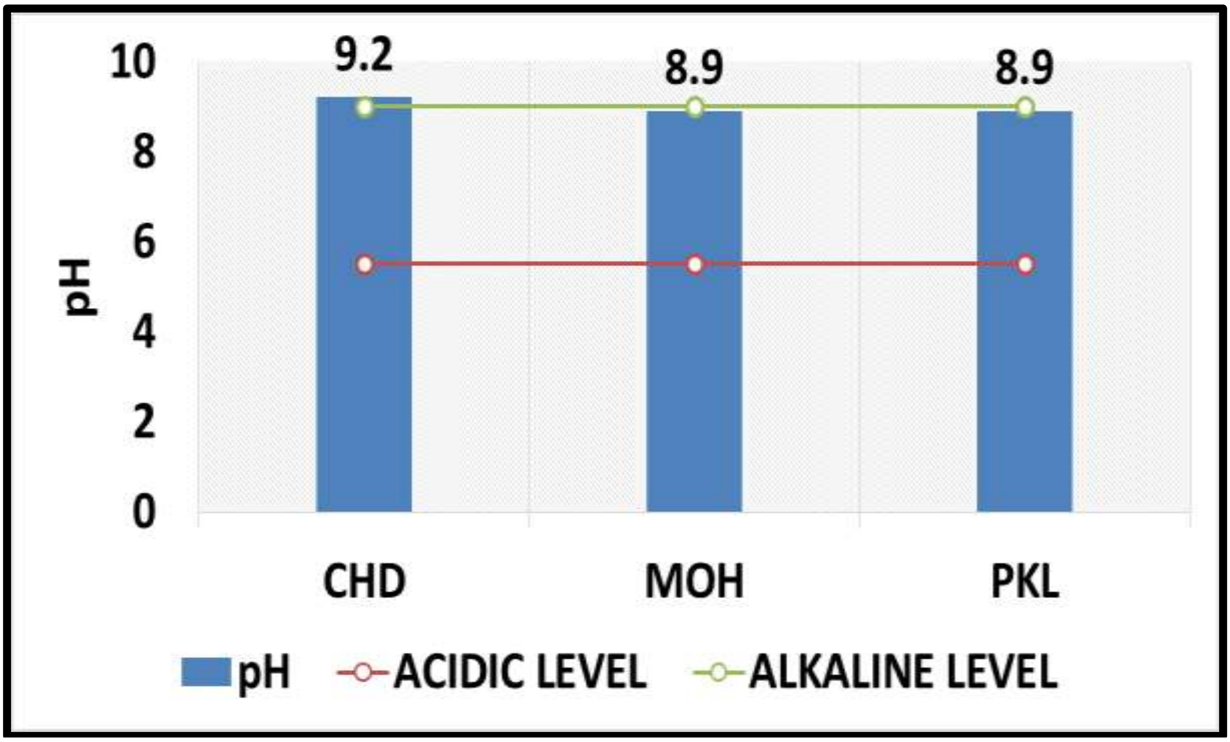


Figure 5.3: Average pH values of Leachate samples from Chandigarh, Mohali and Panchkula respectively

For our study, it was observed that TDS varied in the ranges of 35900 to 36690 mg/L for samples from Chandigarh dumping site, 3161-3290 mg/L for Mohali leachate samples and 30480 to 31000 mg/L for Panchkula leachate samples. The average TDS from Chandigarh, Mohali and Panchkula, respectively, over the entire monitoring campaign is presented in *figure 5.4*. TDS comprises mainly inorganic salts and dissolved organics [41]. The high values of TDS in all the three dumping sites leachate samples are attributed to the leaching of the ions from the dump site [41, 85-87]. The increase in TDS value increases salinity and thereby increases toxicity by hampering the characteristic composition of water [2, 118-120]. TDS is one of the parameters taken into account for licensing discharge of landfill leachate in many countries such as U.K. [41]. EC is the amount of a solution to carry an electric current which mostly depends on the concentration of salts present. High EC values were observed in all the leachate samples of Chandigarh, Mohali and Panchkula over the entire monitoring period.

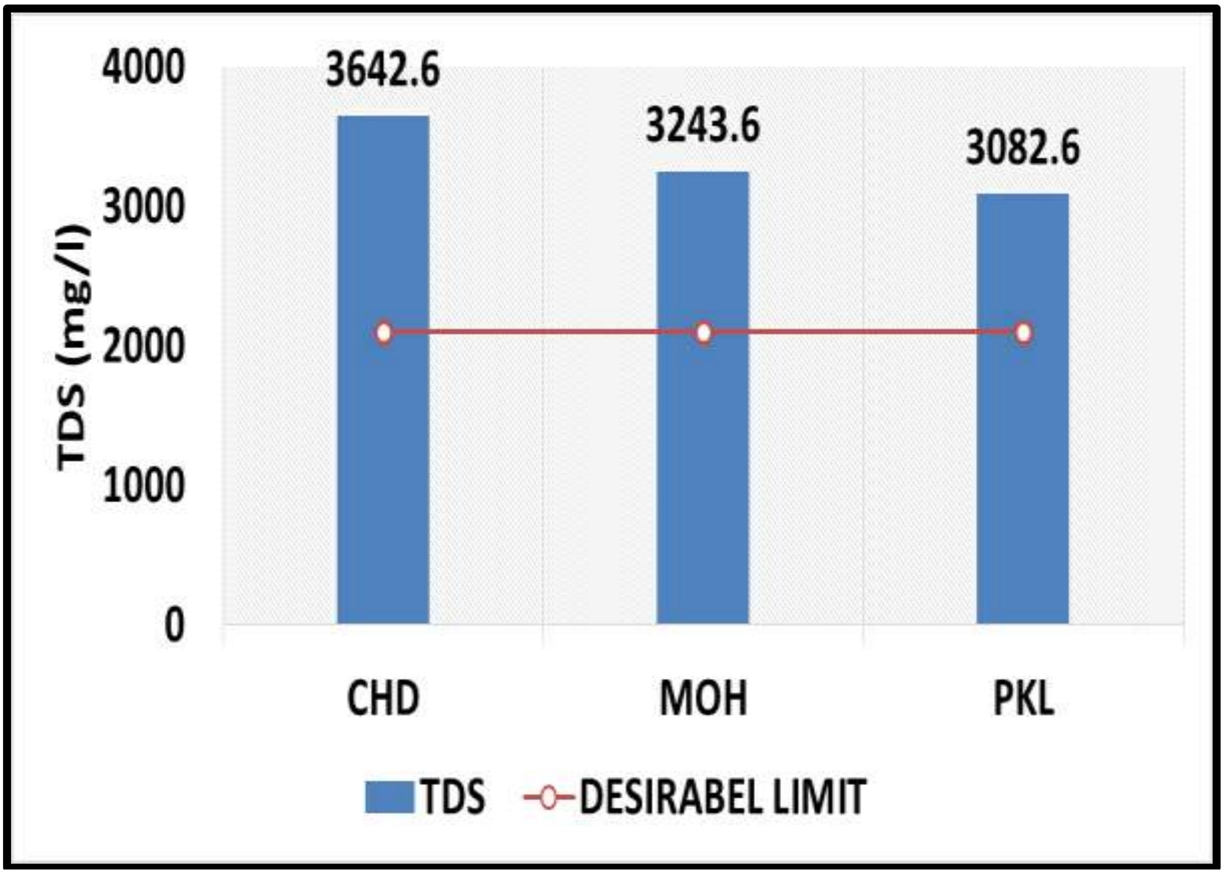


Figure 5.4: Average TDS concentration of Leachate samples from Chandigarh, Mohali and Panchkula respectively

For our study, the COD varied in the range of 19930 to 19961 mg/L for Chandigarh, 17323 to 17968 mg/L for Mohali and 18208-19920 mg/L for Panchkula leachate samples over the entire monitoring campaign. Similarly, the BOD values were within the ranges of 360 to 425 mg/L for Chandigarh, 470 to 510 mg/L for Mohali and 310 to 370 mg/L for Panchkula over the same monitoring campaign. The results show that BOD/COD values were less than 0.1 for all the samples from the three dumpsites over the monitoring campaign. This signifies that almost negligible fractions of organic matter are present in the leachate. This is primarily because the organic fraction of the MSW gets decomposed being converted to biogas (methane and carbon dioxide). During methanogenic phase, the organic strength of the leachate is reduced by methanogenic bacteria such as methanogenic archaea and concentration of VFAs also declines which results in a ratio of BOD/COD less than 0.1 [38, 41]. *Figure 5.5* represents the average COD and BOD in Tricity.

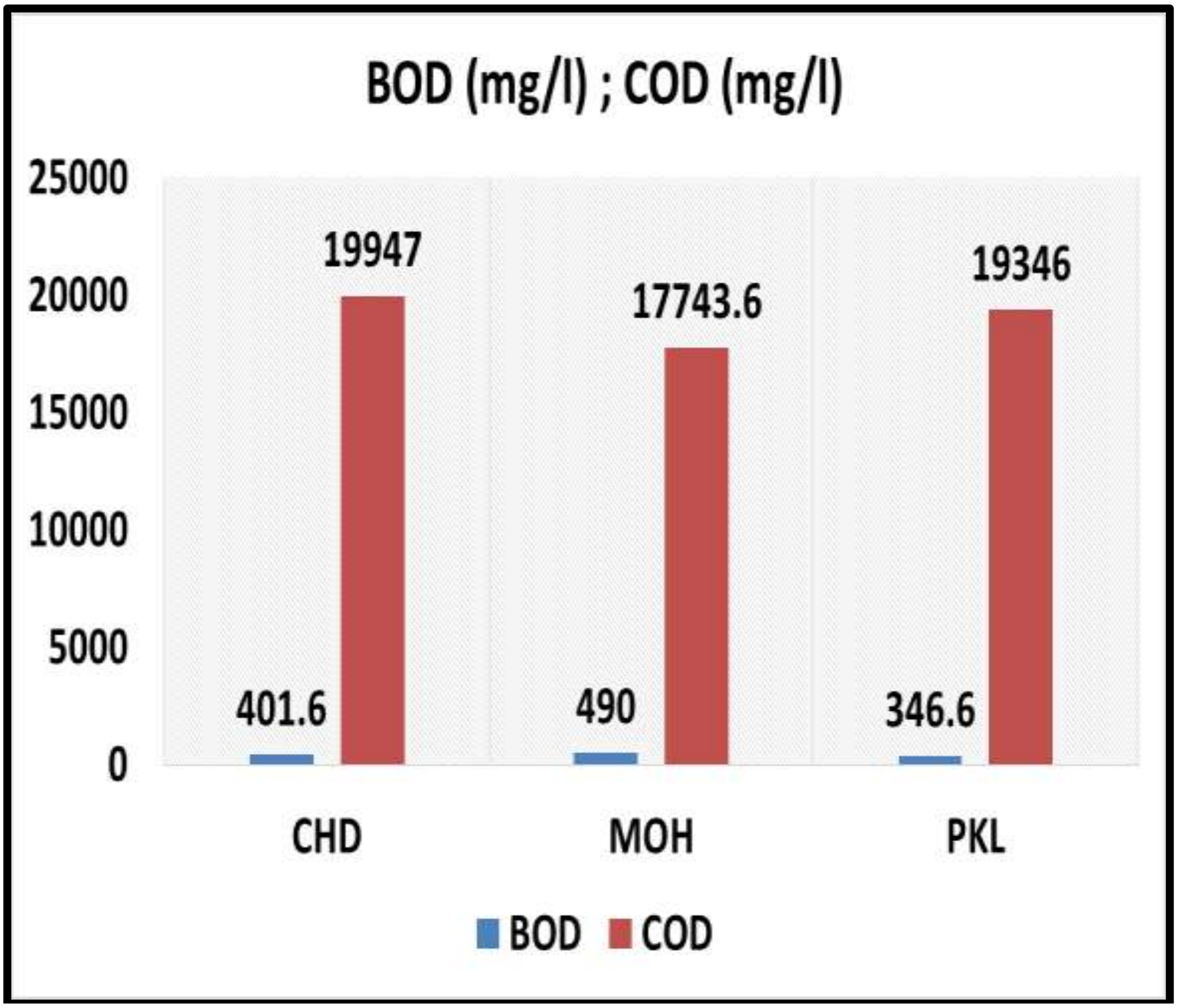


Figure 5.5: Average BOD and COD concentration of Leachate samples from Chandigarh, Mohali and Panchkula respectively

The concentration of NH_3-N in all the three dumping sites was high ranging amidst 1150 to 1210 mg/L for Chandigarh, 1190 to 1328 mg/L for Mohali samples and 1010 to 1030 mg/L for Panchkula samples over the monitoring campaign as shown in *figure 5.6*. This is primarily due to decomposition of the organic waste releasing to production of biogas with a high fraction of ammonia gas [16]. This also indicates that the landfill sites are nearing the end of their lifespan as they are already in the methanogenic phase as also corroborated from the pH results. High concentrations of chloride ion were also observed from all the three sites over the monitoring campaign. Chlorides act as a conservative pollutant as its reaction effects are often negligible [102]. The average chloride concentration for Chandigarh, Mohali and Panchkula over the entire monitoring campaign is presented in *figure 5.7*.

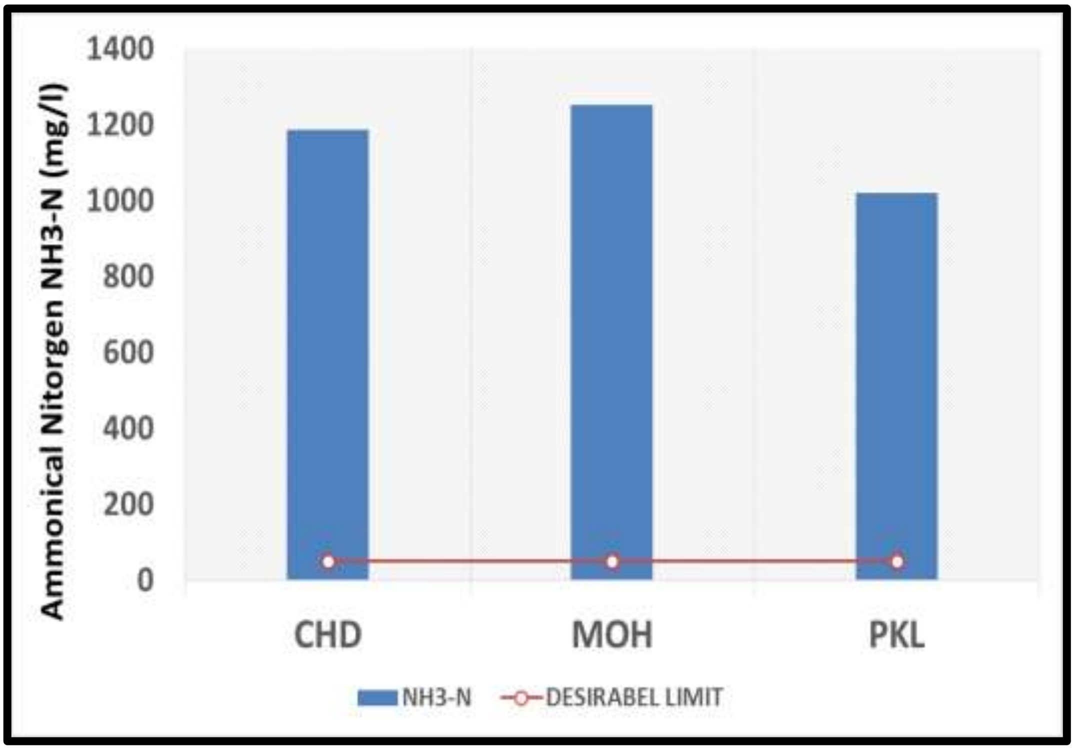


Figure 5.6: Average Ammonical Nitrogen concentration of Leachate samples from Chandigarh, Mohali and Panchkula respectively

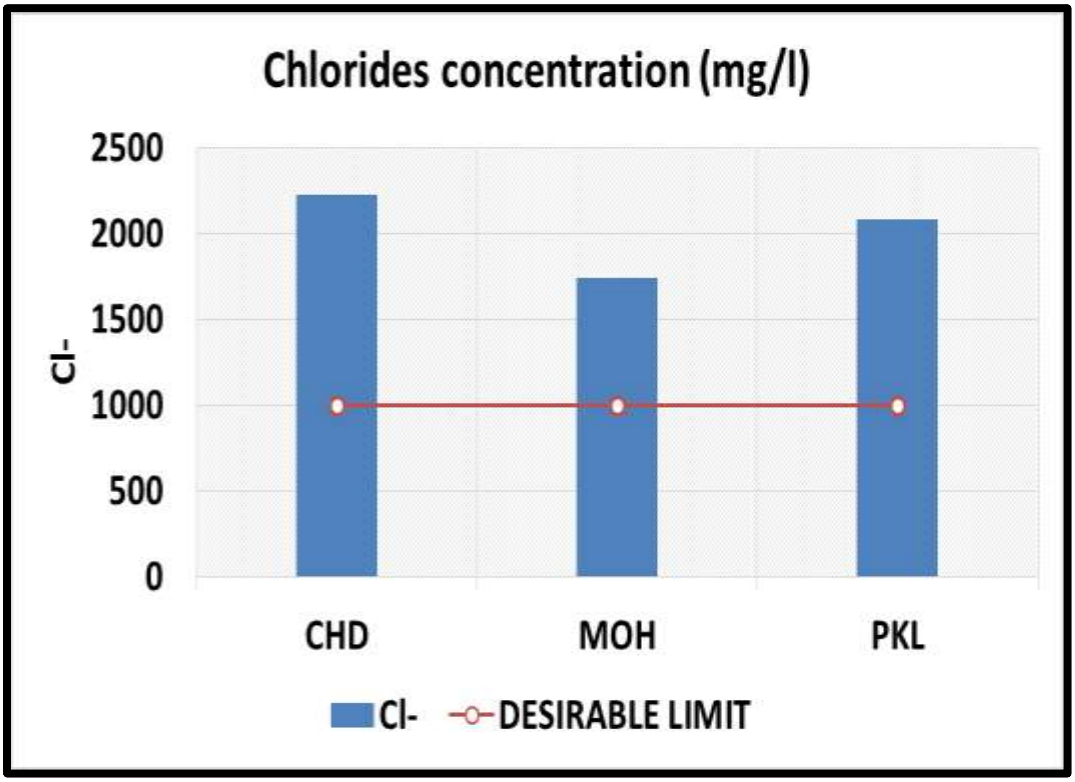


Figure 5.7: Average Chloride concentration of Leachate samples from Chandigarh, Mohali and Panchkula respectively

Table 5.5: Leachate Characteristics of the monitoring campaign carried out at different dumpsites

Parameters	**Chandigarh**			**Mohali**			**Panchkula**			**Standards for Disposal**		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**Inland surface water**	**Public sewers**	**Land disposal**
Temp (°C)	18.6	20.2	24.7	16.7	19.2	23.1	19.1	22.4	25.6	**-**	**-**	**-**
pH	9.6	9.1	9.0	8.9	9.0	9.0	8.6	9.1	9.0	**5.5-9.0**	**5.5-9.0**	**5.5-9.0**
TDS	35900	36690	36690	31610	32800	32900	30480	31000	31000	**2100**	**2100**	**2100**
BOD	360	420	425	470	490	510	310	360	370	**30**	**350**	**100**
COD	19930	19950	19961	17323	17940	17968	18208	19910	19920	**250**	**-**	**-**
NH_3-N	1150	1200	1210	1190	1239	1328	1010	1022	1030	**50**	**50**	**-**
Total Fe	11.2	12.2	12.1	7.72	7.80	7.95	8.83	8.89	8.88	**-**	**-**	**-**
Cu	3.72	3.80	3.66	3.32	4.90	4.85	2.23	2.40	2.40	**3.0**	**3.0**	**-**
Ni	0.98	0.98	0.96	0.77	0.99	0.99	0.87	0.87	0.88	**3.0**	**3.0**	**-**
Zn	10.41	11.60	12.2	8.4	8.6	8.7	8.39	8.41	8.60	**5.0**	**15**	**-**
Pb	0.64	0.66	0.70	0.07	0.07	0.08	0.11	0.19	0.20	**0.1**	**1.0**	**-**
Cr	0.14	0.16	0.20	2.47	3.20	3.20	0.75	0.89	0.90	**-**	**-**	**-**
Cl^-	2136	2230	2320	1659	1780	1786	2012	2100	2122	**1000**	**1000**	**600**
TCB	8×10^7	8×10^7	10×10^7	7×10^7	8×10^7	7×10^6	9×10^6	9×10^7	9×10^6	**--**	**-**	**-**
EC	36980	48200	53200	34450	34970	45500	39230	42920	49450	**-**	**-**	**-**
TH	1386	1763	1973	1562	1686	1982	1986	2001	1986	**-**	**-**	**-**
Ca^{2+}	4902.3	5690	3794	5911	5942	5996	5792	5839	5892	**-**	**-**	**-**
Mag^{2+}	460	572	838.4	550	593	625	634.1	662	6876	**-**	**-**	**-**
TA	6620	6491	6893	6990	6997	6890	6869	6920	6994	**-**	**-**	**-**
Na^+	1892.3	1967.8	1983.4	1912	1944.8	1999	1875.4	1893.8	1976.9	**-**	**-**	**-**
K^+	775	821	886	878	934	864	885	912	934	**-**	**-**	**-**
F^-	82	89	92	86	93	86	92	89	96	**2.0**	**1.5**	**-**
SO_4^{2-}	1789.6	4834	2712.8	1881	1755	1923	1967	1962	1865	**-**	**-**	**-**
PO_4^{3-}	51	66	66.8	75	86.6	93.3	72	69	88.7	**-**	**-**	**-**

(All values in mg/l except pH and EC)

High concentrations of heavy metals were detected in the leachate samples, like copper which was primarily due to the dumping of toxic waste like metal scrap, batteries, toxic medicines, paints etc. The presence of lead, nickel and very low concentration of cadmium was also reported. Presence of heavy metals in the leachate samples is attributed to the unsegregated MSW in the dumping sites [31]. Total iron found in the leachate samples from all the landfill sites was also high and were primarily due to the iron and steel based scrap parts being disposed of along with MSW. *Figure 5.8* represents the heavy metals over the monitoring campaign in Tricity. TCB is the major indicator of organic contamination of the water and wastewater quality. Very high concentrations of TCB were found in all the leachate samples from the three dumping sites. Similar results were obtained in a study conducted on three landfill sites in Malaysia [41], which showed presence of very high concentrations of TCB which resulted in high pollution ratings. The high average concentrations of major ions and heavy metals in the leachate depicted that these open dumping sites are a potential source of human and environmental hazards. Leachates produced from these dumping sites are heterogeneous in nature due to a mixture of various harmful chemicals. The risk assessment of the leachate is a major environmental issue due to increased number of unscientific disposal sites and with the rising importance of protecting ground water.

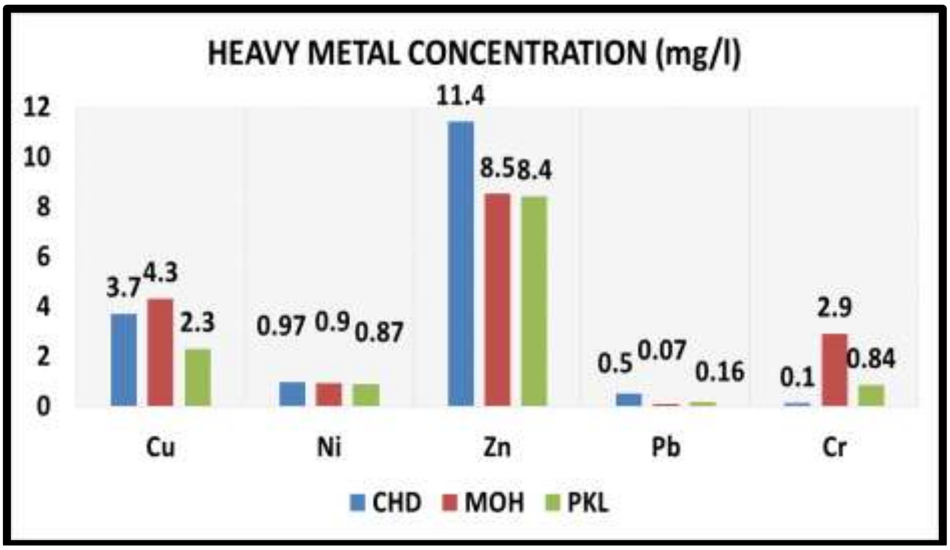


Figure 5.8: Heavy Metal concentration of Leachate samples from Chandigarh, Mohali and Panchkula respectively.

5.3.2 Toxicological Analysis

5.3.2.1 Detection of Organic Contaminants

Organic micropollutants detected in leachate samples of Chandigarh, Mohali and Panchkula are as given in *Table 5.6*. The qualitative analysis of pollutants which were detected using scan mode of GC-MS included compounds belonging to aliphatics, alcohols, terpenoids, ketones, benzenes, phthalates, pharmaceuticals and halogenated compounds. They can be classified as alpha-limonene diepoxide commonly used in the flavor industry [179, 38], brominated dioxins used formed during burning of PVC based plastics and materials used as flame retardants [9, 10, 38], Bisphenol A and bis-(2-ethylhexyl) phthalate (DEHP) commonly used as plasticizers. Studies have reported [54, 55, 179, 110] that Bisphenol-A is the most frequently occurring compound in the leachate as it being one of the highest volumes of chemical produced in plastic packaging and also is a part of metal waste. Apart from these, products like Naphthalenol, 2-Naphthol and 2, 7-Naphthalenediol was also detected in leachate samples. The presence of these organic contaminants has also been reported in various studies [54, 55, 110, 179] of leachate samples in Indian scenario as well as other world countries [212].

Table 5.6: Major organic compounds in leachates of Chandigarh, Mohali and Panchkula

Organic Pollutant	Landfill Leachate			Organic Pollutant	Landfill Leachate		
	CHD(CL)	MOH (ML)	PKL(PL)		CHD (CL)	MOH (ML)	PKL (PL)
Tricosane	+	N.D	N.D	Acenapthene	+	+	+
Pentacosane	+	+	N.D	Octahydrophenanthrene[a]	+	N.D	N.D
Hexacosane[a]	+	+	+	Phenanthrene[a]	+	+	+
Heptacosane	+	N.D	+	Indene	+	+	+
Octacosane[a]	+	+	+	Tetradecahydro-1H-cyclopenta[a]phenanthrene	+	N.D	N.D
Nonacosane	+	+	+	Benzene	+	+	+
Docosane[a]	+	N.D	+	Aminobenzene	+	N.D	N.D
Tetracosahexane	+	N.D	N.D	Benzamide	N.D	N.D	+
Hexadecane[a]	+	N.D	+	Benzophenone	N.D	+	+
4-Dimethylsilyloxytetrsdecane	+	N.D	N.D	Naphthalenone	+	+	N.D
Trifluoroacetoxyhexadecane	+	+	N.D	2,15-Hexadecanedione	N.D	+	+
Alpha-Limonene diepoxide	+	N.D	N.D	Ibuprofen	+	N.D	N.D
2-Napthol	+	+	+	Bis-(2ethylhexyl)phthalate	+	+	N.D
2,7-Napthalenediol	+	+	+	Diisobutyl phthalate	+	N.D	N.D
Cholestan-3-ol	+	+	+	2-(2,7-Dibromo-1-naphthyl)acetamide	+	+	N.D
2-Napthalenemethanol	+	+	+	7,8-Dibromo-4,4,7-trimethyl-hexahydro-benzo [1,3] dioxin-2-one	N.D	+	N.D
Benzeneethanol	+	+	+	1,30Dibromotriacontane	+	N.D	N.D
2,5-Dimethylbenzenethiol	+	N.D	+	1-Chlorooctadecane	+	+	N.D
Bisphenol A	+	N.D	N.D	2,2-Dichloro-1-methyl-cyclohexanol	+	N.D	N.D
Naphthalene[a]	+	+	+	Acenapthylene	+	+	+

"+" Presence of contaminants, N.D. not detected, [a]Organic Pollutants in US EPA list of priority pollutants in environment

An enormous number of other organic contaminants can also be expected to be present in the leachate samples at a concentration below the detection limit of the analytical methods used. However, the low concentrations do not eliminate the threat posed by them on the health of humans as well as animals. In this context, the quantitative analysis of the leachate samples was performed using SIM mode of GC-MS which showed the presence of many PAH's as shown in *Table 5.7*. The compounds which remain unobserved in scan mode were detected in SIM mode indicated that the PAH's were highest in ML. The toxic equivalence factor (TEF) expresses an aggregate measure of toxicity based on a number of contributing compounds. The Bap TEF seeks to provide a toxicity weighted sum of concentrations of the specific PAH's. The concentration level and type of PAH's in the three sampling sites differ due to the difference of pollution sources and other environmental factors [55, 110]. Presence of PAH's also associated with the burning of organic matter [55, 110, 179]. The percolation of leachate into ground water and with the assimilation of the compounds present in them, will lead to entry of these compounds in the food chain and their bio accumulation [110].

5.3.2.2 Human Risk Assessment

Results of human risk assessment for leachate samples of Chandigarh, Mohali and Panchkula are as given in *Table 5.7*, illustrate the potential risks for human health due to ingestion of ground water polluted due to leachate. The risk posed due to exposure to drinking water contaminated with leachate was estimated considering a hypothetical situation of 1:100 dilution of leachate in drinking water. Risk assessment is one of the faster evolving tools to evaluate the hazards on human health and also to determine the level of treatment required to solve particular environmental problems. Concentration of carcinogenic PAH's in contaminated drinking water is indicated by BaP TEQ's was found to range from 54.71×10^{-8} to 305.031×10^{-8} mg/l. The cancer risk varied from 4.88×10^{-8} to 27.3×10^{-8}. The level of toxicity established on the basis of CR for leachates is ML>PL>CL. The cancer risk due to PAH's measured was lower than the risk threshold of 10^{-6} [213]. Though, the cancer risk did not exceed the risk threshold under the present conditions still the carcinogenic effects due to organic as well as inorganic contaminants as specified in the results of the current study cannot be neglected. The absence of any engineered barriers and the improper leachate collection system landfills in Chandigarh, Mohali and Panchkula respectively results in the release of cocktail of chemicals present in leachate which contaminate surrounding soil as well as ground water. The previous studies [179] have shown high cancer risk in drinking water due to PCB's, PCDD's and arsenic. The evaluation of risk in the present study underlined possible adverse effects on human health after the exposure to the drinking water contaminated by leachate at a hypothesized condition. Recent studies [54, 55, 214] have also demonstrated that leachate from the MSW sites induces DNA damage due to presence of high content of heavy metals in leachate.

Table 5.7: Human risk assessment results for PAH's in the leachate samples

PAH[a]	**TEF**[b]	**CHD(CL)**		**MOH(ML)**		**PKL(PL)**	
		Concentration (mg/L)	BaP TEQ's	Concentration (mg/L)	BaP TEQ's	Concentration (mg/L)	BaP TEQ's
NaP	0	2.06×10^{-3}	0	3.145×10^{-3}	0	2.67×10^{-3}	0
AcPY	0.001	1.12×10^{-3}	1.12×10^{-6}	1.22×10^{-3}	1.22×10^{-6}	4.313×10^{-3}	4.313×10^{-6}
AcP	0.001	1.48×10^{-3}	1.48×10^{-6}	1.68×10^{-3}	1.68×10^{-6}	2.301×10^{-3}	2.301×10^{-6}
Flu	0.001	0.565×10^{-3}	0.565×10^{-6}	0.998×10^{-3}	0.99×10^{-6}	8.9928×10^{-3}	8.9928×10^{-6}
Phe	0.001	1.98×10^{-3}	1.98×10^{-6}	6.86×10^{-3}	6.86×10^{-6}	12.13×10^{-3}	12.13×10^{-6}
Ant	0.01	2.28×10^{-3}	22.8×10^{-6}	2.776×10^{-3}	277.6×10^{-6}	14.4750×10^{-3}	144.750×10^{-6}
Fl	0.001	0.269×10^{-3}	0.269×10^{-6}	0.5556×10^{-3}	0.5556×10^{-6}	0.605×10^{-3}	0.605×10^{-6}
Pyr	0.001	5.9×10^{-3}	5.9×10^{-6}	6.2×10^{-3}	6.2×10^{-6}	7.6653×10^{-3}	7.653×10^{-6}
BaA	0.1	1.98×10^{-3}	0.0198×10^{-6}	0.0198×10^{-3}	1.98×10^{-6}	1.98×10^{-3}	0.0198×10^{-6}
BbF	0.1	0.5×10^{-3}	0.5×10^{-6}	0.2×10^{-3}	0.2×10^{-6}	0.98×10^{-3}	0.98×10^{-6}
BkF	0.1	4.6×10^{-3}	0.46×10^{-6}	6.67×10^{-3}	0.667×10^{-6}	6.67×10^{-3}	0.667×10^{-6}
BaP	1	0.006×10^{-3}	6×10^{-6}	0.006×10^{-3}	6×10^{-6}	0.003×10^{-3}	3×10^{-6}
IDP	0.1	0.006×10^{-3}	6×10^{-6}	0.002×10^{-3}	0.2×10^{-6}	0.002×10^{-3}	2×10^{-6}
BP	0.01	0.0702×10^{-3}	0.702×10^{-6}	0.061×10^{-3}	0.61×10^{-6}	0.0569×10^{-3}	0.569×10^{-6}
Chry	0.01	0.0605×10^{-3}	0.605×10^{-6}	0.026×10^{-3}	0.26×10^{-6}	0.0220×10^{-3}	0.220×10^{-6}
Total BaP TEQ's (mg L^{-1})		54.71×10^{-6}		305.031×10^{-6}		188.201×10^{-6}	
1:100 dilution		54.71×10^{-8}		305.031×10^{-8}		188.201×10^{-8}	
CDI(mg Kg^{-1} day^{-1})		0.669×10^{-8}		3.73×10^{-8}		2.30×10^{-8}	
SF (Kg day mg^{-1})		7.3		7.3		7.3	
CR		4.88×10^{-8}		27.2×10^{-8}		16.82×10^{-8}	

PAHs[a]: NaP naphthalene, AcPY acenaphthylene, AcP acenaphthene, Flu fluorene, Phe phenanthrene, Ant anthracene, Car carbazole, Fl furoanthene, Pyr pyrene, BaA benzo[a] anthracene, TrP triphenylene, BbF benzo[b]fluoranthene, BkF benzo[k] fluoranthene, BaP benzo[a]pyrene, IDP indeno[1,2,3-cd]pyrene, DBA dibenzo[a,h]anthracene, BP benzo[ghi]perylene, Ch chrysene, ATSDR(2009.2015,2016)[b], www.alsglobal.com Enviromail No-59(2013)[b]

5.3.2.3 Leachate Induced Cytotoxic Effects on Neuro-2a Cell Lines

The cytotoxicity effects of the leachate samples were evaluated by measuring the cell viability of Neuro-2a cells using MTT assay. The positive control and test samples were added in different dilutions and the half maximal effective concentration (EC_{50}) was calculated. Cell viability was expressed as percentage of the corresponding control (0.5% *v/v* Milli-Q). The cell viability in terms of MTT assay derived EC_{50} values as given in *Table 5.8*. After 24 hour of treatment, lowest EC_{50} value was observed in ML and highest in CL.

Table 5.8: MTT EC_{50} values of leachate samples

Treatments[a]	MTT EC_{50}[b]	R^2 (EC_{50})
CL	15.46	0.9661
ML	6.81	0.9617
PL	9.99	0.7549

[a]Neuro-2a cell lines were treated with different test samples (dilutions ranging from 5 to 20% *v/v*) for 24 hours in MTT assay, [b]EC_{50}-half maximal effective concentration

The results of the MTT assay put forward that the leachate from all the three dumping sites of each Chandigarh, Mohali and Panchkula cities contained significant load of toxicants. Cytotoxicity induced due to leachate can be attributed due to the presence of compounds like phenanthrene, anthracene, pyrene etc. which lead to DNA damage and blocking of cell cycle progression and mitosis causing cell proliferation [179, 9, 10, 38, 166]. Disturbances in cell proliferations have also been reported [179] due to compounds like Bisphenol-A, phthalates esters and dioxins in leachate samples. Heavy metals found in leachate samples have also found to have cytotoxic effects. Leachate induced cytotoxicity has been reported earlier in Neuro-2a [214] cell lines, HepG2 cells [54, 55, 110] through cell proliferation and also in MCF-7 breast cancer cells by necrosis [179, 213]. The harmful constituents present in leachate samples are responsible for the cell disturbances causing cell deaths as assessed in our study and suggest that exposure of human population to these leachates lead to adverse health effects.

5.3.3 Leachate Pollution Index

The sub-index (p_i) value of the different parameters of the leachate samples for all the three sites were obtained from the sub-index curves based on their concentrations values as per the methodology described by Kumar and Alappat, 2005 to calculate LPI. The "p" values obtained were multiplied with the respective weights assigned to each parameter [33, 34, 38]. The methodology for calculation of LPI has already been discussed in an earlier section. In the present study, out of 18, only 13 significant parameters were determined as data for all parameters was not available, LPI has been calculated on the basis of available data and thereby equation (5.5) was used to determine the LPI. The LPI values of Chandigarh, Mohali and Panchkula dumping sites are reported in *Table 5.9, 5.10* and *5.11* respectively. LPI gives a mean value which enables to determine if the landfill requires immediate attention in terms remediation measures [118-120, 85-87].

Table 5.9: LPI of the leachate from Chandigarh dumping site

Parameters	**Concentration**			**Weights (w_i)**	**Individual pollution rating (p_i)**			**Overall pollution rating ($w_i \times p_i$)**		
	S1	**S2**	**S3**		**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
pH	9.6	9.1	9.0	0.055	25	20	20	1.375	1.1	1.1
TDS	3590	3669	3669	0.050	10	13	13	0.5	0.65	0.65
BOD	360	420	425	0.061	11	13	13	0.671	0.793	0.793
COD	19930	19950	19961	0.062	55	58	60	3.41	3.596	3.72
TKN	-	-	-	-	-	-	-	-	-	-
NH_3-N	1150	1200	1210	0.051	100	100	100	5.1	5.1	5.1
Total Fe	11.2	12.2	12.1	0.045	8	10	10	0.36	0.45	0.45
Cu	3.72	3.80	3.66	0.05	11	11	10	0.55	0.55	0.5
Ni	0.98	0.98	0.96	0.052	7	7	7	0.364	0.364	0.364
Zn	10.41	11.60	12.2	0.056	7	8	10	0.392	0.448	0.56
Pb	0.64	0.66	0.70	0.063	7	8	10	0.441	0.504	0.63
Cr	0.14	0.16	0.20	0.064	6	8	9	0.384	0.512	0.576
Hg	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-
Cl^-	2136	2230	2320	0.048	20	22	25	0.96	1.056	1.2
Cyanide	-	-	-	-	-	-	-	-	-	-
Total Coliforms	8×10^7	8×10^7	10×10^7	0.052	100	100	100	5.2	5.2	5.2
Total				**0.709**				**19.707**	**15.123**	**20.843**
LPI								27.80	21.30	29.36
LPI (Mean of all the three samplings)								**26.15**		

Table 5.10: LPI of the leachate from Mohali dumping site

Parameters	Concentration			Weights (w_i)	Individual pollution rating (p_i)			Overall pollution rating ($w_i \times p_i$)		
	S1	S2	S3		S1	S2	S3	S1	S2	S3
pH	8.9	9.0	9.0	0.055	10	20	20	0.55	1.1	1.1
TDS	3161	3280	3290	0.050	13	15	15	0.65	0.75	0.75
BOD	470	490	510	0.061	15	15	18	0.915	0.915	1.098
COD	17323	17940	17968	0.062	50	52	55	3.1	3.224	3.41
TKN	-	-	-	-	-	-	-	-	-	-
NH_3-N	1190	1239	1328	0.051	100	100	100	5.1	5.1	5.1
Total Fe	7.72	7.80	7.85	0.045	5	6	6	0.225	0.27	0.27
Cu	3.32	4.90	4.85	0.05	8	11	11	0.4	0.55	0.55
Ni	0.77	0.99	0.99	0.052	5	7	7	0.26	0.364	0.364
Zn	8.4	8.6	8.7	0.056	5	5	5	0.28	0.28	0.28
Pb	0.07	0.07	0.08	0.063	5	5	5	0.315	0.315	0.315
Cr	2.47	3.20	3.20	0.064	5	6	6	0.32	0.384	0.384
Hg	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-
Cl^-	1659	1780	1786	0.048	20	20	20	0.96	0.96	0.96
Cyanide	-	-	-	-	-	-	-	-	-	-
Total Coliforms	7×10^7	8×10^7	7×10^6	0.052	100	100	100	5.2	5.2	5.2
Total				**0.709**				**18.275**	**19.412**	**19.781**
LPI								25.78	27.38	27.90
LPI (Mean of all the three samplings)								**27.02**		

Table 5.11: LPI of the leachate from Panchkula dumping site

Parameters	Concentration			Weights (w_i)	Individual pollution rating (p_i)			Overall pollution rating ($w_i \times p_i$)		
	S1	S2	S3		S1	S2	S3	S1	S2	S3
pH	8.6	9.1	9.0	0.055	5	20	20	0.275	1.1	1.1
TDS	3048	3100	3100	0.050	11	9	9	0.55	0.45	0.45
BOD	310	360	370	0.061	8	11	11	0.488	0.671	0.671
COD	18208	19910	19920	0.062	50	58	58	3.1	3.596	3.596
TKN	-	-	-	-	-	-	-	-	-	-
NH_3-N	1010	1022	1030	0.051	100	100	100	5.1	5.1	5.1
Total Fe	8.83	8.89	8.88	0.045	9	13	13	0.405	0.585	0.585
Cu	2.23	2.40	2.40	0.05	8	9	9	0.4	0.45	0.45
Ni	0.87	0.87	0.88	0.052	7	7	7	0.364	0.364	0.364
Zn	8.39	8.41	8.60	0.056	5	6	7	0.28	0.336	0.392
Pb	0.11	0.19	0.20	0.063	6	9	9	0.378	0.567	0.567
Cr	0.75	0.89	0.90	0.064	9	11	11	0.576	0.704	0.704
Hg	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-
Cl^-	2011.5	2100	2122	0.048	25	28	28	1.2	1.344	1.344
Cyanide	-	-	-	-	-	-	-	-	-	-
Total Coliforms	9×10^6	9×10^7	9×10^6	0.052	100	100	100	5.2	5.2	5.2
Total				**0.709**				**18.316**	**20.467**	**20.523**
LPI								25.83	28.87	28.95
LPI (Mean of all the three samplings)								**27.88**		

The calculated LPI values obtained for Chandigarh, Mohali and Panchkula dumping sites were 26.15, 27.02 and 27.88 respectively and are shown in *figure 5.9*. These LPI values are much higher than the standard LPI value of the treated leachate disposal limit of 7.378 to inland surface water [33, 34]. Higher values of LPI signify that leachate produced from all these three dumping sites of Chandigarh, Mohali and Panchkula is highly contaminated and proper treatment techniques must be ensured before discharging the leachate. All the three dumping sites do not have any provision of base liners or leachate collection and treatment systems. LPI values indicates the contamination potential due to leachate produced from the landfill sites in the particular areas and act as an important tool for identifying and measuring the hazards caused due to percolation of the leachate in soil strata as well in aquifers. The characteristics of leachate changes over time, the LPI value will also differ. Hence, the LPI value would correspond to the leachate samples analysed at a particular time for a specific landfill site.

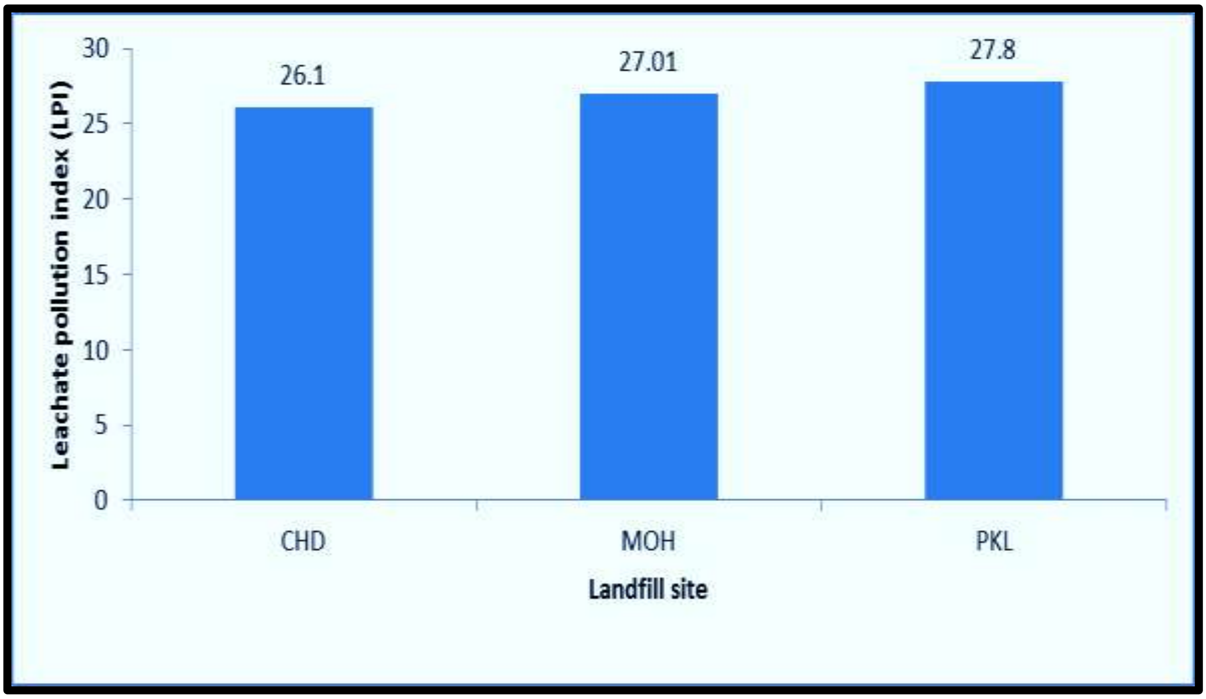


Figure 5.9: Leachate pollution index for three dumping site

5.4 Summary and Discussion

The present study is an integrated approach using physico-chemical characterization, bioassays, human risk assessment and pollution potential indexing was used efficiently to access the effect of leachate pollution on environment. The leachate derived from municipal solid waste dumping sites of all the three cities of Chandigarh, Mohali and Panchkula demonstrates exceedingly high values for all physico-chemical and biological parameters analysed. The results also indicated that although there was no cancer risk by the PAH's in the leachate samples from Tricity, but the presence of other contaminants cause cytotoxicity in mammalian cell lines. Highest cytotoxicity was present in Mohali leachate and the toxicological ranking based on cancer risk due to leachates is ML>PL>CL. In the present study LPI values of 26.15, 27.02 and 27.88 were obtained for Chandigarh, Mohali and Panchkula respectively signifying high levels of toxicity. High values of LPI obtained in all the landfill sites indicated that the leachate generated is toxic and proper treatment procedures must be ensured. While the current and forthcoming legislation pushes forward to reduce both the quantity of disposed wastes and the environmental impacts of landfill sites, there is still need to manage the current landfill sites and find solutions to remediate and control environmental pollution from these sites.

CHAPTER-6

IMPACT OF OPEN DUMPING OF MSW ON GROUND WATER QUALITY

6.1 Introduction

Unscientific dumping of solid wastes leads to several associated environmental hazards like air, soil and ground water pollution causing adverse public health impacts [82-84]. In particular, contamination of ground water by leachate generated from unlined landfill sites is highly predominant and is most prevalent in developing countries due to disposal of MSW in open landfills [2, 85-87, 67, 32]. The rate of depletion of ground water levels and deterioration of available ground water resources is of immediate concern in major cities and towns of the country [61]. The susceptibility of an aquifer to pollution from landfill leahate is highly dependent on number of factors like location of dumping site, composition of waste dumped, toxicity of leachate, depth and flow of water table and type of landfill [89, 103]. Ground water is the major source of water supply in both urban and rural areas of developing nations and its contamination is a major environmental and health concern [61, 102]. The impact of leachate on ground water has been reported in many studies [2, 113, 75-77, 85-87] with a common conclusion of presence of high level of organic and inorganic pollution due to percolation of leachate. A study conducted [164] reported high values of pH, nitrate and BOD in ground water sample collected from the vicinity area of Malang landfill. A research [16, 107] conducted in metropolitan city of Delhi, reported high levels of trace elements like K^+, Cl^- and NH_4-N. Studies [1, 14, 113] have investigated the leachate composition generated from dumping sites and related it with ground water quality of nearby areas. An inadequate solid waste management system and absence of properly designed solid waste disposal facilities with fast growing population has led to contamination of the ground water and surface water resources.

The contamination of ground water is a potential environmental problem and needs to be addressed. Hence, different methods have been evaluated to monitor the ground water quality index around MSW dumping sites [120, 168]. The quality of the ground water can be studied scientifically if an accurate estimate of water quality is available in form of an index [89, 186]. Water quality index (WQI) is one of the simplest and widely used methods to evaluate the quality of ground water. There exists a number of different indexing methods to evaluate the groundwater quality aggregate index such as National Sanitation Foundation Water Quality Index (NSFWQI), Stream Health Index (SHI), Oregon Water Quality Index (OWQI) , Bureau of Indian Standards (BIS) 10500 weighted WQI and sustainable information network [120, 185- 186]. The quality of ground water depends upon the categorization of the index values achieved. Higher the ground water quality index value better is the assessment of the ground water.

In the present study, as described in the previous chapters, the waste generated in Tricity is dumped in open dumping sites. Residential and agricultural land is located in the vicinity of the dumping sites of Chandigarh, Mohali and Panchkula, respectively with seasonal rivulets (Sukhna Choe in Chandigarh, Patiala-Ki-Rao in both Chandigarh and Mohali and Ghaggar in Panchkula) flowing nearby the dump sites as described in earlier chapters (Figure 5.1, Chapter 5). Although the Municipal Corporations of all the three cities are providing water supply but around 40% residents are still using ground water supplies like hand pumps or bore wells for daily needs. Percolation of leachate from these open dumping sites poses threat to ground water sources so a study was planned to evaluate the effect of dumping sites on the ground water resources in the vicinity areas of dumping sites of Chandigarh, Mohali and Panchkula, respectively. The study also reported the WQI, calculated over a period of three seasons for determining the impact of leachate percolation on the groundwater quality. Multivariate analysis viz., Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were also carried out to understand the interrelationships of the results obtained.

6.2 Materials and Methods

6.2.1 Collection of Ground Water Samples

To determine the possible ground water contamination due to percolation of leachate into the aquifers, ground water samples were collected from the vicinity of the three disposal sites of Chandigarh, Mohali and Panchkula during the same monitoring campaign as described in the previous chapter (Chapter 5, Section 5.2.1). The ground water samples were collected from the hand pumps and other nearby submersibles close to the solid waste dumping sites at different downstream locations (1Km, 2Km, 2.5 Km, 3Km, 4Km and 5Km) from the MSW dumping sites. *Figure 6.1(a) and (b)* shows the sketch and the aerial view of the studied area with ground water sampling points. A total of fifty four samples (n=3 for each site) were utilized for the study purposes during all the three sampling periods. Ground water samples were collected in glass bottles (autoclaved to remove any contamination) and plastic bottles (thoroughly cleaned) and pre-soaked in 1M nitric acid (HNO_3) for 24 hours. The samples for heavy metal analysis were preserved by adding few drops of concentrated Sulphuric acid (H_2SO_4) in the glass bottles [202]. The collected ground water samples were transported to laboratory and stored in refrigerator at 4^oC temperature till complete analysis [202].

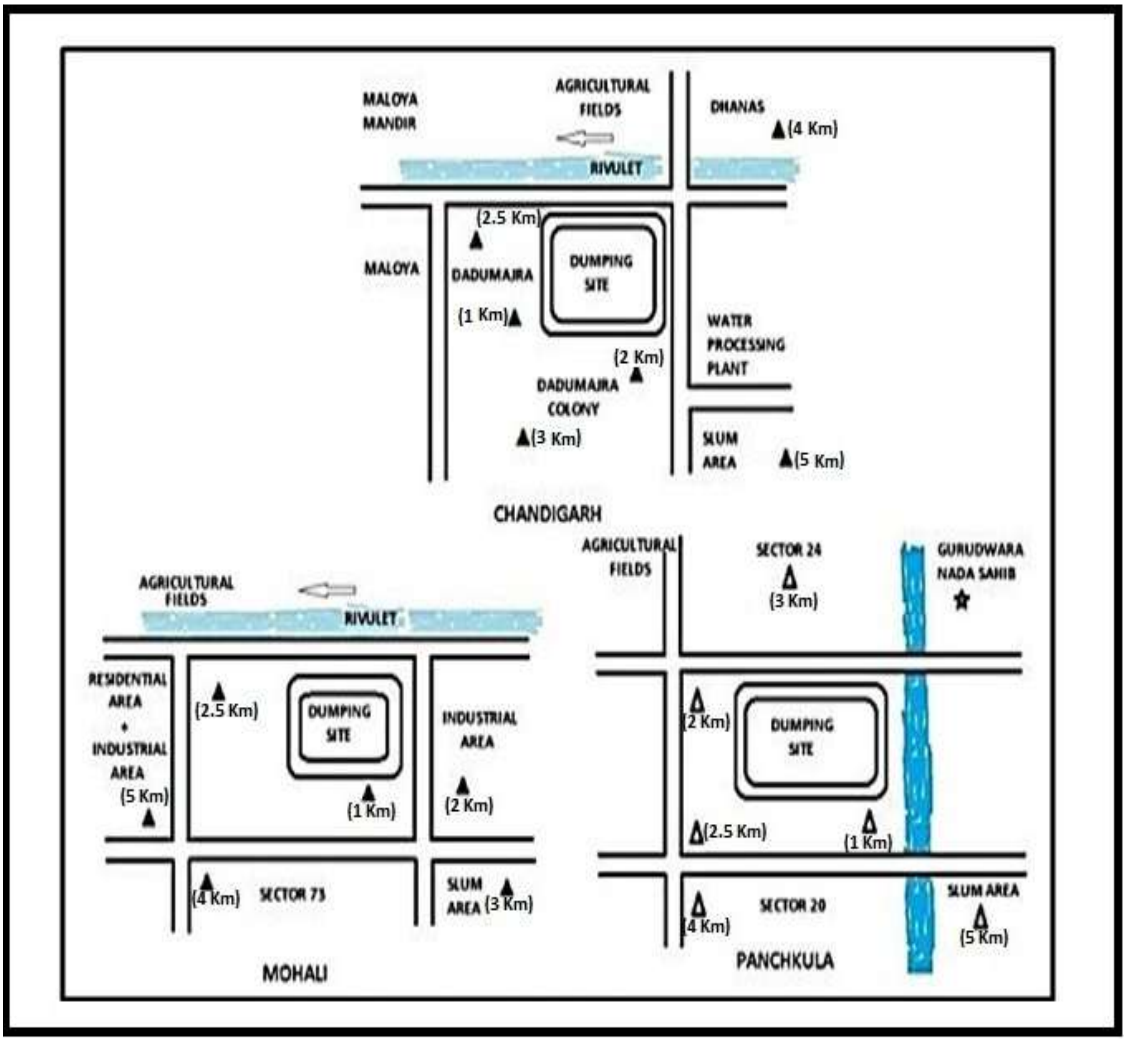


Figure 6.1(a): Sktech of the Study area with ground water sampling points

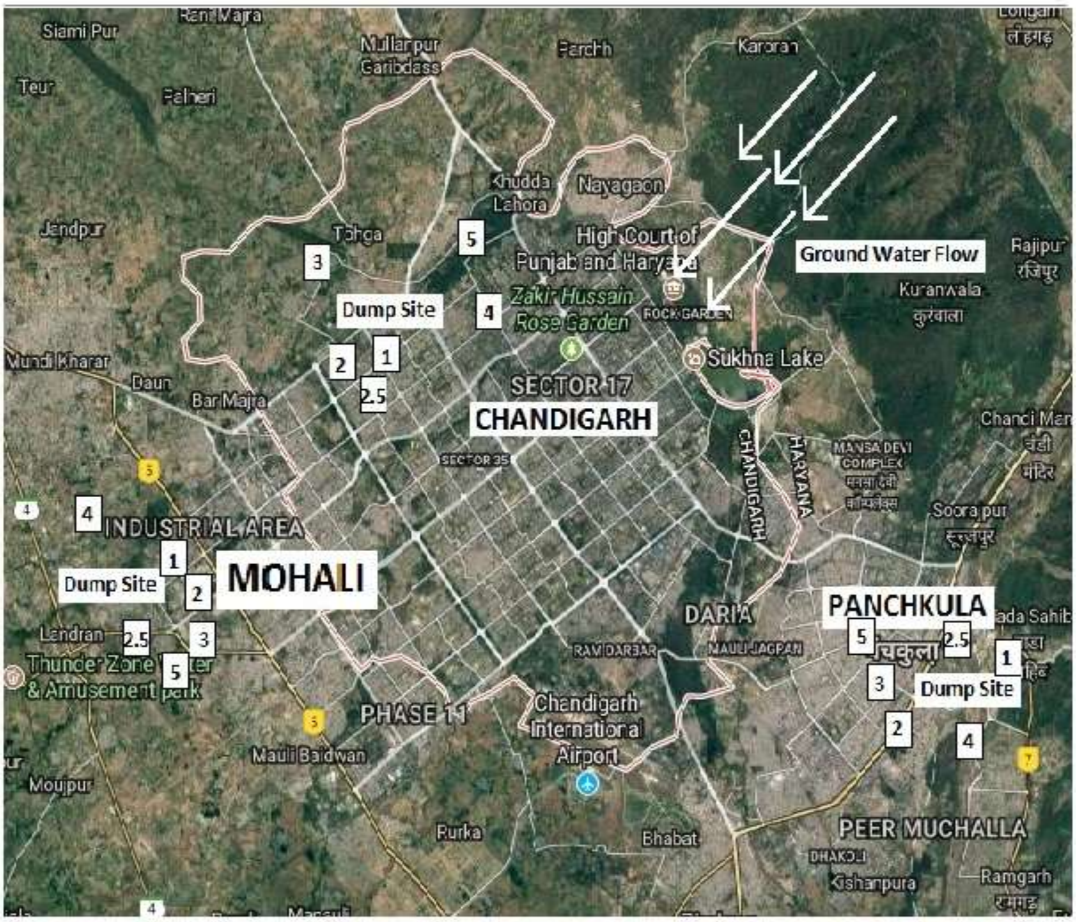


Figure 6.1(b): Aerial View of the study area with ground water sampling points

6.2.2 Analysis

Ground water samples were determined for physico-chemical, heavy metals, and microbiological parameters according to the standards APHA and BIS methods [202, 210]. All the samples in the experimental work were analysed for physico-chemical parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD), total alkalinity (TA), total hardness (TH), chloride (Cl^-), sulphate (SO_4^{2}), phosphate (PO_4^{3-}), calcium (Ca^{+2}), magnesium (Mg^{2+}), ammonical nitrogen (NH_3-N), fluoride (F^-), nitrate (NO_3^-), sodium (Na^+) and potassium (K^+) and heavy metals i.e. copper (Cu), chromium (Cr), lead (Pb), zinc (Zn), nickel (Ni) and cadmium (Cd). Estimation of pH, EC and TDS was done with pH meter and conductivity meter respectively.

COD was estimated using reflux titrimetry method. Ca^{2+}, Mg^{2+}, Cl^{-}, TA, TH were analyzed by titration methods. PO_4^{3-} , NH_3-N, NO_3^{-}, and SO_4^{2-} were analysed by spectrophotometer while Na^{+} and K^{+} by flame photometry. Heavy metals were analysed using atomic absorption spectroscopy. Microbiological analysis was performed using most probable number (MPN) method [202]. The results obtained were compared with the standards prescribed by Bureau of Indian Standards [210] and World Health Organization (WHO, 2008; 2017) as shown in *Table 6.1*. The brief procedure for analysis of physico-chemical parameters, heavy metals and microbiological analysis is as described in Chapter 5, section 5.2.2.

Table 6.1: Drinking water quality standards as per BIS (2012) and WHO (2008; 2011; 2017)

Parameters	**BIS (2012)**		**WHO (2008; 2011; 2017)**
	Desirable Limit	**Max. Permissible Limit**	**Desirable Limit**
Odor	Unobjectionable	Unobjectionable	-
pH	6.5-8.5	No Relaxation	6.5-9.2
EC	300	-	300
TDS (mg/l)	500	2000	500
Total Hardness(mg/l)	200	600	300
Magnesium(mg/l)	30	-	150
Calcium(mg/l)	75	200	100
Ammonical Nitrogen(mg/l)	0.5	No Relaxation	-
Nitrate(mg/l)	45	No Relaxation	10
Chlorides(mg/l)	250	1000	200
Fluoride(mg/l)	1	1.5	1.5
Total Alkalinity(mg/l)	200	600	-
Sodium(mg/l)	-	-	200
Potassium(mg/l)	-	-	-
Sulphate(mg/l)	200	400	200
Phosphate(mg/l)	-	-	-
Copper(mg/l)	0.05	1.5	2
Zinc(mg/l)	5	15	3.0
Lead(mg/l)	0.01	No Relaxation	0.01
Cadmium(mg/l)	0.003	No Relaxation	0.003
Nickel(mg/l)	0.02	No Relaxation	0.07
Chromium(mg/l)	0.05	No Relaxation	0.05
Coliforms	Must not be detectable in 100 ml sample	-	0

[210]

6.2.3 Water Quality Index

Formation of public policy and implementation of the water quality improvement programs requiresaccurate information on quality of water. Water quality index (WQI) is a method of rating of existing water quality status in a single expression which is helpful for selection of treatment techniques [120]. WQI provides information about the water quality in a single value. WQI utilizes the water quality data and helps in modification of the policies formulated by the environmental agencies [186]. It represents the assessment of water quality through determination of physico-chemical and biological parameters of ground water [82]. WQI was initially developed by Horton [86-87] and after that concept has been modified by many scientists and researchers [86-87, 33, 186]. A general approach for determination of WQI includes parameter selection wherein these parameters are selected based upon their impact on water quality. Once the parameters are fixed, determination of sub-indices of these parameters is quantified which are finally aggregated using an aggregate indexing method by means of different mathematical expressions [186, 120] and are explained as:

Parameter selection

The selection of parameters is carried out by judgement of professional experts, government institutions and agencies. The selection of variables is divided into five major classes: oxygen level, physical characteristics and dissolved substances, eutrophication level and health aspects depending upon the impact these parameters have on water quality [215].

Determination of Sub-index

The quality function in form of curves for each parameter is considered as the sub-index. These sub-indices transform to non-dimensional scale values from the variables of its different units [186].

Aggregation of sub-indices

Aggregation of sub-indices is done using mathematical expressions and frequently utilized through arithmetic or geometric averages.

The different variables and the sub-indices used for different parameters were taken from reference tables [186] as given in *Table 6.2* for the present study.

For the considered different parameters, variations of sub-indices are generally assumed as **uniformly decreasing**

$$s = \left(1 + \frac{q}{qc}\right)^{-m} \qquad (6.1)$$

Where; q = quality variable;

q_c = characteristic value of q;

m = a positive number

and

Unimodal

$$s = pr + (n + p)(1 - r)\left(\frac{q}{q_*}\right)^{n} \div p + n(1 - r)\left(\frac{q}{q_*}\right)^{n+p} \qquad (6.2)$$

Where; r = sub-index for q=0;

n and p=exponents

Table 6.2: Quality Variables and their sub-indices

Water quality variables (q)	**q_i**	**M**	**q_c**	**q_r**	**q_***	**n**	**P**	**R**	**Sub-index (S_i)**
Coliforms (MPN/100ml)	10	0.3	4	-	-	-	-	-	0.69
Nitrate (mg/l)	5.0	3.0	40	-	-	-	-	-	0.70
Phosphate (mg/l)	0.6	1.0	0.7	-	-	-	-	-	0.53
Turbidity (JTU)	6.0	1.5	50	-	-	-	-	-	0.84
5 day BOD(mg/l)	4.0	3.0	20	-	-	-	-	-	0.58
Aluminum (mg/l)	0.15	-	-	0.2	-	-	-	-	0.59
Arsenic (mg/l)	0.04	-	-	0.05	-	-	-	-	0.52
Cadmium (mg/l)	0.0003	-	-	0.0005	-	-	-	-	0.78
Chromium (mg/l)	0.035	-	-	0.05	-	-	-	-	0.66
Copper (mg/l)	0.04	-	-	0.05	-	-	-	-	0.52
Cyanide (mg/l)	0.03	-	-	0.05	-	-	-	-	0.78
Iron (mg/l)	0.05	-	-	0.1	-	-	-	-	0.89
Lead (mg/l)	0.4	-	-	0.05	-	-	-	-	0.52
Manganese (mg/l)	0.03	-	-	0.05		-	-	-	0.78
Mercury (mg/l)	0.0005	-	-	0.01	-	-	-	-	0.89
Selenium (mg/l)	0.007	-	-	0.01	-	-	-	-	0.66
Zinc (mg/l)	3.0	-	-	5.0	-	-	-	-	0.78
Dissolved oxygen (mg/l)	0.75	-	-	0.01	1.0	3.0	1.0	-	0.87
Fluoride (mg/l)	1.3	-	-	5.0	1.0	4.0	4.0	0	0.62
pH	8.0	-	-	-	7.0	4.0	6.0	0	0.80
Temperature (◦c)	24	-	-	-	20	0.5	7.0	0	0.92
Total Solids (mg/l)	150	-	-	-	25	1.0	1.0	0.8	0.89

Where, q= quality variable; q_c= characteristic value of q; m= a positive number; n= sub-index number; SI= sub-index of ith parameter; q_r and q_*= variables. (Source:-reference table from Swamee and Tyagi, 2005; 2007)

Different methods for determination of WQI have been formulated including those proposed by National Sanitation Foundation Water Quality Index (NSFWQI), Weight Arithmetic Water Quality Index (WAWQI), Oregon Water Quality Index (OWQI), WQI as per BIS 10500, Canadian Council of Ministers of the Environment Water Quality Index, Stream Health Index (SHI) and Sustainable Information Network, 2005 [137]. These indices are often based on the varying number and types of water quality parameter as compared with the respective standards of the particular areas [186]. Aggregating index method is used for identifying effects of municipal solid waste leachate on ground water quality and [118-120] provides most reliable results for indexing.An improved aggregate index method as given by [120] is flexible and allows the inclusion of additional water quality parameters and provides consistent results for the overall index irrespective of the number of parameters selected.

In the present study, WQI is determined using two methods viz., Oregon water quality index (OWQI) and BIS 10500 standards.

Oregon Water Quality Index (OWQI)

OWQI was developed in 1970s which is a simple and concise method for expressing the ambient water quality [215-216]. It is also useful for indicating damage of water quality and progress of water quality management practices.

The mathematical expression of the WQI method as per OQWI is given by:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI2}}} \quad (6.3)$$

The water quality rating evaluated by Oregon water quality index is given in *Table 6.3*.

Table 6.3: Water quality rating as per OWQI

WQI Value	Rating of water quality
90-100	Excellent water quality
85-89	Good water quality
80-84	Fair water quality
60-79	Poor water quality
0-59	Very poor water quality

Water Quality Index- BIS 10500

Determination of WQI as based on the BIS 10500 standards was determined by assigning weights (w_i) according to the relative importance of each chemical parameter for drinking purposes and has been summarized in *Table 6.4* [61]. The parameters like chloride, nitrate, total solids, ammonical nitrogen, sulphate, fluorides and electrical conductivity has been assigned maximum weightage of 5 because of their high significance in maintaining quality of ground water [61]. Other determined parameters like calcium, magnesium, total hardness and total alkalinity were assigned weight between 1 and 5 depending on their importance in water quality assessment. The relative weight (W_i) is computed (Table 6.4) using following equation:

$$W i = \frac{wi}{\sum_{i=1}^{n} wi} \tag{6.4}$$

Where; W_i= relative weight

w_i =weight of each parameter, n= number of parameters

A quality index (q_i) based on the parameters were computed by dividing the concentration of each water sample by its respective standard as assigned by BIS 10500 and multiplying the result by 100:

$$qi = \frac{Ci}{Si} \times 100 \tag{6.5}$$

Where; q_i=quality rating based on concentration of the i^{th} parameter

C_i= concentration of each parameter (mg/l), S_i= Indian drinking water standard

For computing WQI, SI is first determined for each parameter:

$$SI = W_i \times q_i \tag{6.6}$$

Where; SI= sub-index of the i^{th} parameter

WQI is then determined using following equation:

$$WQI = \sum SI \tag{6.7}$$

As per the BIS 10500, the water quality index values, the water can be classified into five categories i.e., excellent water (<50); good water (50-100); poor water (100-200); very poor water (200-300); and water unsuitable for drinking purposes (>300).

Table 6.4: Relative weight of chemical parameters for calculating WQI based on BIS 10500 for Tricity

Chemical Parameters	BIS (mg/l)	Weight (w_i)	Relative weight (W_i)
TDS	500	5	0.1
NH_3-N	0.5	5	0.1
SO_4^{2-}	200	5	0.1
TH	300	4	0.08
$Ca2^{+}$	75	4	0.08
Mag^{2+}	30	3	0.06
TA	200	4	0.08
NO_3^{2-}	45	5	0.1
Cl^{-}	250	5	0.1
EC	300	5	0.1
F^{-}	1	5	0.1
		Σw_i=50	**ΣW_i=1**

Both Oregon water quality index and WQI as per BIS 10500 creates a score which helps to evaluate the water quality by combining the various water quality variables into a single number hence making it easier to categorize the water quality parameters [216, 120].

6.2.4 Multivariate Analysis

Multivariate statistical analysis are often used in environmental monitoring or modeling dataset applications for reducing dimensionality and biasness that will be helpful for the assessment of the data. These statistical tools help in classification, modelling and interpretation of large data sets and allow the reduction of data in the form of extraction of data which will be helpful for the water quality assessment [61, 182]. It further helps in understanding huge data sets from environmental monitoring programs giving more quantitative and independent approach of ground water samples by making correlations between chemical parameters and ground water samples [167, 217]. Multivariate analysis provides unbiased methods to detect the associations between the samples or variables using standardized data. In this study, two multivariate statistical methods were applied viz., Principal component analysis (PCA) and Hierarchical cluster analysis (HCA) using IBM-SPSS statistics V 22.0. Such associations (PCA and HCA) among physico-chemical variables, based on similar magnitudes and variations in chemical and physical compositions may reveal the various effects on ground water [61, 217].

Fifteen parameters include pH, total solids, ammonical nitrogen, phosphate, turbidity, biochemical oxygen demand (BOD), sulphate, total hardness (TH), calcium, magnesium, total alkalinity, nitrates, chlorides, fluorides and electrical conductivity (EC). PCA and HCA have been broadly used as they are balanced methods which can indicate natural associations between samples or variables [60-62]

Principal components analysis (PCA)

Principal component analysis is a variable reduction procedure which is used when variables are correlated with one another. The principal component analysis (PCA) is a procedure which identify the small variables from a large set of data which are called ‘principal components’ for analyzing relationships among the observed variables [60-62, 90]. This analysis helps in explaining the maximum amount of variance. PCA extracts the Eigen values and Eigen vectors from the covariance matrix of the original variables. The principal components thus derived are obtained by multiplying the correlated variables with the Eigen vectors or the loadings. Eigen values of these principal components are attained by measuring the associated variance, loadings of the original variables in principal components and the individual transformed observations called the scores [60-62]. The principal components with Eigen values more than unity are retained. It helps in identification of source of pollutants [182] and also used to reduce the data [167,217]

Hierarchical cluster analysis (HCA)

The goal of cluster analysis is to reduce the number of data by combining the variables with similar characteristics. Clustering of the variables is done with the correlation distance measure, linkages and formation of dendogram. Hierarchical cluster analysis (HCA) is one statistical tool which groups the similar pair of correlation in a large symmetric matrix. HCA provide the logical and pair-by pair comparison between various chemical constituents. HCA is the most common and widely used multivariate statistical analysis method in environmental studies [61] as it indicates groupings of samples by ranking or linking inter-sample similarities in data set, creating a cluster tree or dendogram [138]. The assumption for

HCA techniques includes equal variance and normal distribution of the variables. The classification of the water samples based on their parameters is termed as Q-mode classification as a single parameter is rarely sufficient to distinguish different water types. The individual samples are compared based on the similarities and linkage methods are then grouped into clusters. The linkage technique used in the study is Ward's method [218]. Ward method uses analysis of variance (ANOVA) approach to evaluate the distances between the clusters and also helps in calculating the sum of distance from each individual to the center of its parent group. The linkage method forms a link between the samples with similar characteristics. This clustering helps in deciding the level or scale of clustering that is most appropriate for the particular study. Unlike PCA that normally uses only two or three components for display purposes, HCA uses all the information contained in the original data set.

6.3 Results and Discussion

6.3.1 Ground water Characteristics

The physico-chemical characteristics of the ground water samples collected from Chandigarh, Mohali and Panchkula are described in *Table 6.5*. The analytical results are described in this section one by one. Obtained results were also compared to the WHO and BIS standards for drinking water quality (Table 6.1). The results of all the parameters are symbolized as (a) for Chandigarh, (b) for Mohali and (c) for Panchkula respectively.

Physico-chemical Parameters

Temperature

The temperature of ground water samples from Chandigarh, Mohali and Panchkula varies from 19-27.8°C during all the monitoring campaign with an average of 23.2°C for Chandigarh, 23.3°C for Mohali and 23.4°C for Panchkula.

pH

The water quality is greatly dependent on pH as it is affected by the change in chemical and biological properties of water. Very low values of pH will cause rusting and corrosion of pipes while very high values of pH can impart taste similar to that of baking soda to the water samples. The average pH values for all the ground water samples from Chandigarh, Mohali and Panchkula at various distances were 7.7, 7.8 and 7.1 respectively as shown in *figure 6.2*. The pH values of samples observed are in near neutral range [210]. High value of pH in ground water samples can be owed to the landfill utilization for a long time approximately 25 years and generation of stabilized and matured leachate [41].

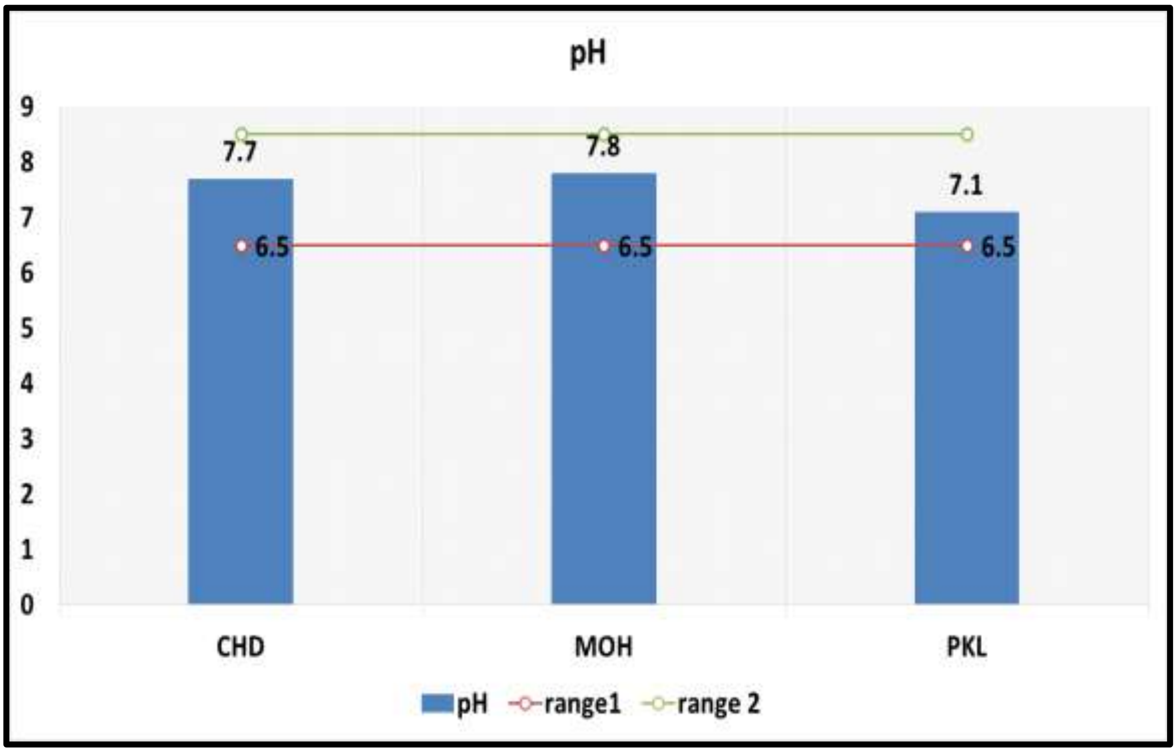
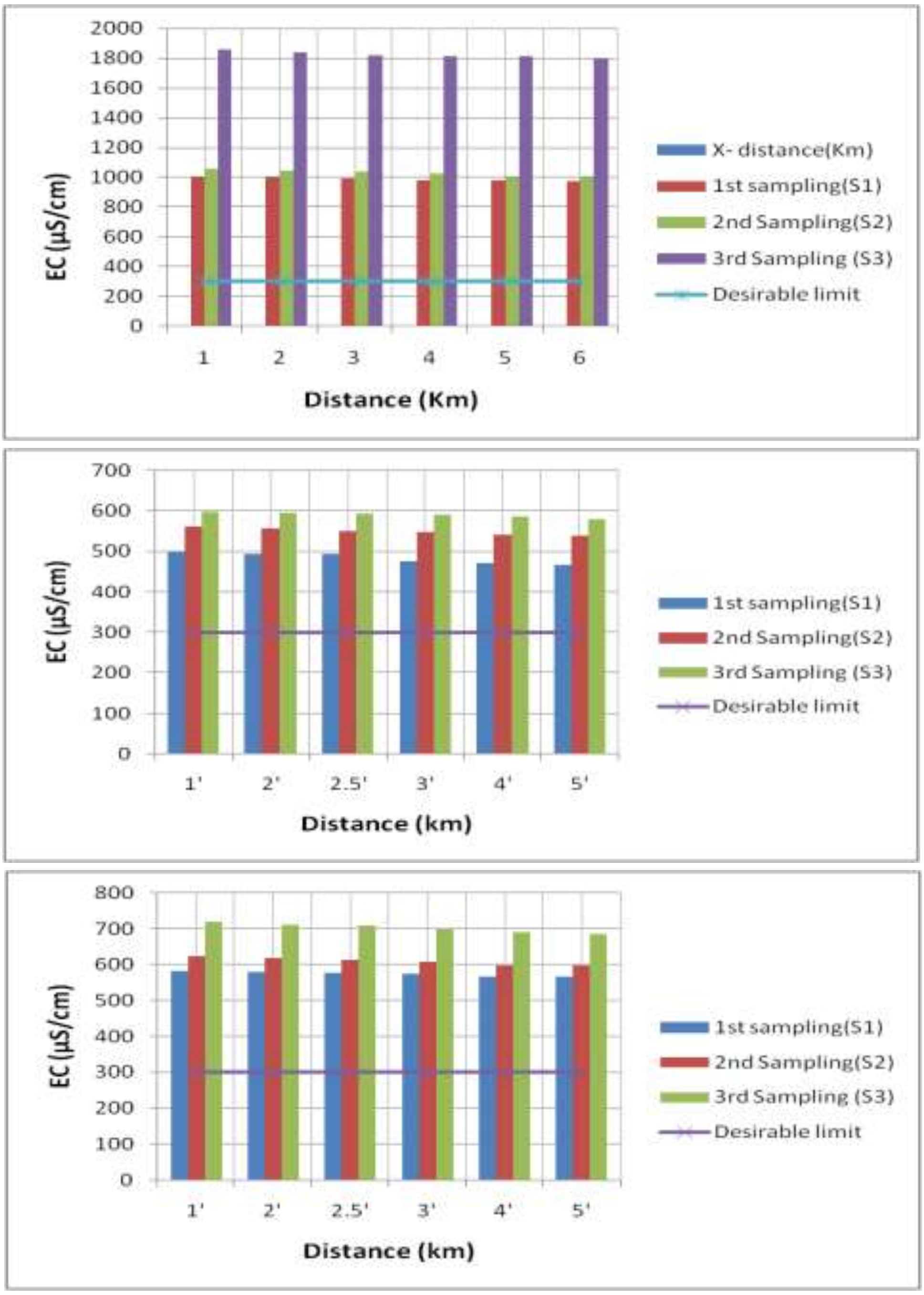


Figure 6.2: Average pH values of ground water samples from Chandigarh, Mohali and Panchkula

Electrical Conductivity (EC)

Electrical conductivity ranges from 976-1861 µS/cm in Chandigarh, 466.6-593.6 µS/cm in Mohali and 566.7 -713 µS/cm in Panchkula as shown in *figure 6.3*. High conductivity values in all the samples specify the substantial amount of dissolved ions due to contamination from the leachate [16, 217]. The water samples fall under the class of medium to high saline range.



(a)

(b)

(c)

Figure 6.3: EC concentrations of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkula at different distances over entire monitoring period

Total Dissolved Solids

Total dissolved solids (TDS) are defined as amount of inorganic and some part of organic materials which are present in water [202, 210]. TDS aids in determining the salinity and general quality of water. Average concentration of TSS in all the samples from Chandigarh, Mohali and Panchkula were found to be 710 mmho/cm, 600 mmho/cm and 455 mmho/cm respectively as represented in *figure 6.4*. High TDS values were reported in almost all the samples of ground water from all the three cities. Very high and very low values of TDS are objectionable for drinking purposes [83, 107].

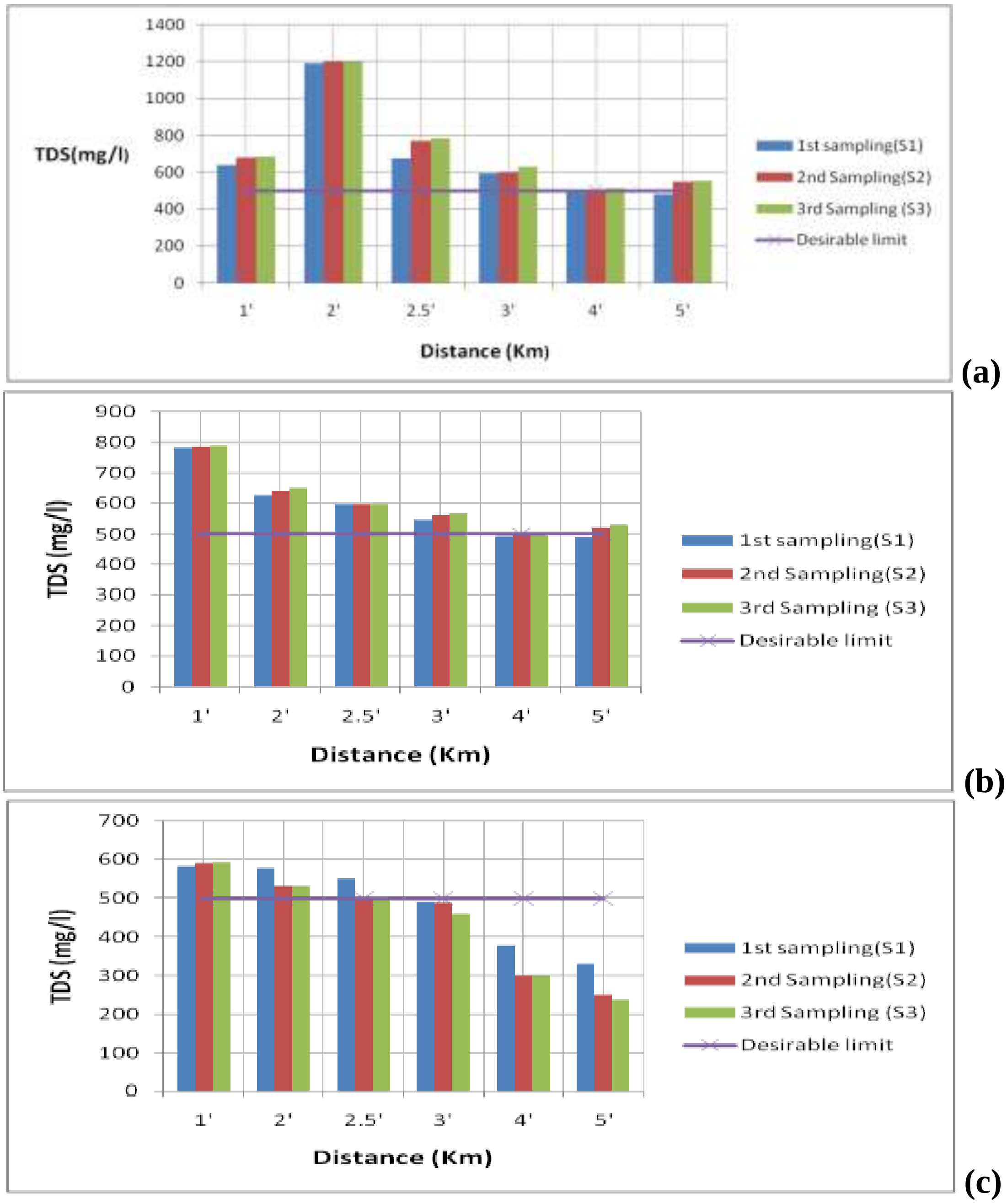
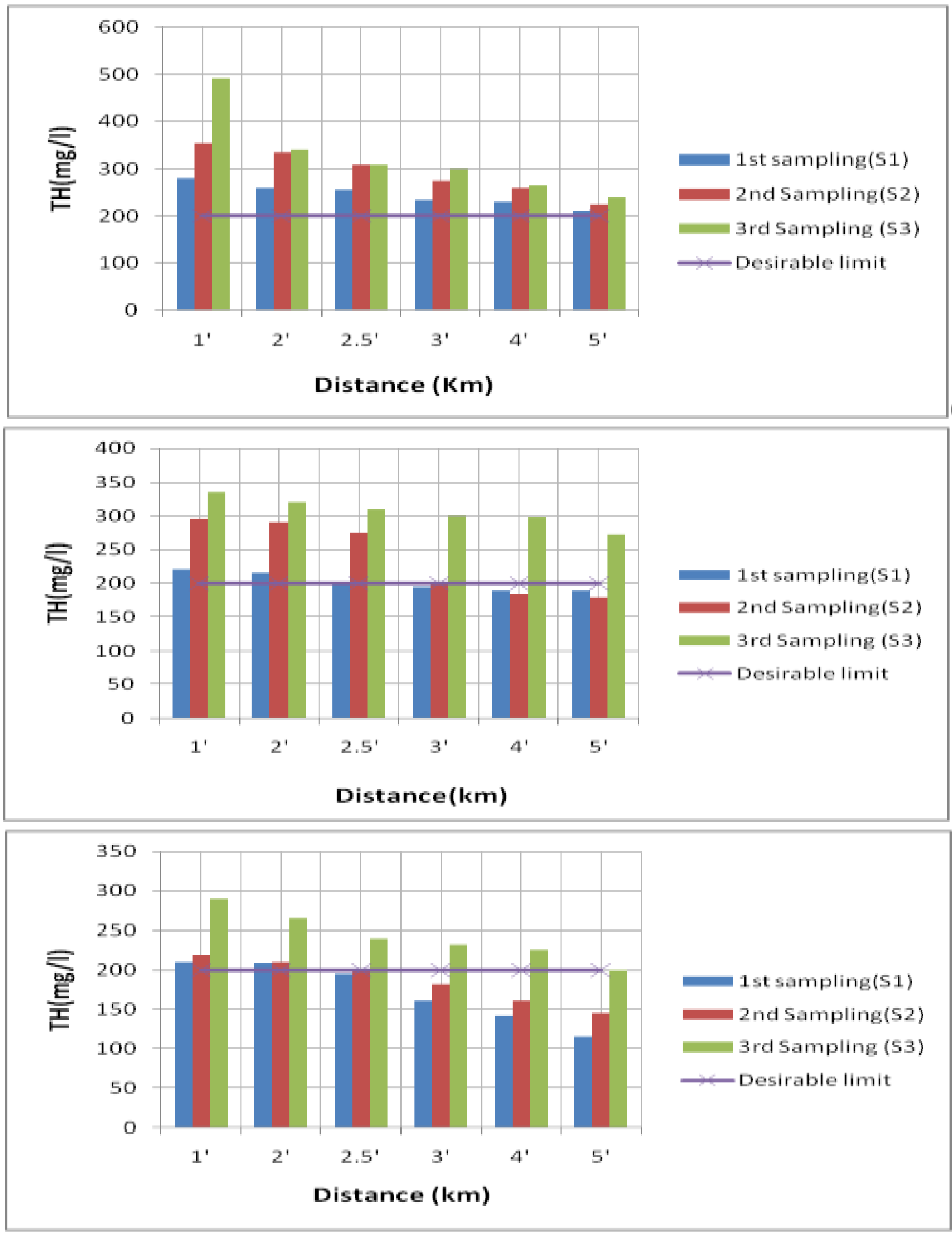


Figure 6.4: TDS concentrations of ground water samples (a) Chandigarh, (b) Mohali and (c) Panchkula at different distances over entire monitoring period

Total Hardness (TH)

Hardness of samples varies from 142 – 492 mg/l. Many samples of ground water from Chandigarh and Mohali areas shows that source water is ‘Very Hard’; above 300 mg/L of $CaCO_3$ (WHO 2008; BIS 10500, 2012) as represented in *figure 6.5*. All other ground water samples are ‘Moderately Hard’; lie between 75-150 mg/L of $CaCO_3$ [210]. Higher values of hardness in water samples can cause the scaling in clothes during washing and also increases the wear and tear of textiles.



(a)
(b)
(c)

Figure 6.5: TH of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkula at different distances over entire monitoring period

Calcium (Ca^{2+})

The average calcium values of ground water samples at various distances for Chandigarh, Mohali and Panchkula were 60 mg/l, 65 mg/l and 64 mg/l, respectively. Calcium was found above desirable limit in 40% of the total samples from Tricity as shown in *figure 6.6*. Studies [1, 14] have also detected high concentration of Ca^{2+} in ground water samples from the close vicinity of landfill and have reported the contamination of the ground water samples due to percolation of leachate.

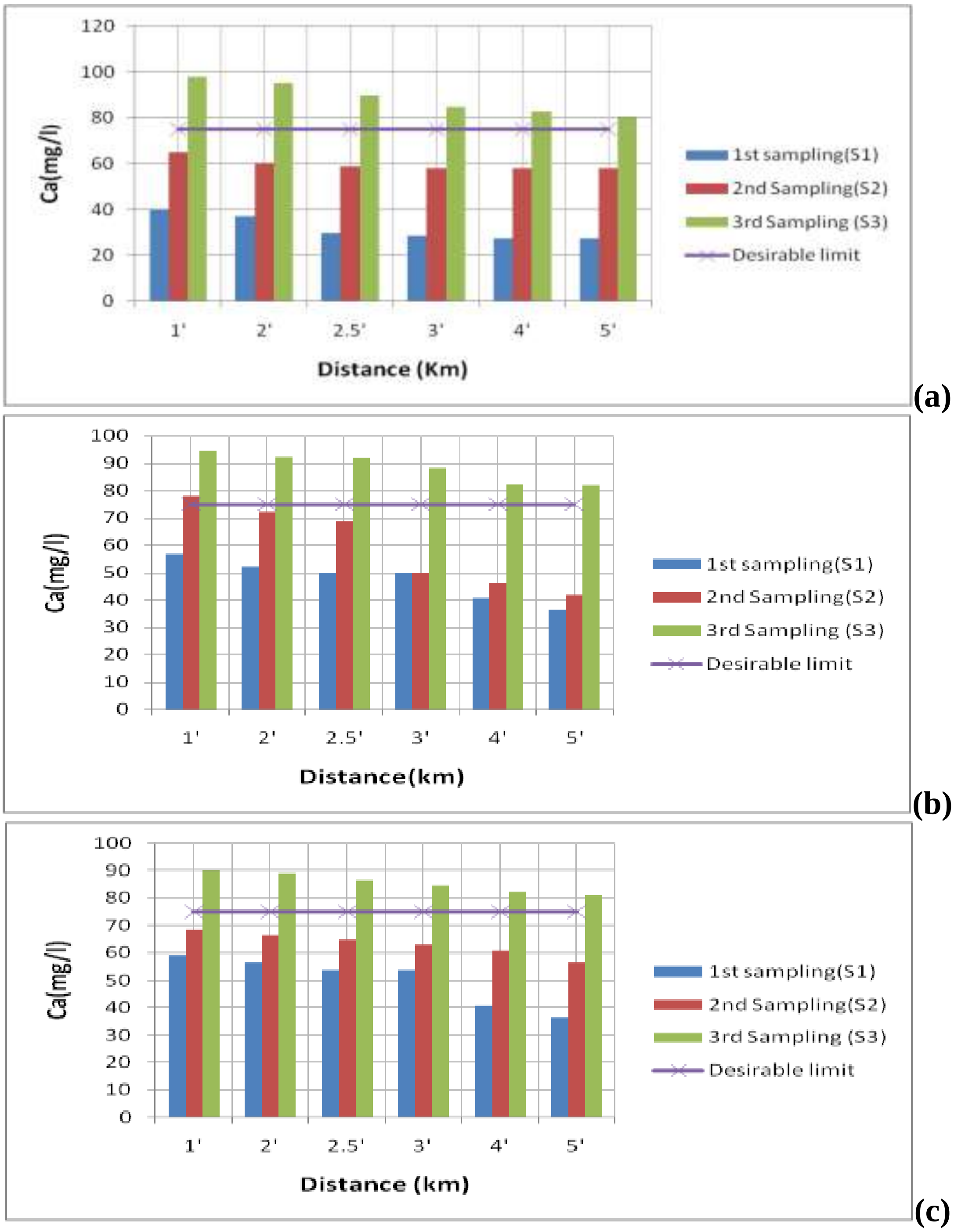


Figure 6.6: Calcium concentrationof ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

Magnesium (Mg^{2+})

Magnesium occurs as an enzyme activator in living beings and its insufficiency can lead to structural and functional damages however; its presence in higher values also could be toxic leading to diuretic and cathartic effect. The values of magnesium in ground water samples from Tricity vary from 61.6 to 96.1 mg/l throughout all the monitoring campaigns (*figure 6.7*).

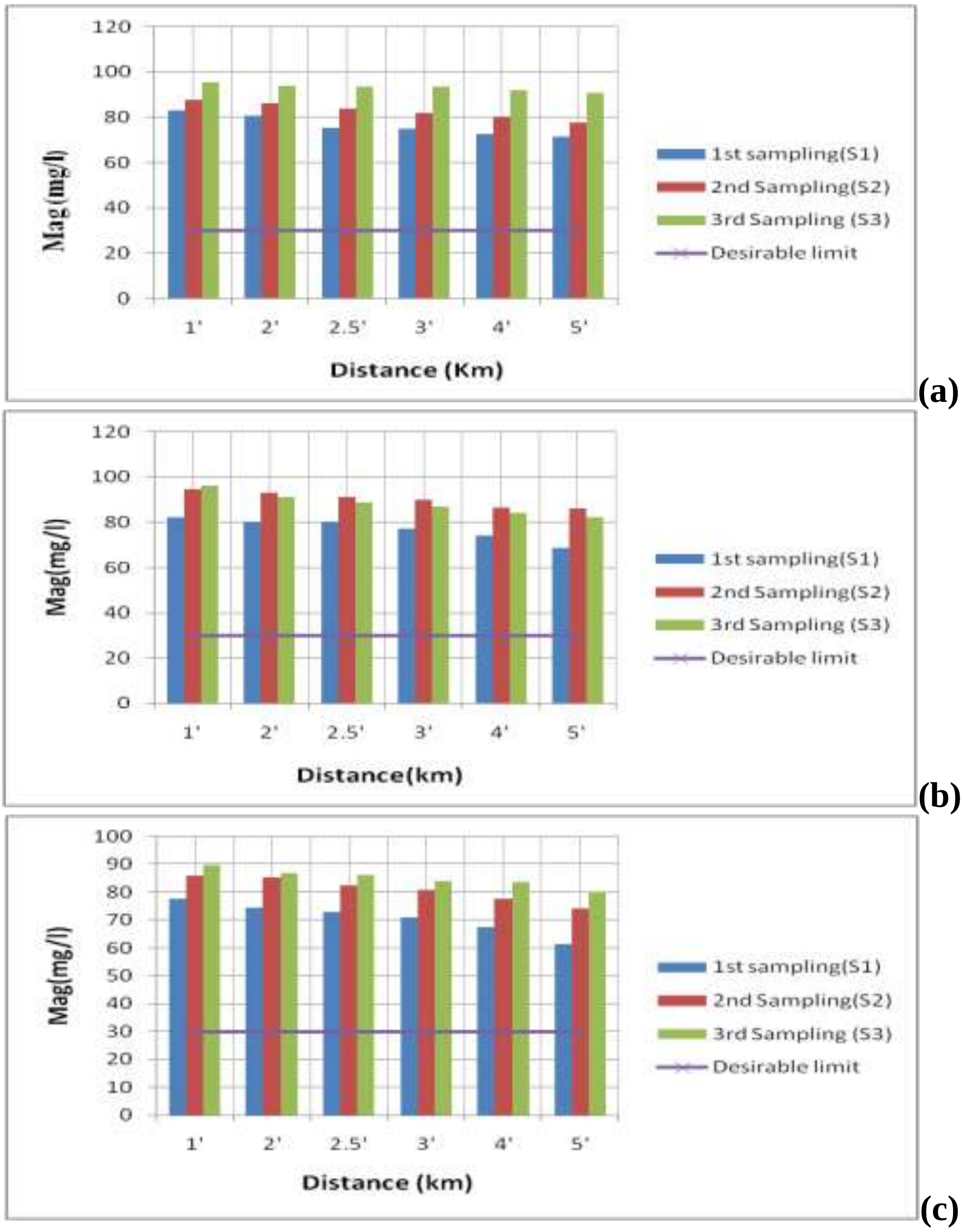
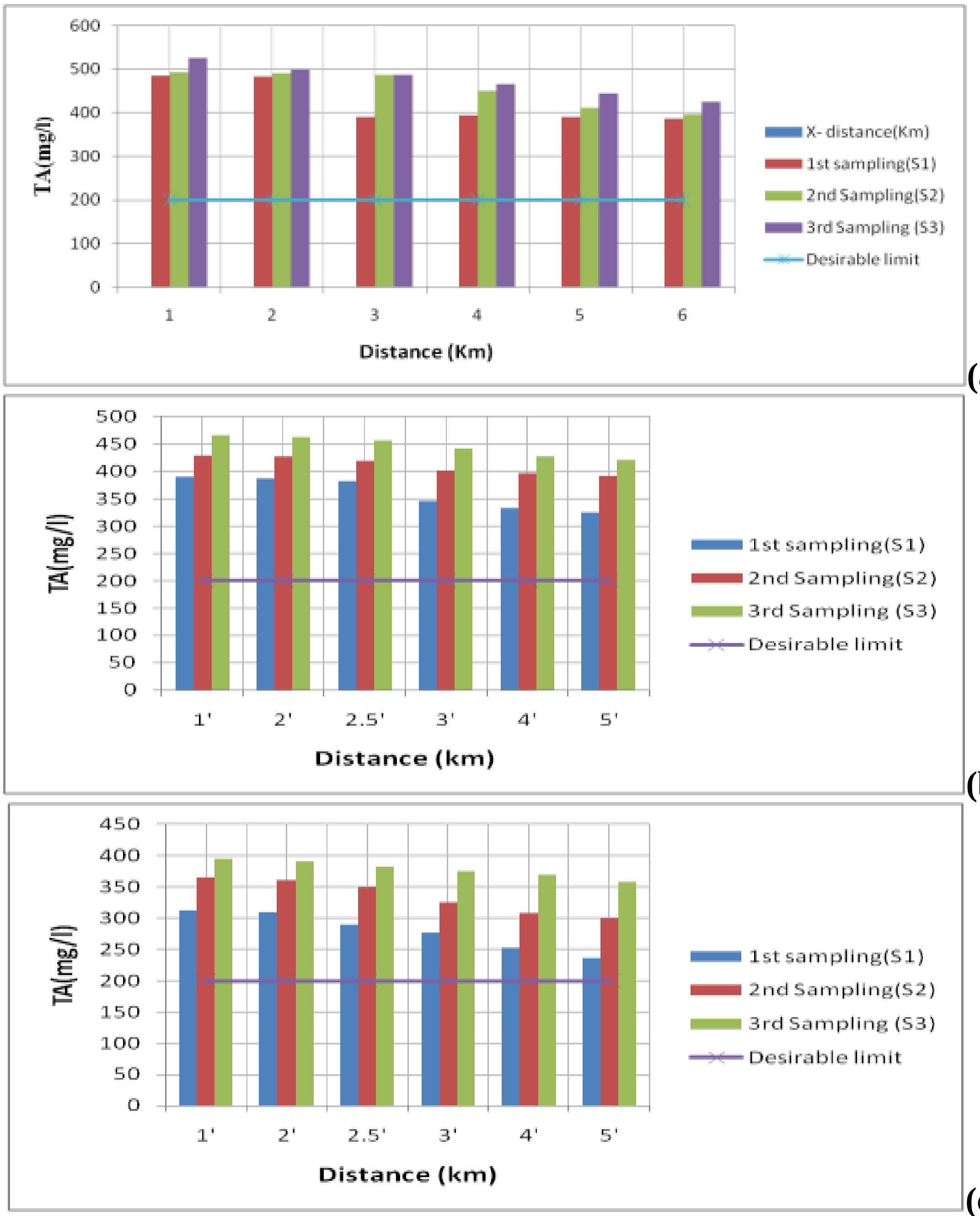


Figure 6.7: Magnesium concentrationof ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

Total Alkalinity (TA)

The average total alkalinity from all the three areas ranges from 331-450 mg/l. Reported values of alkalinity are more than the desirable limit in all the samples. *Figure 6.8* shows the values of total alkalinity in Tricity over all the monitoring campaign at various distances. Highly alkalinity and hardness in water are the two main parameters which affect the palatability of water. The samples with low alkalinity can be corrosive and can irritate eyes.



(a)
(b)
(c)

Figure 6.8: TA of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkula at different distances over entire monitoring period

Chlorides (Cl^-)

Values of chloride vary between 80-114.2 mg/l for Chandigarh, 80.8-111 mg/l for Mohali and 67.1-95.4 mg/l for Panchkula as represented in *figure 6.9*. The high occurrence of chlorides indicates the ground water pollution due to the percolation of domestic effluents, septic tanks [16]. The values of chloride were below the desirable limit as per [210] which is 250 mg/l. Chloride is considered as an conservative pollutant and is not affected by other biochemical processes [82].

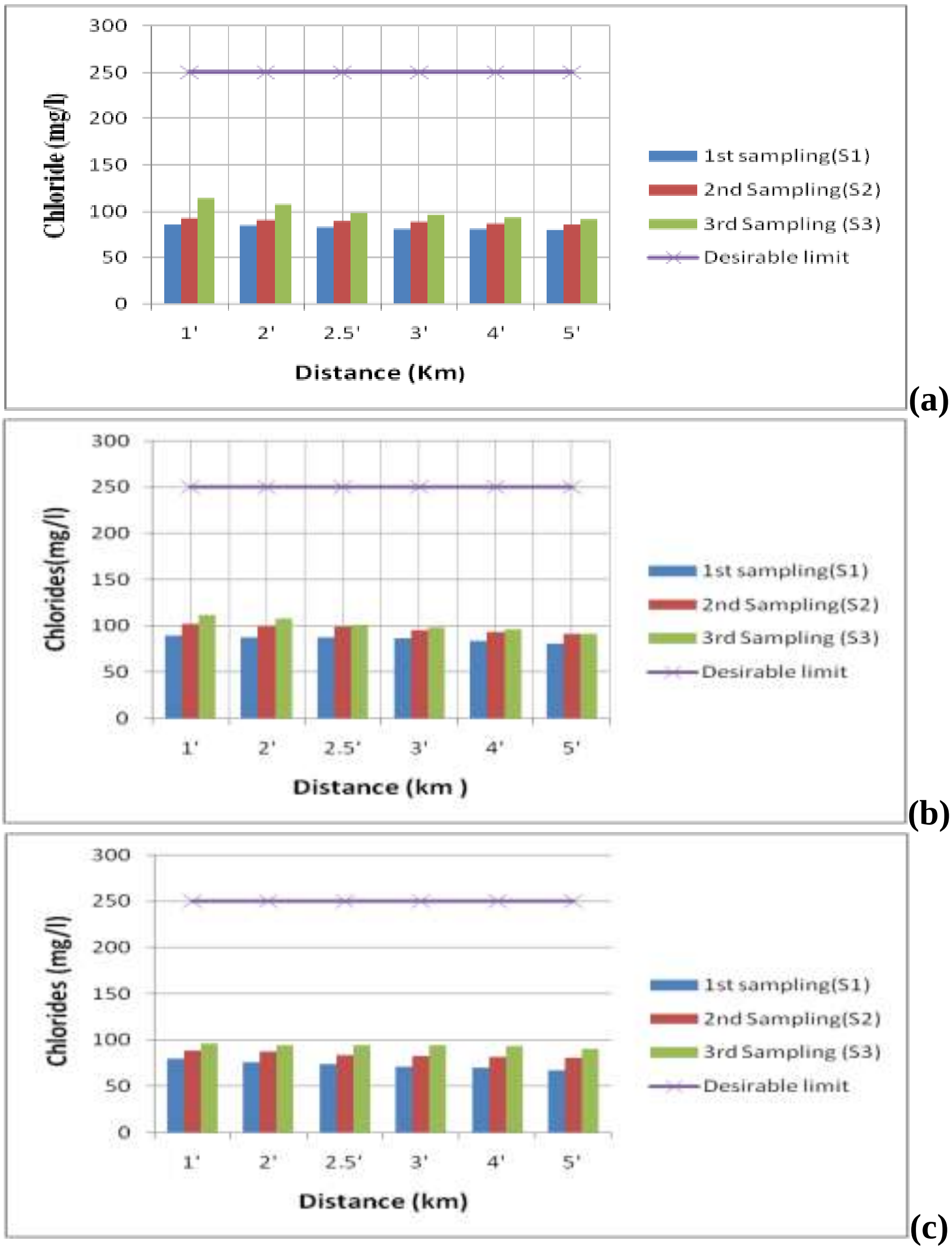
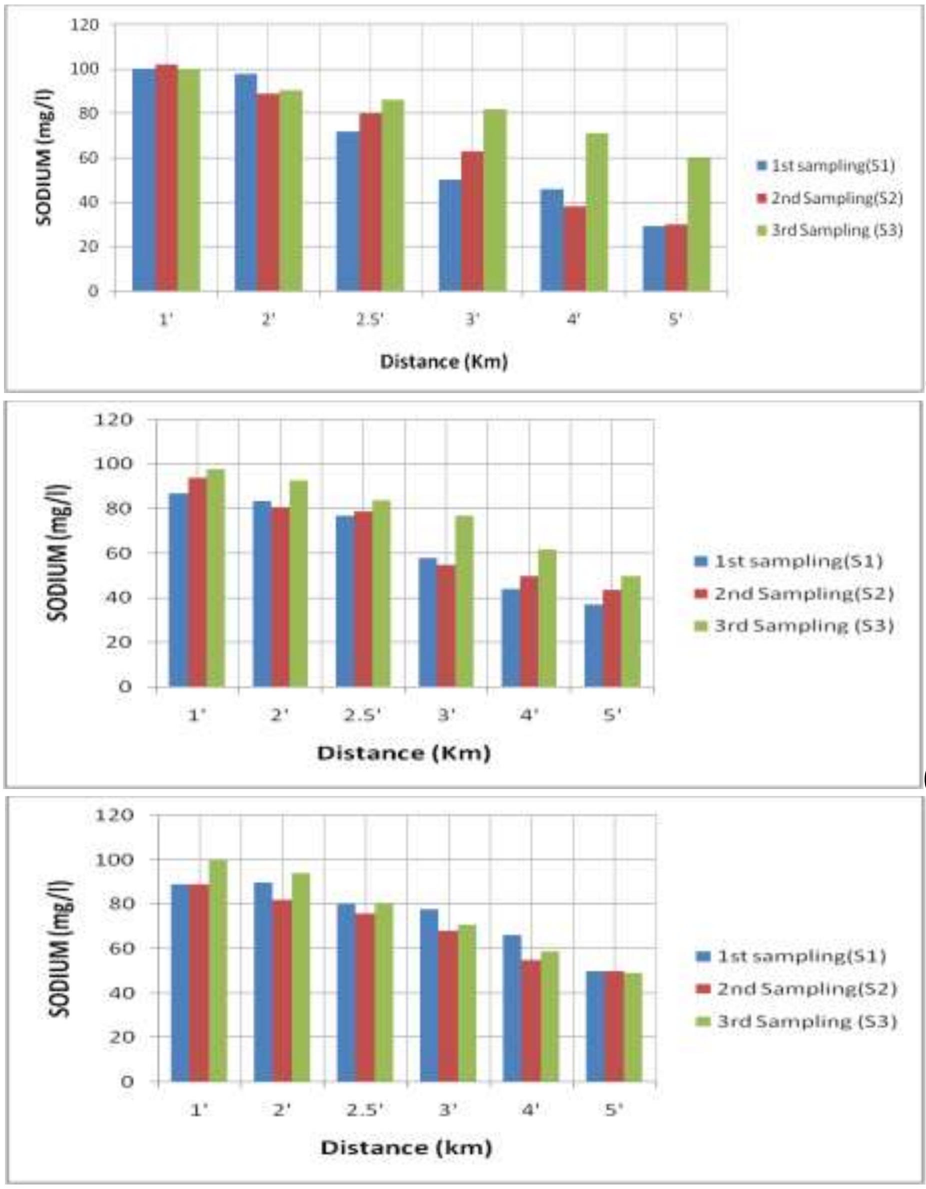


Figure 6.9: Chloride concentration of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

Sodium (Na^+) and Potassium (K^+)

Figure 6.10 and *6.11* shows the concentration of sodium and potassium, respectively during all the monitoring campaigns at different distances for Tricity. Sodium salts are not toxic substances but few studies have shown correlation between occurrences of hypertension in persons who consumed water having high concentration of sodium. Similarly, as potassium is found in very low concentrations in drinking water so far no guidelines have been proposed but it has been reported in few studies [82] that excessive concentrations of potassium may cause certain health effects like kidney malfunctions, cardiac problems and hypertension. Potassium ion is also considered as a tracer isotope for detecting contamination due to percolation of leachate in ground water [16].



(a)

(b)

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Figure 6.10: Sodium concentration of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

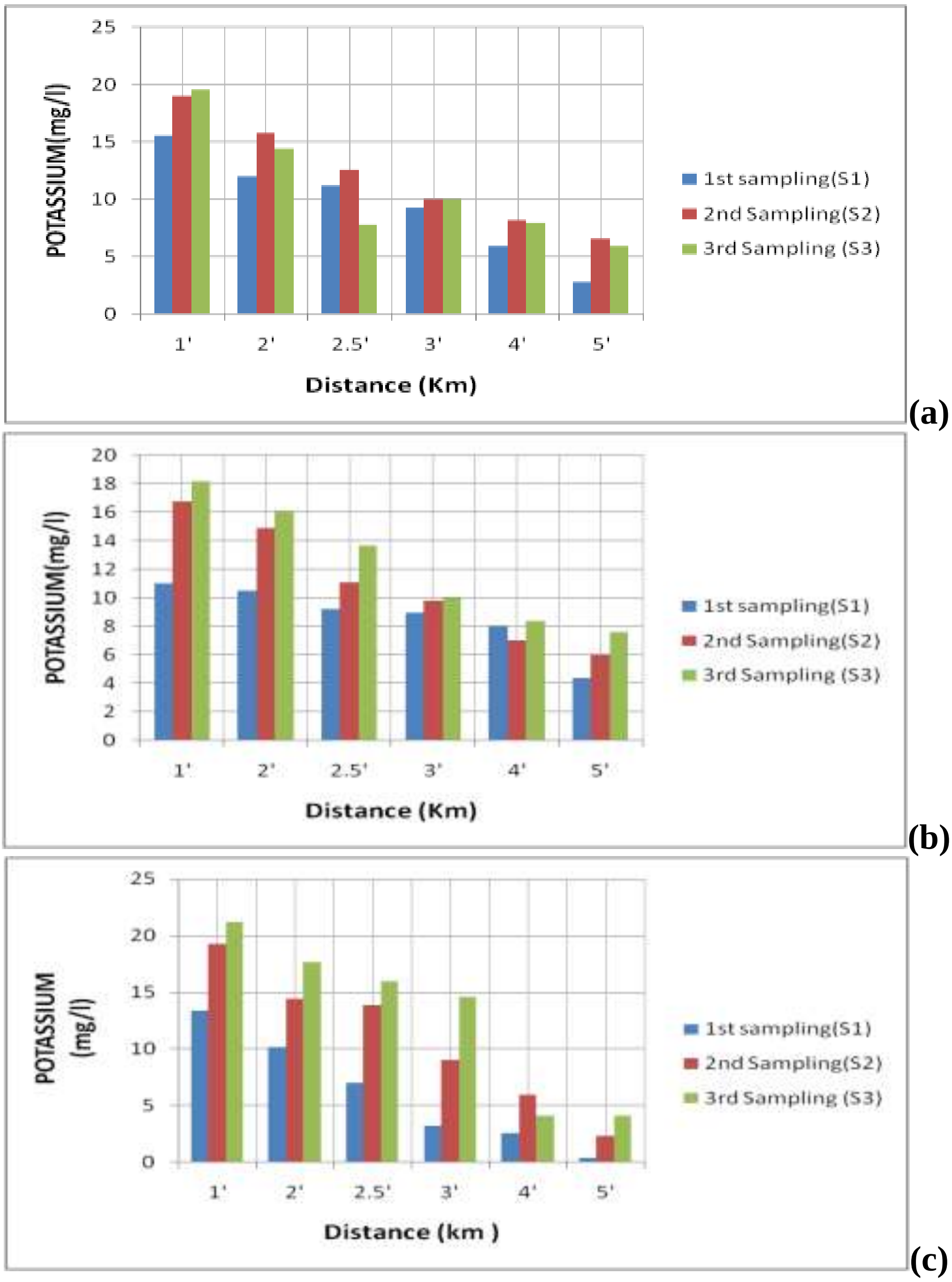
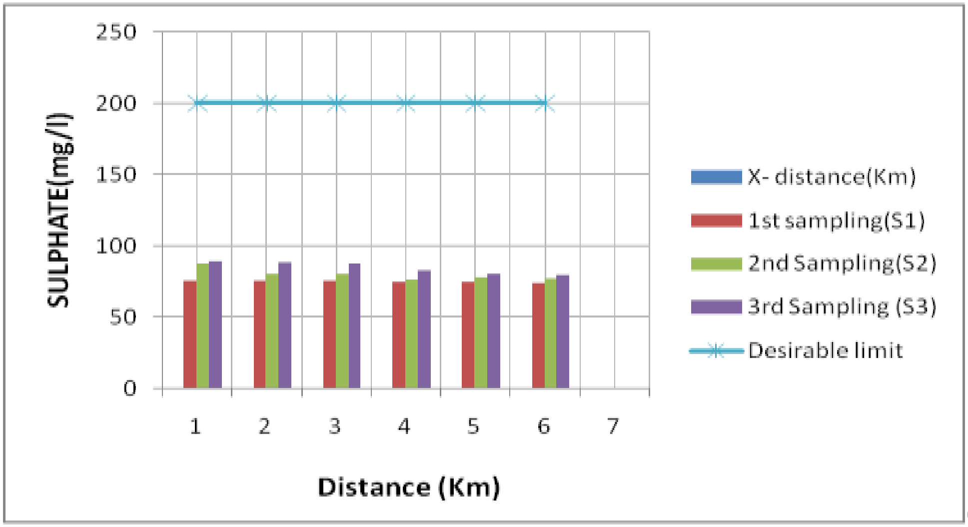


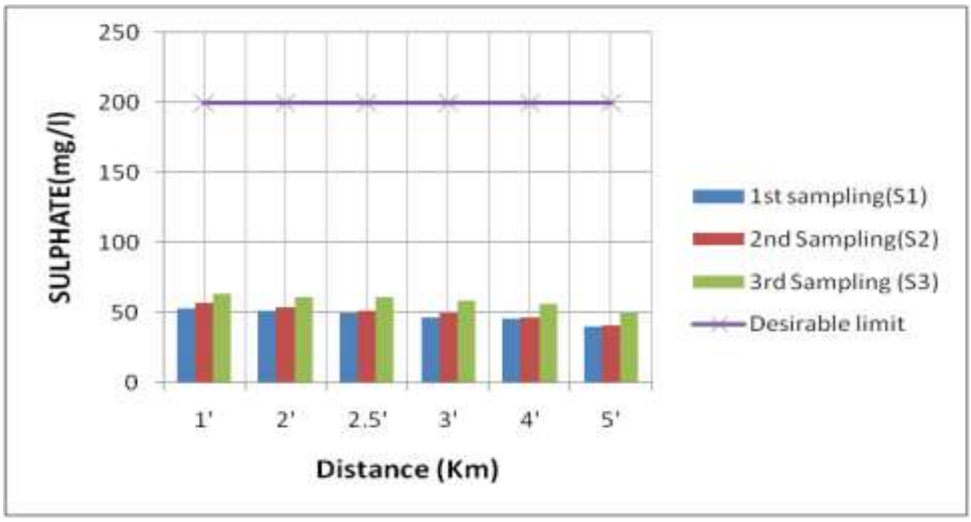
Figure 6.11: Potassium concentration of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

Sulphate (SO_4^{2-})

Concentration of sulphate ranges from 73.1- 89.1 mg/l for Chandigarh, 40.2-64 mg/l for Mohali and 30-59.9 mg/l for Panchkula which is much below than the WHO standard limit of 250mg/l as presented in *figure 6.12*. Higher concentrations of Sulphate can lead to biological corrosion and can cause dysentery in infants [180]. All the samples of ground water reported that sulphate was below the desirable limit as prescribed by BIS and WHO which was 200 mg/l for drinking purpose. Increased concentration of sulphate in drinking water may impart it a bitter medicinal taste making it unpleasant.



(a)



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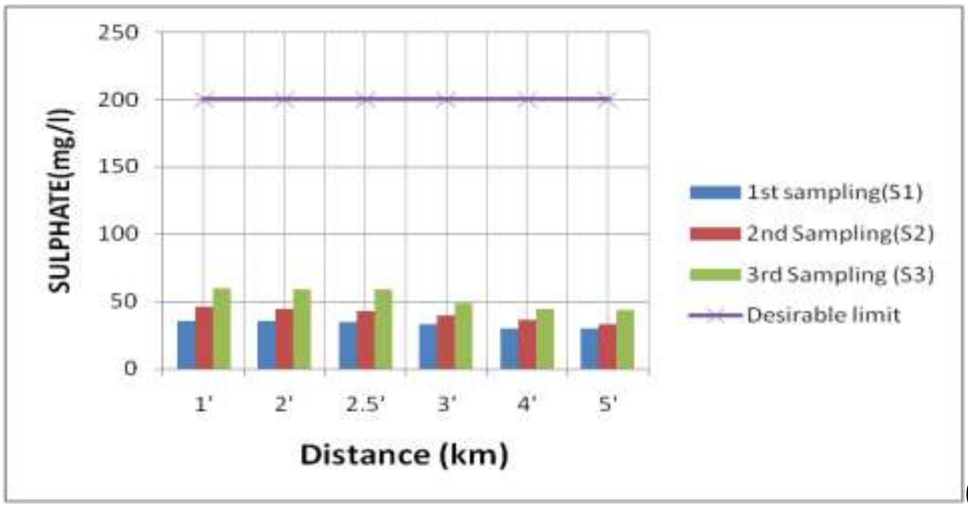


(c)

Figure 6.12: Sulphate concentration of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

Phosphate (PO_4^{3-})

Concentration of phosphate in ground water samples over the entire monitoring campaign in Chandigarh, Mohali and Panchkula varied from 0.001 to 0.99 mg/l. No guidelines have been proposed for phosphate in water.

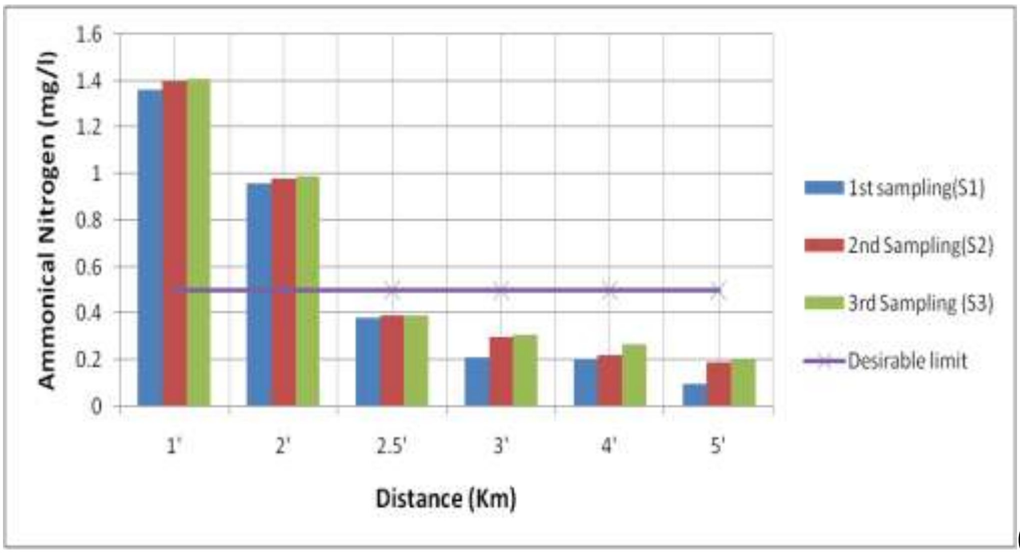
Fluoride (F^-)

The concentration of fluoride was reported to less than the desirable limit. Fluoride ranges from non- detected to 0.18 mg/l during all the monitoring campaign in Tricity.High values of fluoride in drinking water can cause dental and skeletal fluorosis [35, 110].

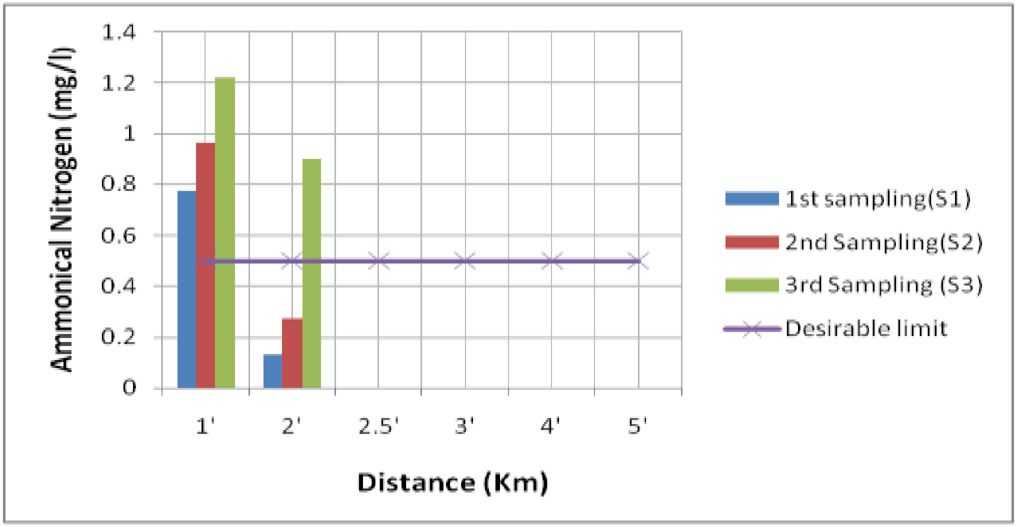
Ammonical Nitrogen (NH_3-N) and Nitrate (NO_3^-)

Organic contamination due to leachate was indicated by the presence of ammonical nitrogen. Average values of ammonical nitrogen range from 0.241-0.57 mg/l and were reportedly higher in ground water samples from Chandigarh and Mohali as shown in *figure 6.13* respectively. The presence of ammonical nitrogen can alter the taste and odor of drinking water and can lead to formation of nitrite as well. Studies [16, 161] have reported the presence of ammonical nitrogen in ground water samples near to the landfill sites due to anaerobic conditions which lead to production of ammonia.

The samples reported very low concentration of nitrate ranging from 8.37-10.2 mg/l, high concentration indicates the impact of leachate and may lead to methaemoglobinemia which is common among infants in which nitrate is reduced to nitrite and becomes toxic. Many researchers [75, 76] have reported nitrate is a highly oxidizable compound and is the end product of aerobic decomposition found in ground and surface water near the vicinity of landfill sites. The concentration of nitrate for Chandigarh, Mohali and Panchkula over the entire monitoring campaign is shown in *figure 6.14* respectively.



(a)



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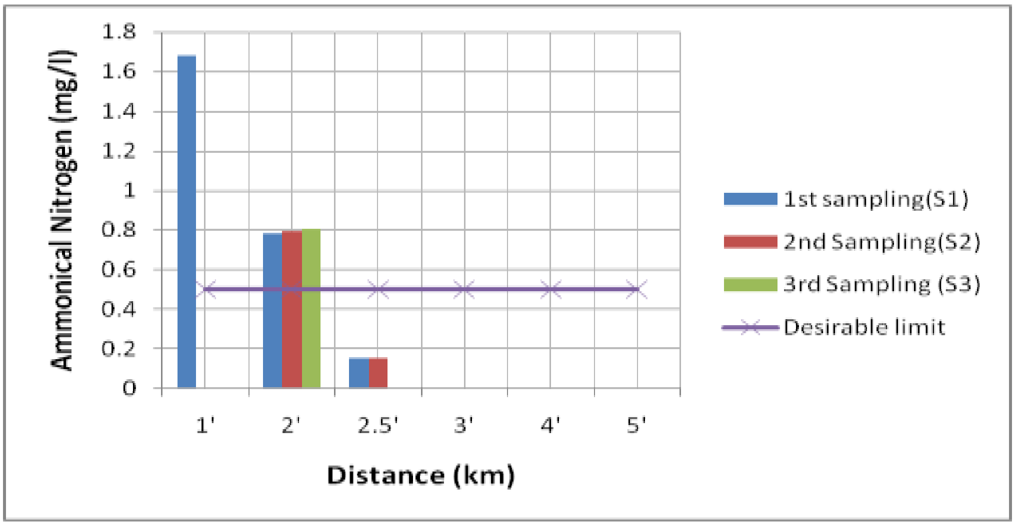


(c)

Figure: 6.13: Ammonical Nitrogen concentration of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

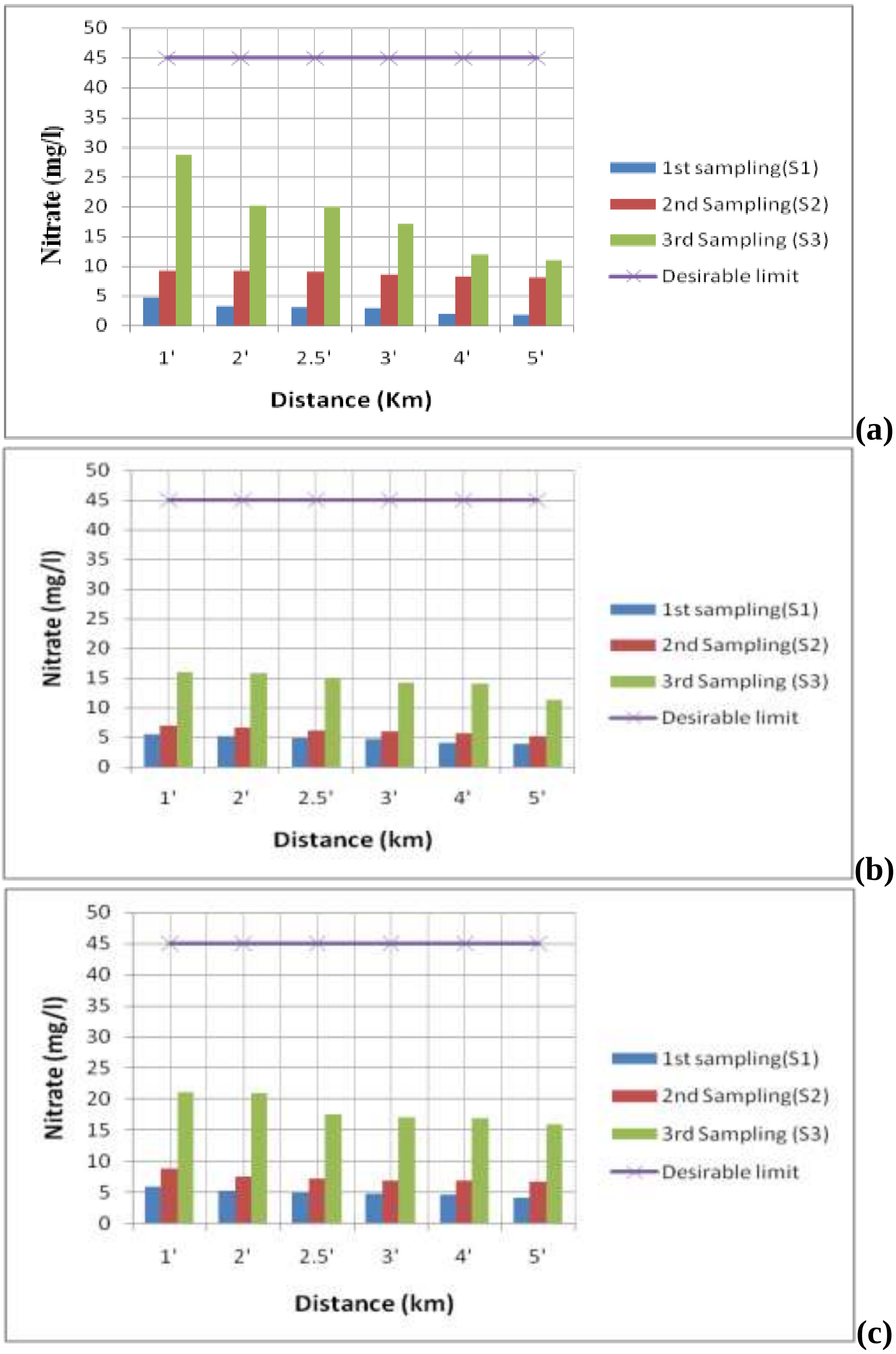
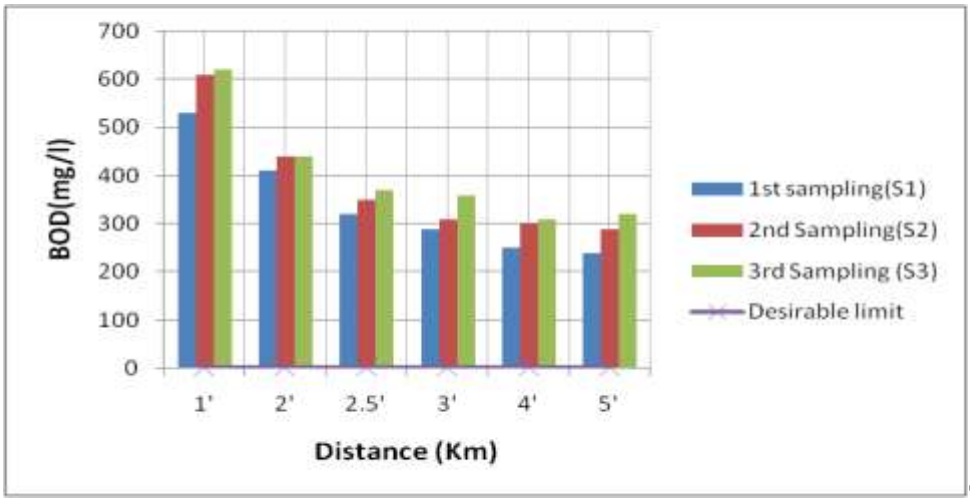


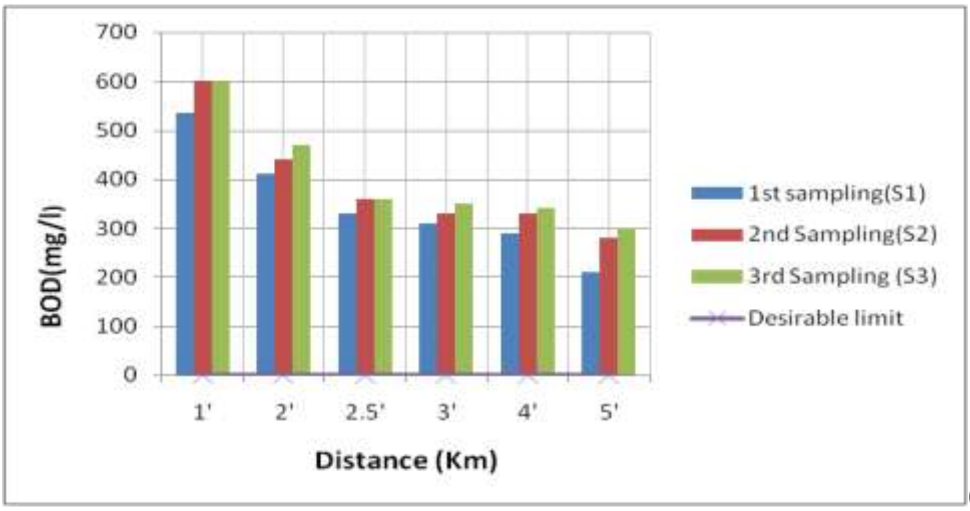
Figure 6.14: Nitrate concentration of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkulaat different distances over entire monitoring period

Biochemical oxygen demand (BOD)

Biochemical oxygen demand (BOD) determines the amount of organic pollutants present in the water [30]. BOD was reported in all the groundwater samples indicating the effect of percolation of leachate on the aquifer. *Figure 6.15* shows the concentration of BOD in ground water samples of Chandigarh, Mohali and Panchkula. The presence of BOD in ground water samples in the vicinity of landfills have also been reported in various studies [7].



(a)



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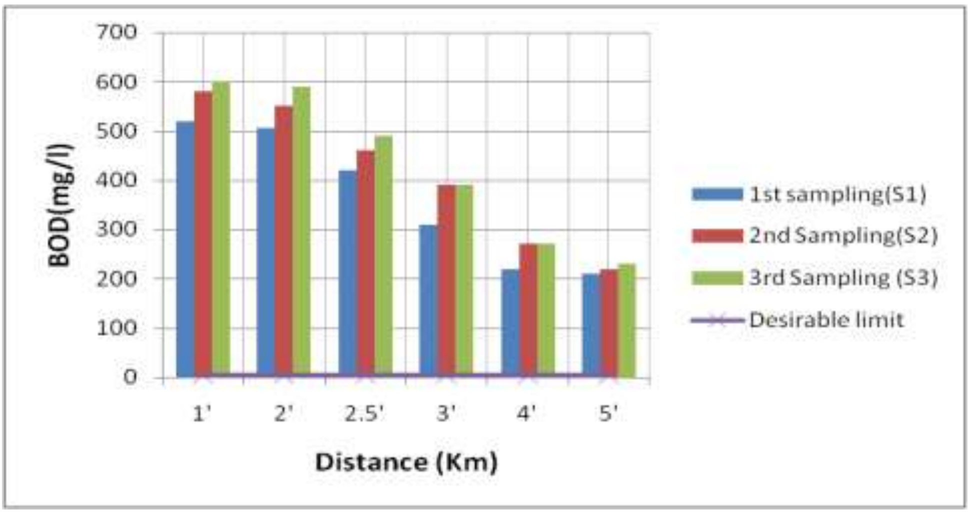


(c)

Figure 6.15: BOD concentration of ground water samples for (a) Chandigarh, (b) Mohali and (c) Panchkula

Table 6.5: Physico-chemical Characteristics of ground water at different downstream distances for different seasonal campaigns for Tricity region

Parameters	X-distance(Km)	Chandigarh			Mohali			Panchkula			Standards	
		S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**WHO**	**BIS**
Temperature (°C)	1	27	26.9	25	25	27.8	27	27	26.5	27.2	-	-
	2	26.7	26	23.2	23.2	26	26	25.8	26	25		
	2.5	24	24	24	24	24	25.4	24.2	25	23		
	3	22	24	22	22	22	25.8	23	23	22		
	4	22	21	20	20	22	22	22	20	22		
	5	20	22	19	19	20	20	21	20	20		
pH	1	7.8	9.1	9.1	8.8	8.9	9.2	7.8	7.8	8.1	**6.5-9.2**	**6.5-8.5**
	2	7.6	8.2	8.3	8.4	8.3	8.3	7.6	7.6	7.7		
	2.5	7.3	8	8	8	7.9	7.9	7.5	7.5	7.5		
	3	7.1	7.9	7.96	7.9	7.7	7.2	7	7.2	7.3		
	4	7.2	7.4	7.7	7.9	7.6	7	6.6	6.6	6.7		
	5	6.8	7.2	7.1	7.6	6.6	6	6	6	6		
TDS (mg/l)	1	643.2	680.1	687	783.3	788.1	789	582.4	590	592.1	**500**	**500**
	2	1191	1200	1200	626.7	642	650	577.6	531.2	530		
	2.5	677.7	770.2	787	597.7	599	599	550	500	500		
	3	597.7	600.9	632.1	550	562.7	568.1	491	489.2	460		
	4	492.6	510	517	494	500	500	376	299.7	299		
	5	482.6	550	555	492	521.9	530.1	330	249.6	236.1		
Ammonical Nitrogen (NH_3-N) (mg/l)	1	1.36	1.4	1.41	0.77	0.96	1.22	1.68	0	0	-	**0.5**
	2	0.96	0.98	0.99	0.13	0.27	0.9	0.78	0.79	0.8		
	2.5	0.38	0.39	0.39	0	0	0	0.15	0.15	0		
	3	0.21	0.3	0.31	0	0	0	0	0	0		
	4	0.2	0.22	0.27	0	0	0	0	0	0		
	5	0.1	0.19	0.2	0	0	0	0	0	0		
Phosphate (mg/l)	1	0.7	0.9	0.99	0	0	0	0.007	0.007	0.008	-	-
	2	0.06	0.09	0.09	0	0	0	0.006	0.99	0		
	2.5	0.04	0.06	0.06	0	0	0	0.001	0.998	0		
	3	0	0	0	0	0	0	0	0	0		
	4	0	0	0	0	0	0	0	0	0		
	5	0	0	0	0	0	0	0	0	0		
Turbidity (JTU)	1	10	10	9	9	10	10	10	10	10	-	**1**
	2	7	7	7	9	9	9	10	10	10		
	2.5	6	7	8	8	9	10	9	9	9		
	3	4	6	6	8	8	8	7	7	7		

Parameters	X-distance(Km)	Chandigarh			Mohali			Panchkula			Standards	
		S1	S2	S3	S1	S2	S3	S1	S2	S3	WHO	BIS
	4	2	4	5	7	8	8	7	8	8		
	5	2	2	3	6	7	7	4	4	3		
Biochemical Oxygen Demand (BOD) (mg/l)	1	530	610	620	535	600	600	520	580	600	**-**	**5**
	2	410	440	440	410	440	470	505	550	590		
	2.5	320	350	370	330	360	360	420	460	490		
	3	290	310	360	310	330	350	310	390	390		
	4	250	300	310	290	330	340	220	270	270		
	5	240	290	320	210	280	300	210	220	230		
Sulphate (mg/l)	1	75.19	87.2	89.1	52.9	57.3	64	35.6	46.2	59.9	**200**	**200**
	2	75.17	80.15	87.5	52	54.1	61.6	35.1	44.7	59.1		
	2.5	74.6	80.1	87.2	50	51.6	61	34.3	42.6	58.7		
	3	74.2	75.5	82	46.9	50.09	59	32.7	39.9	48.1		
	4	73.9	77.2	80.1	46.1	47.1	56.1	30.1	36.3	44.2		
	5	73.1	76.4	79	40.2	41.3	50	30	33	43.9		
Sodium (mg/l)	1	100	102	100	87	94	98	89	89	100	**-**	**-**
	2	98	89	90.6	83.7	81	93	90	82	94		
	2.5	72	80	86.2	77	79	84	80.1	76	80		
	3	50	63	82	58.1	55	77	78	68	71		
	4	46	38	71	44	50	62	66	55	59		
	5	29	30	60	37.3	43.8	50	50	50	49		
Potassium (mg/l)	1	15.6	19	19.6	11	16.8	18.2	13.4	19.3	21.2	**-**	**-**
	2	12	15.8	14.4	10.5	14.9	16.1	10.2	14.4	17.7		
	2.5	11.2	12.6	7.8	9.2	11.1	13.7	7	13.9	16		
	3	9.3	10	10	9	9.8	10	3.2	9	14.6		
	4	6	8.2	8	8	7	8.4	2.6	6	4.1		
	5	2.8	6.6	6	4.4	6	7.6	0.43	2.3	4.1		
Total Hardness (TH) (mg/l)	1	280	355	492	220	296	335	210	218	290	**300**	**200**
	2	260	335	340	215	290	320	208	210	265		
	2.5	255	310	310	202	275	310	195	200	240		
	3	235	275	300	195	200	300	160	182	232		
	4	230	260	265	190	185	298	142	160	225		
	5	210	225	240	190	180	272	115	145	200		
Calcium (Ca) (mg/l)	1	40.2	65.1	97.8	56.7	78.1	94.6	59.2	68.4	89.9	**100**	**75**
	2	37.3	60.2	95.1	52.1	72.4	92.1	56.5	66.5	89		
	2.5	30	58.7	90	50	68.6	92	53.8	64.8	86.2		
	3	28.5	58.1	84.6	50	50	88.3	53.6	62.9	84.3		
	4	27.6	58	82.8	40.8	46	82.2	40.5	60.6	82.1		

Parameters	X-distance(Km)	Chandigarh			Mohali			Panchkula			Standards	
		S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**WHO**	**BIS**
	5	27.4	58	80	36.6	41.8	82	36.6	56.5	80.9		
Magnesium (Mg) (mg/l)	1	83.1	88	95.5	82.1	94.6	96.1	77.6	86.1	89.8	**150**	**30**
	2	80.9	86.3	94.2	80.1	92.9	90.9	74.5	85.3	86.9		
	2.5	75.6	83.9	93.8	80	91.1	88.6	72.9	82.6	86.3		
	3	75	82	93.6	77.1	90	86.9	71	80.8	84.2		
	4	72.8	80	92.1	74	86.3	84.1	67.5	77.7	83.6		
	5	71.7	77.7	90.9	68.6	86.1	82	61.6	74.1	80.1		
Total Alkalinity (TA) (mg/l)	1	484	492	524	388	428	464	312	365	396	**-**	**200**
	2	481	490	500	386	425	462	310	361	391		
	2.5	390	485	486	380	418	455	290	350	382		
	3	392	450	464	345	400	440	276	325	375		
	4	390	410	443	332	395	425	252	308	370		
	5	386	395	424	325	390	419	236	300	358		
Nitrates (mg/l)	1	4.7	9.2	28.7	5.5	6.9	15.9	6	8.8	21.2	**10**	**45**
	2	3.2	9.2	20.1	5.1	6.6	15.8	5.4	7.6	21		
	2.5	3	9.0	20	4.8	6.2	15.0	5	7.2	17.6		
	3	2.9	8.6	17.1	4.6	6.0	14.2	4.9	7	17.1		
	4	2	8.3	11.9	4.0	5.6	14.1	4.6	6.9	16.9		
	5	1.8	8.0	10.9	3.9	5.2	11.3	4.2	6.8	16		
Chlorides (mg/l)	1	86.1	93.2	114.2	88.9	101.7	111	79.8	88.4	95.4	**250**	**250**
	2	84.9	90.9	107	87.3	100	107.6	75.5	86.9	94.3		
	2.5	83.2	90	98.9	86.9	99.1	101	73.1	83.6	93.8		
	3	81.7	88.7	96.4	86.3	94.6	98	70.9	82	93.6		
	4	80.9	86.9	93.6	83.1	93.2	95.6	69.6	81.7	93		
	5	80	86.3	91.7	80.8	91.2	90.8	67.1	80	90.1		
Fluorides (mg/l)	1	0.1	0.1	0.06	0.07	0.1	0.1	0.15	0.18	0.18	**1.5**	**1.0**
	2	0.01	0.07	0.07	0.01	0.0	0.1	0.1	0.10	0.9		
	2.5	0.03	0.174	0.18	0.09	0.1	0	0.01	0.1	0.01		
	3	0.03	0.13	0	0.01	0.1	0.1	0	0	0		
	4	0.06	0.1	0.01	0	0.0	0	0	0	0		
	5	0	0	0	0	0.01	0	0	0	0		
EC (µS/cm)	1	1005	1059	1861	498.2	562.2	597.7	582.4	624.9	720.1	**300**	**300**
	2	1000	1045	1840	493.8	558	597.1	580	619	713		
	2.5	992	1040	1822	493.6	550	593.6	577.5	613.6	709.1		
	3	981	1025	1812	477	547.6	592.1	575.2	609.1	700.6		
	4	980	1000	1811	472	542.7	586	568.1	600	692		
	5	976	1000	1802	466.6	540	580	566.7	598.3	686		

Heavy Metals Parameters

The heavy metals analysis results areas shown in *Table 6.6*.

Cadmium (Cd)

Cadmium was not detected in majority of the ground water samples from Chandigarh, Mohali and Panchkula during the entire sampling periods. Cadmium being extremely toxic metal as it gets accumulated in kidneys and liver causing carcinogenic effects. The itai-itai disease caused in Japan was due to ingestion of cadmium laden rice.

Chromium (Cr)

The hexavalent form of chromium is very lethal as it leads to the malfunctioning of various biological muscles and irritation of gastrointestinal tracts. Chromium was not detected in any of the ground water samples of Tricity.

Copper (Cu)

Copper was found in ground water samples which were in close vicinity of the dumping sites in all the three cities of Chandigarh, Mohali and Panchkula. The samples were within the desirable range of BIS and WHO. If copper is present in higher concentrations then it may lead to vomiting, diarrhea, stomach problems, nausea and kidney damage sometimes.

Lead (Pb)

Lead has been found in ground water samples specially the samples which are in close proximity to the dumping sites in each of the three cities during the entire monitoring campaign. The high concentration of lead can be very lethal causing physiological and biochemical dysfunctions in human body. It gets accumulated in the body tissues and causes acute toxicity leading to nervous disorders.

Zinc (Zn)

Zinc was found in ground water samples but was well within the desirable limit of 5 mg/l.high concentration of zinc lead to hematological disorders and also imparts bitter taste to water. Studies conducted [16, 217] have reported that zinc has the highest affinity to leach.

Nickel (Ni)

Nickel was not detected in any of the samples of ground water over the entire monitoring campaign in Tricity.

Figure 6.16 illustrates the average concentrations of heavy metals in Chandigarh, Mohali and Panchkula over the entire monitoring campaign.

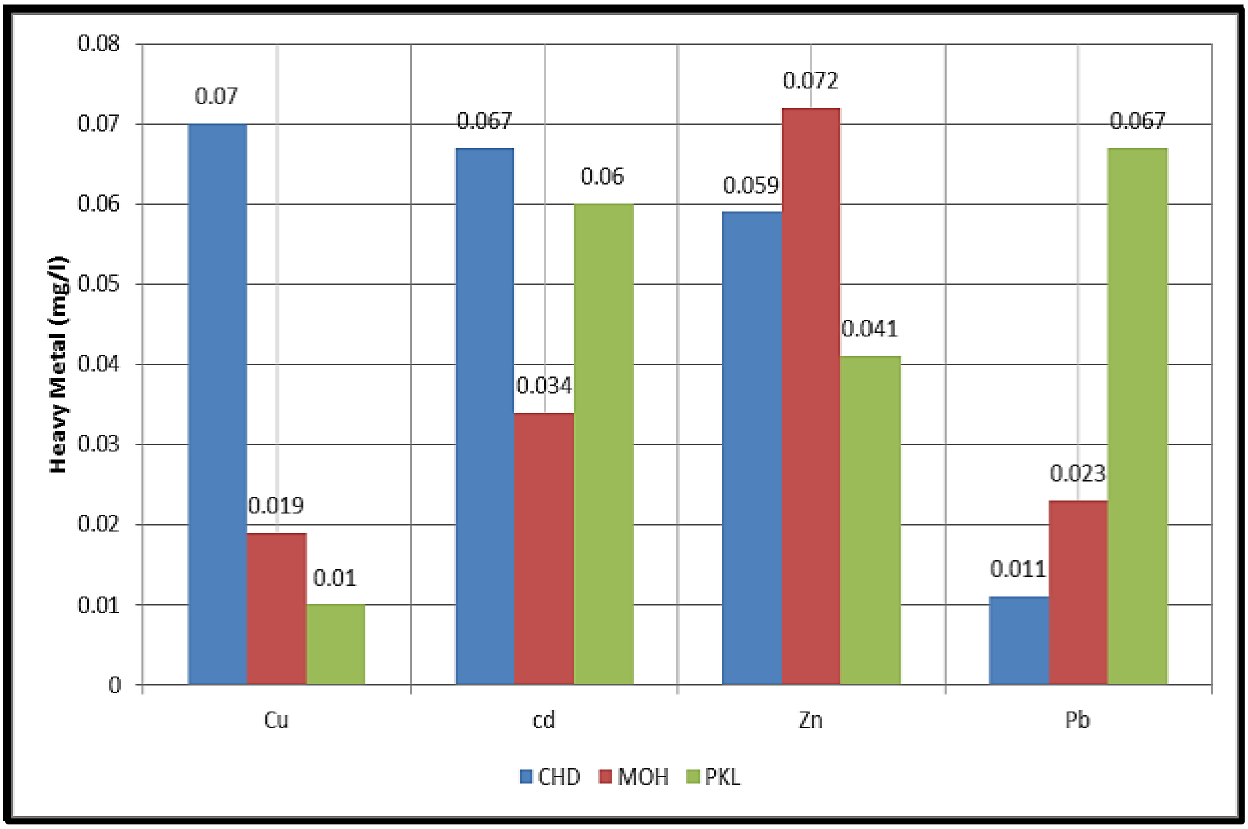


Figure 6.16: Average Heavy metal concentration of ground water samples from Chandigarh, Mohali and Panchkula

Table 6.6: Heavy Metal characteristics of ground water at different downstream distances for different seasonal campaigns for Tricity region

Parameters	X-distance (Km)	Chandigarh			Mohali			Panchkula			Standards	
		S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**WHO**	**BIS**
Lead (mg/l)	1	0.02	0.01	0.01	0.06	0.06	0.002	0.37	0.22	0.17	**0.01**	**0.01**
	2	0.02	ND	0.01	0.01	0.01	0.001	0.2	0.1	0.01		
	2.5	0.001	ND	ND	0.001	0.001	ND	0.1	0.01	0.01		
	3	ND	ND	ND	0.001	ND	ND	0.01	0.01	ND		
	4	ND	ND	ND	ND	ND	ND	0.01	ND	ND		
	5	ND	ND	ND	ND	ND	ND	0.001	ND	ND		
Cadmium (mg/l)	1	0.008	0.002	0.001	0.007	0.001	0.001	0.007	0.001	0.001	**0.03**	**0.03**
	2	0.01	ND	0.001	0.01	0.001	0.001	0.001	ND	0.001		
	2.5	0.001	ND	ND	ND	ND	ND	ND	ND	ND		
	3	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	4	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	5	ND	ND	ND	ND	ND	ND	ND	ND	ND		
Chromium (mg/l)	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	**0.05**	**0.05**
	2	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	2.5	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	3	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	4	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	5	ND	ND	ND	ND	ND	ND	ND	ND	ND		
Nickel (mg/l)	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	**0.07**	**0.02**
	2	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	2.5	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	3	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	4	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	5	ND	ND	ND	ND	ND	ND	ND	ND	ND		
Zinc (mg/l)	1	0.20	0.15	0.19	0.21	0.17	0.17	0.24	0.22	0.18	**3**	**5**
	2	0.20	0.10	0.11	0.20	0.22	0.20	0.14	0.17	0.11		
	2.5	0.11	0.001	ND	0.01	0.1	0.01	0.1	0.1	0.01		
	3	0.01	0.001	ND	0.01	ND	0.001	0.01	0.10	0.01		
	4	ND	ND	ND	0.001	ND	ND	0.01	ND	ND		
	5	ND	ND	ND	ND	ND	ND	ND	ND	ND		
Copper (mg/l)	1	0.1	0.11	0.01	0.06	0.02	0.02	ND	ND	0.01	**3**	**0.05**
	2	ND	ND	ND	0.02	0.01	0.001	ND	ND	ND		
	2.5	ND	ND	ND	ND	0.01	ND	ND	ND	ND		
	3	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	4	ND	ND	ND	ND	ND	ND	ND	ND	ND		
	5	ND	ND	ND	ND	ND	ND	ND	ND	ND		

(ND-not detected)

Microbiological Analysis

Total coliforms were analysed using MPN method. More than 50% of the ground water samples have shown the presence of coliform bacteria as shown in *Table 6.7*. The samples were in the close vicinity of the dumping sites. The presence of coliforms in some of the samples of ground water confirms that infiltration of leachate into the ground water has deteriorated the quality.

The contamination of ground water samples in all the three cities of Chandigarh, Mohali and Panchkula can be owed to the percolation due to leachate. Leachate percolation in the ground water can be a result of composition of leachate, rainfall, depth and distance from the source of pollution [16, 217]. Ground water samples collected in the study were collected from different distances from the dumping sites of Chandigarh, Mohali and Panchkula. Ground water samples collected from the close vicinity of dumping sites were found to be more contaminated than that of the farther away samples (>3km). This can be attributed to the fact that the gravitational movement of viscous fluid like leachate is hindered due to mass of solid soil matter [16] and with increasing time leachate penetrates deeper and spread over long distances. The ground water quality improves with the increase in the distance of the sampling sites from the source of pollution i.e., dumping site.

Table 6.7: MPN results for presence of coliforms in ground water samples at different downstream distances for different seasonal campaigns for Tricity region

Parameter	X-distance (Km)	Chandigarh			Mohali			Panchkula		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
MPN	1	105/100 (UN)	105/100 (UN)	101/100 (UN)	101/100 (UN)	91/100 (UN)	105/100 (UN)	102/100 (UN)	110/100 (UN)	101/100 UN
	2	101/100 (UN)	98/100 (UN)	24/100 (UN)	90/100 (UN)	90/100 (UN)	91/100 (UN)	90/100 (UN)	93/100 (UN)	90/100 (UN)
	2.5	45/100 (UN)	85/100 (UN)	2/100 (S)	27/100 (UN)	35/100 (UN)	27/100 (UN)	45/100 (UN)	24/100 (UN)	25/100 (UN)
	3	35/100 (UN)	45/100 (UN)	0/100 (S)	24/100 (UN)	3/100 (S)	3/100 (S)	0/100 (S)	1/100 (S)	2/100 (S)
	4	2/100 (S)	5/100 (S)	0/100 (S)	0/100 (S)	1/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)
	5	1/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)	0/100 (S)

[S-Satisfactory; UN-Unsatisfactory]

6.3.2 Water Quality Index (WQI)

WQI is one of the most effective tools to provide feedback on the quality of water to the policy makers and environmentalists [37, 180] by giving a single value. In the present study WQI is calculated using two methods viz., OWQI and WQI determined on the BIS 10500 standards and values for all the three cities of Chandigarh, Mohali and Panchkula respectively were calculated using equation (6.3) for OWQI and equation (6.7) for standards for drinking water purposes as recommended by BIS 10500.

The values of the sub-indices of ground water from Chandigarh, Mohali and Panchkula are given in *Table 6.8, 6.9 and 6.10* respectively. The sub-indices for different parameters were calculated using the equations (6.1) and (6.2). The variations in all the parameters have shown that with the decrease in sub-index value the related possible contamination levels in ground water increases. After the calculation of the sub-indices, WQI value was calculated for OWQI using equation (6.3). The values of WQI and the classification as per OWQI obtained for Chandigarh, Mohali and Panchkula are shown in *Table 6.11*. The values obtained for WQI of each city were compared to the standard values of WQI as per OWQI in *Table 6.3*.

Table 6.8: Sub-indices for Chandigarh

Parameters	X- distance (Km)	Chandigarh					
		S1		S2		S3	
		q	s	q	s	q	s
pH	1	7.8	0.52	9.1	0.20	9.1	0.20
	2	7.6	0.61	8.2	0.38	8.3	0.35
	2.5	7.3	0.77	8	0.44	8	0.44
	3	7.1	0.91	7.9	0.48	7.96	0.46
	4	7.2	0.84	7.4	0.71	7.7	0.56
	5	6.8	1.18	7.2	0.84	7.1	0.91
TDS (mg/l)	1	643.2	0.269	680.1	0.25	687	0.251
	2	1191	0.13	1200	0.13	1200	0.13
	2.5	677.7	0.25	770.2	0.22	787	0.21
	3	597.7	0.29	600.9	0.28	632.1	0.27
	4	492.6	0.35	510	0.34	517	0.33
	5	482.6	0.363	550	0.31	555	0.31
Ammonical Nitrogen (NH_3-N) (mg/l)	1	1.36	0.90	1.4	0.90	1.41	0.90
	2	0.96	0.93	0.98	0.92	0.99	0.92
	2.5	0.38	0.97	0.39	0.97	0.39	0.97
	3	0.21	0.98	0.3	0.97	0.31	0.97
	4	0.2	0.98	0.22	0.98	0.27	0.98
	5	0.1	1	0.19	0.98	0.2	0.98
Turbidity (JTU)	1	10	0.76	10	0.76	9	0.78
	2	7	0.82	7	0.82	7	0.82
	2.5	6	0.84	7	0.82	8	0.80
	3	4	0.89	6	0.84	6	0.84
	4	2	0.94	4	0.89	5	0.86
	5	2	0.94	2	0.94	3	0.91
Temperature (°C)	1	27	0.74	26.9	0.74	25	0.86
	2	26.7	0.76	26	0.80	23.2	0.94
	2.5	24	0.91	24	0.91	24	0.91
	3	22	0.97	24	0.91	22	0.97
	4	22	0.97	21	0.99	20	1
	5	20	1	22	0.97	19	0.99
Phosphate (mg/l)	1	0.7	0.48	0.9	0.42	0.99	0.40
	2	0.06	0.91	0.09	0.88	0.09	0.88
	2.5	0.04	0.94	0.06	0.91	0.06	0.91
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
BOD (mg/l)	1	530	0.0004	610	0.00003	620	0.0003
	2	410	0.0001	440	0.00008	440	0.00008
	2.5	320	0.0002	350	0.00015	370	0.00013
	3	290	0.0002	310	0.00022	360	0.00014
	4	250	0.004	300	0.00024	310	0.00022
	5	240	0.0004	290	0.00026	320	0.00020
TCB	1	105	0.37	105	0.37	101	0.37
	2	101	0.37	98	0.50	24	0.55
	2.5	45	0.55	85	0.56	2	0.88
	3	35	0.845	45	0.88	0	1
	4	2	0.88	5	0.78	0	1
	5	1	0.93	0	1	0	1

Table 6.9: Sub-indices for Mohali

Parameters	X- distance (Km)	Mohali					
		S1		S2		S3	
		q	s	q	s	q	s
pH	1	8.8	0.25	8.9	0.23	9.2	0.19
	2	8.4	0.33	8.3	0.35	8.3	0.35
	2.5	8	0.44	7.9	0.45	7.9	0.48
	3	7.9	0.48	7.7	0.56	7.2	0.84
	4	7.9	0.48	7.6	0.61	7	1
	5	7.6	0.61	6.6	1.42	6	2.52
TDS (mg/l)	1	783.3	0.21	788.1	0.21	789	0.21
	2	626.7	0.27	642	0.26	650	0.26
	2.5	597.7	0.29	599	0.29	599	0.29
	3	550	0.31	562.7	0.31	568.1	0.30
	4	494	0.35	500	0.35	500	0.35
	5	492	0.35	521.9	0.33	530.1	0.33
Ammonical Nitrogen (NH_3-N) (mg/l)	1	0.77	0.94	0.96	0.93	1.22	0.91
	2	0.13	0.99	0.27	0.98	0.9	0.93
	2.5	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
Turbidity (JTU)	1	9	0.78	10	0.76	10	0.76
	2	9	0.78	9	0.78	9	0.78
	2.5	8	0.80	9	0.78	10	0.76
	3	8	0.80	8	0.80	8	0.80
	4	7	0.82	8	0.800	8	0.800
	5	6	0.84	7	0.821	7	0.821
Temperature (°C)	1	25	0.86	27.8	0.684	27	0.741
	2	23.2	0.94	26	0.808	26	0.808
	2.5	24	0.91	24	0.912	25.4	0.845
	3	22	0.972	22	0.972	25.8	0.821
	4	20	1	22	0.972	22	0.972
	5	19	0.995	20	1	20	1
Phosphate (mg/l)	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	2.5	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
BOD (mg/l)	1	535	0.0004	600	0.00033	600	0.00003
	2	410	0.0001	440	0.0008	470	0.00068
	2.5	330	0.0001	360	0.0001	360	0.00014
	3	310	0.0002	330	0.0001	350	0.00015
	4	290	0.0002	330	0.0001	340	0.00017
	5	210	0.0006	280	0.0002	300	0.0002
TCB	1	101	0.375	91	0.400	105	0.376
	2	90	0.387	90	0.387	91	0.400
	2.5	27	0.577	35	0.845	27	0.577
	3	24	0.557	3	0.821	3	0.821
	4	0	1	1	0.935	0	1
	5	0	1	0	1	0	1

Table 6.10: Sub-indices for Panchkula

Parameters	X- distance (Km)	Panchkula					
		S1		S2		S3	
		q	s	q	s	q	s
pH	1	7.8	0.522	7.8	0.514	8.1	0.416
	2	7.6	0.610	7.6	0.610	7.7	0.564
	2.5	7.5	0.660	7.5	0.660	7.5	0.660
	3	7	1	7.2	0.844	7.3	0.777
	4	6.6	1.422	6.6	1.422	6.7	1.300
	5	6	2.522	6	2.522	6	2.522
TDS (mg/l)	1	582.4	0.299	590	0.295	592.1	0.294
	2	577.6	0.301	531.2	0.329	530	0.330
	2.5	550	0.317	500	0.350	500	0.350
	3	491	0.357	489.2	0.358	460	0.381
	4	376	0.465	299.7	0.572	299	0.573
	5	330	0.525	249.6	0.662	236.1	0.690
Ammonical Nitrogen (NH_3-N) (mg/l)	1	1.68	0.88	0	0	0	0
	2	0.78	0.943	0.79	0.943	0.8	0.942
	2.5	0.15	0.988	0.15	0.988	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
Turbidity (JTU)	1	10	0.760	10	0.760	10	0.760
	2	10	0.760	10	0.760	10	0.760
	2.5	9	0.780	9	0.780	9	0.780
	3	7	0.821	7	0.821	7	0.821
	4	7	0.821	8	0.800	8	0.800
	5	4	0.890	4	0.890	3	0.916
Temperature (°C)	1	27	0.741	26.5	0.880	27.2	0.751
	2	25.8	0.821	26	0.808	25	0.867
	2.5	24.2	0.921	25	0.867	23	0.941
	3	23	0.941	23	0.941	22	0.972
	4	22	0.972	20	1	22	0.972
	5	21	0.994	20	1	20	1
Phosphate (mg/l)	1	0.007	0.989	0.007	0.989	0.008	0.989
	2	0.006	0.99	0.99	0	0	0
	2.5	0.001	0.998	0.998	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
BOD (mg/l)	1	520	0.0005	580	0.000037	600	0.0000037
	2	505	0.0005	550	0.000043	590	0.0000035
	2.5	420	0.0009	460	0.000072	490	0.0000060
	3	310	0.0002	390	0.000161	390	0.000061
	4	220	0.0005	270	0.000328	270	0.000328
	5	210	0.0006	220	0.000518	230	0.000512
TCB	1	102	0.376	110	0.288	101	0.375
	2	90	0.387	93	0.390	90	0.387
	2.5	45	0.551	24	0.557	35	0.845
	3	0	1	1	0.935	2	0.885
	4	0	1	0	1	0	1
	5	0	1	0	1	0	1

Table 6.11: Average WQI as per OWQI for Tricity

Distance/Monitoring	Chandigarh	Mohali	Panchkula
OWQI	74	60	72
Water Quality Classification	Poor Water Quality	Poor Water Quality	Poor Water Quality

The values of WQI obtained using the methodology based on BIS 10500 have been summarized in *Table 6.12* and the classification of water quality have been summarized in *Table 6.13*.

Table 6.12: WQI for Tricity as per BIS 10500

Distance/ Monitoring	**S1**			**S2**			**S3**			**Average**		
	CHD	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**
1 km	132	107	120	149	119	97	185	142	110	155	123	109
2 km	131	88	100	144	111	108	178	126	125	151	108	111
2.5 km	103	82	83	121	92	88	155	103	99	126	92	90
3 km	98	81	82	110	90	87	145	100	95	118	90	88
4 km	97	73	72	104	87	81	140	99	87	114	86	80
5 km	94	72	70	101	82	78	135	92	81	111	82	76
Average WQI	**109**	**84**	**88**	**122**	**97**	**90**	**156**	**110**	**99**	**130**	**97**	**92**

It is observed from *Table 6.12* that the ground water quality in Chandigarh within a 5 km vicinity of the dumpsite experiences poor quality of groundwater with the exception in monitoring campaign over the S1 wherein it experienced a *good* water quality value at distances greater than 2.5 km. The poor quality of groundwater is primarily because Chandigarh has the more concentration of industries than Mohali and Panchkula. The overall water quality in Mohali could be classified as good as observed from *Table 6.12*. Seasonal variation showed that the overall water quality in monitoring campaigns S1 and S2 were of good quality with poor quality of water observed in S3. The quality of groundwater was classified as poor quality for downstream distances of 2 km for monitoring campaigns during S1 and S2 and till 3 km for S3. Thereafter the water quality improved to good standards. Further, with increase in downstream distance it was observed that the quality of groundwater improved. Similarly, it was observed from that the overall quality of groundwater was classified as good for Panchkula (*Table 6.12*).

Table 6.13: Water quality classification for Tricity as per BIS 10500

Distance/Monitoring	**S1**			**S2**			**S3**			**Average**		
	CHD	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**
1 km	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality
2 km	Poor quality	Good quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality	Poor quality
2.5 km	Poor quality	Good quality	Good quality	Poor quality	Good quality	Good quality	Poor quality	Poor quality	Good quality	Poor quality	Good quality	Good quality
3 km	Good quality	Good quality	Good quality	Poor quality	Good quality	Good quality	Poor quality	Poor quality	Good quality	Poor quality	Good quality	Good quality
4 km	Good quality	Good quality	Good quality	Poor quality	Good quality	Good quality	Poor quality	Good quality	Good quality	Poor quality	Good quality	Good quality
5 km	Good quality	Good quality	Good quality	Poor quality	Good quality	Good quality	Poor quality	Good quality	Good quality	Poor quality	Good quality	Good quality
Average WQI	**Poor quality**	**Good quality**	**Good quality**	**Poor quality**	**Good quality**	**Good quality**	**Poor quality**	**Poor quality**	**Good quality**	**Poor quality**	**Good quality**	**Good quality**

Seasonal variation showed that for all the monitoring campaigns poor quality of water existed till downstream distance of 2 km after which the quality of the water increased to *good.* The WQI results revealed that the ground water samples from the nearby location to the dumping sites are affected due to leaching of ions from the leachate. With the increase in downstream distance of the groundwater sources from the dumpsite the WQI and also the quality of the groundwater keeps on improving. Another important observation was that though groundwater classification for Mohali and Panchkula were '*good*', the mean WQI values of 97 and 92 respectively for Mohali and Panchkula shows that for all practical purposes they are on the borderline of being classified from *good* to *poor* water quality. A simple regression analysis between LPI and WQI for the three sites was found to be 0.35 for Chandigarh, 0.58 for Mohali and 0.22 for Panchkula respectively.

Further, it is important to note that while the results obtained from (OWQI) shows that the existing groundwater quality from the Tricity Region is 'poor quality', the groundwater quality evaluated using the BIS method showed that the groundwater quality for Chandigarh was poor quality but for Mohali and Panchkula were classified as good quality. However, the groundwater quality for Mohali and Panchkula is very close to being graded poor as the WQI values are on the borderline conditions.

6.3.3 Multivariate Analysis

Principal components analysis (PCA)

PCA is a data alteration method that reveals simple primary structures which are assumed to be present within a dataset [28, 84]. PCA when applied to the present dataset of the study gave a comparison of compositional patterns between the examined waste systems and helped to identify the factors that influence each other. The numbers of components were based on Kaiser Normalization in which components having Eigen values greater than unity were retained [61]. The contribution of the component is considered to be significant only when it has a corresponding value of Eigen greater than unity [61, 217]. Three principal components were obtained with Eigen values greater than unity in case of Chandigarh and Panchkula cities accounting for almost 88% and 87.8% of total variance respectively in the ground water dataset whereas for Mohali, two components with Eigen values greater than unity accounting 87.1% of total variance in the ground water dataset. *Figure 6.17, 6.18 and*

6.19 represents the plot of loadings for various components of Chandigarh, Mohali and Panchkula respectively. Principal component loading for these components with variance is given in *Table 6.14, 6.15 and 6.16* for all the three cities of Chandigarh, Mohali and Panchkula respectively.

Component 1

The first component in Chandigarh and Panchkula cities is dominated by high positive loading in electrical conductivity, calcium, magnesium, nitrates and sulphate and for Mohali by fluorides, chlorides, nitrates, total dissolved solids and ammonical nitrogen. The moderate positive loading is shown in pH, turbidity and total hardness accounting for 62.76%, 62.14% and 51.97% of the total variance in first components of Chandigarh, Mohali and Panchkula cities respectively. This specifies that these ions are accountable for occurrence of high electrical conductivity, total dissolves solids and hardness. High pH or alkaline environment is responsible for the presence of fluoride in ground water of Mohali city. Presence of hardness in the form of calcium and magnesium in ground water samples can be attributed to the leaching of the minerals and anthropogenic factors which are dominant controlling factors of the loading. Presence of sulphate is the indication of the impacts caused mostly due to the agricultural practices, domestic sewage and animal excreta. Negative loading of pH can be linked with the sulphate as the latter being the acidic ion depicting the lower values of pH [37, 61].

Component 2

The second component is dominated by the presence of sulphate, ammonical nitrogen, turbidity, biochemical oxygen demand, total hardness, pH, electrical conductivity and magnesium, accounting for 17.94%, 24.99% and 22.87% of the total variance for Chandigarh, Mohali and Panchkula respectively. The high loading in pH is related to the low sulphate ions as pH is negatively correlated with the sulphate [61, 62]. Presence of total hardness, ammonical nitrogen and alkalinity may be due to the leaching of minerals in the ground water along with other anthropogenic activities. Agricultural activities may also contribute to the phosphate contamination in the ground water as phosphate is mainly used as fertilizer. The high positive loading in ammonical nitrogen can be attributed to the impacts due to animal excreta and sewage from domestic activities.

Component 3

Component three explaining 7.31% and 1.96% of total variance for Chandigarh and Panchkula respectively has strong positive loading on phosphate and fluoride. Generally, alkaline environment is responsible for the presence of fluoride in ground water [217]. Sometimes weathering of fluoride bearing rocks can also cause excessive presence of fluoride. The presence of phosphate contamination in ground water is attributed to the excessive use of fertilizers, sewage and landfill discharge from domestic waste.

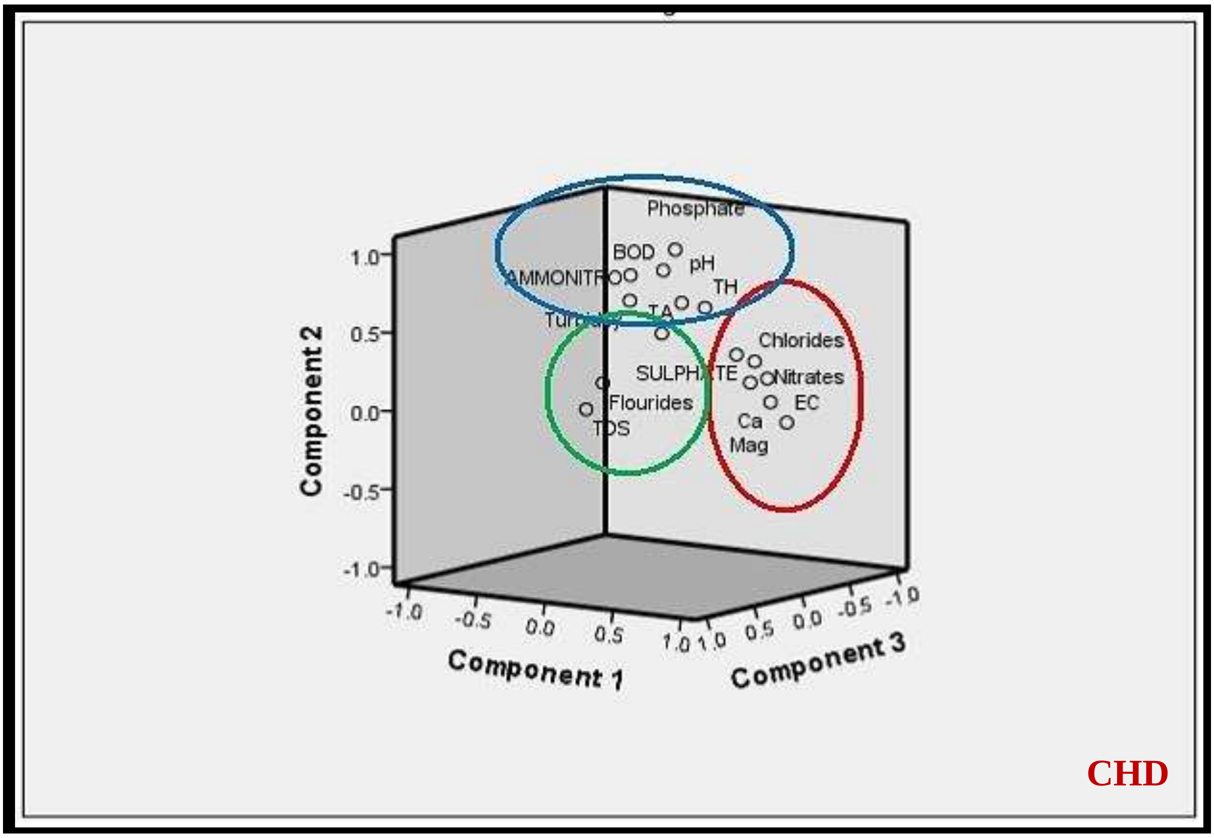


Figure 6.17: Plot of loadings for the components with varimax normalized rotation for Chandigarh City

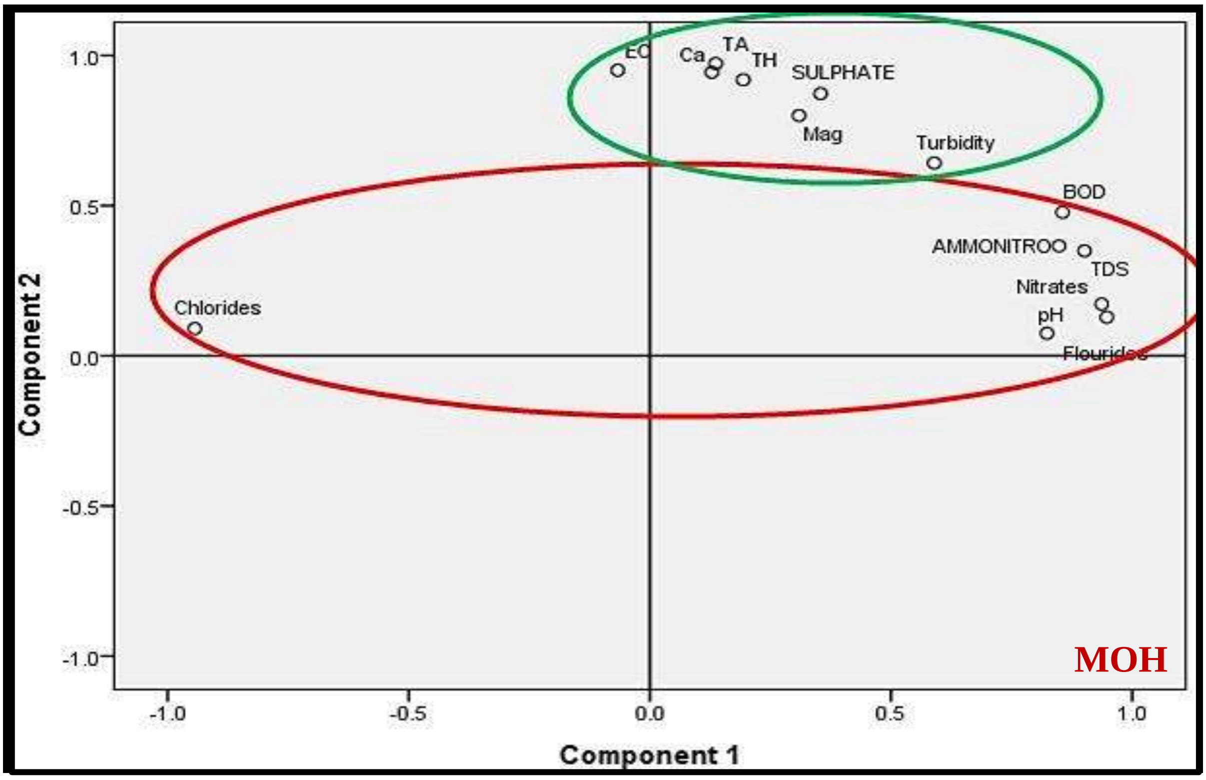


Figure 6.18: Plot of loadings for the components with varimax normalized rotation for Mohali City

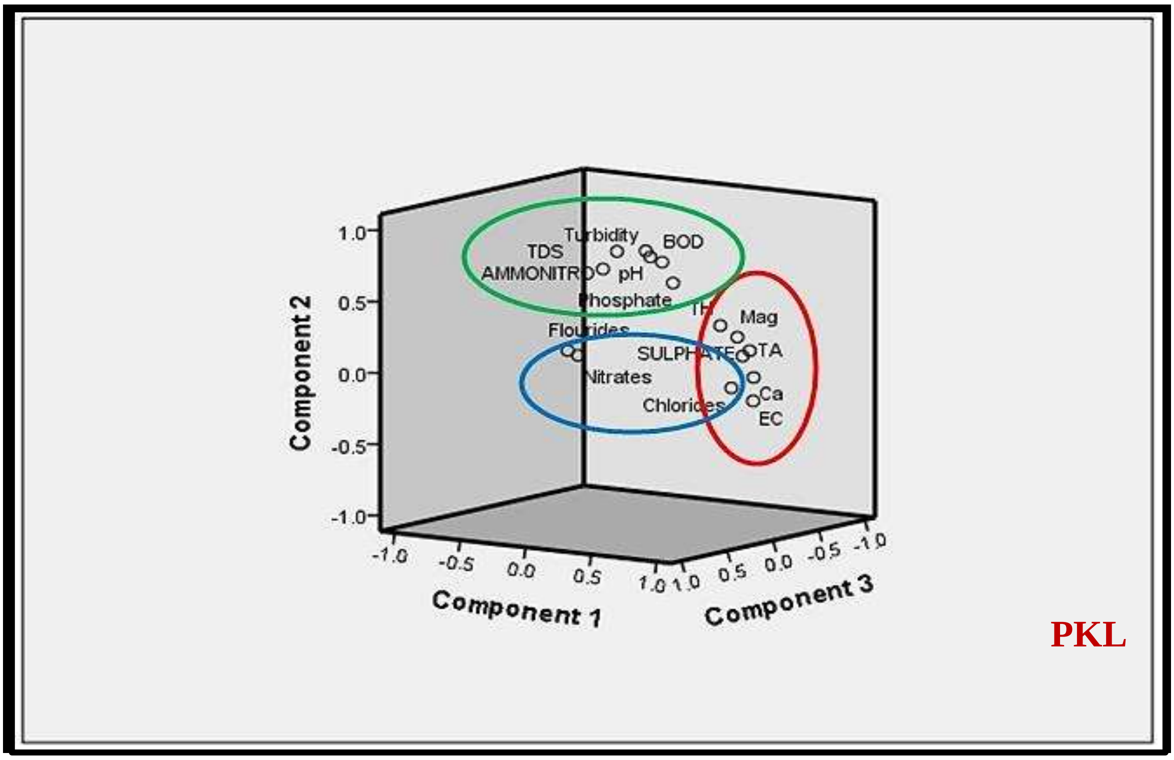


Figure 6.19: Plot of loadings for the components with varimax normalized rotation for Panchkula City

Table 6.14: PCA loadings of variables of significant principal components for Chandigarh city

Parameters	Rotated Component Matrix		
	Component 1	**Component 2**	**Component 3**
Calcium	*0.964*	-	-
EC	*0.953*	-	-
Nitrates	*0.929*	-	-
Magnesium	*0.896*	-	-
Chlorides	*0.885*	-	-
Sulphate	*0.808*	*0.429*	-
Phosphate	-	*0.982*	-
BOD	-	*0.914*	-
Ammonical nitrogen	-	*0.880*	-
Turbidity	-	*0.752*	*0.518*
pH	*0.480*	*0.743*	-
Total Hardness	*0.572*	*0.704*	-
TDS	-	-	*0.850*
TA	*0.497*	*0.583*	*0.594*
Fluorides	-	-	*0.569*
Eigen Value	9.413	2.691	1.096
% of variance	62.755	17.937	7.309
Cumulative %	62.755	80.692	88.001

Table 6.15: PCA loadings of variables of significant principal components for Mohali city

Parameters	Rotated Component Matrix	
	Component 1	**Component 2**
Fluorides	*0.947*	-
Chlorides	*-0.944*	-
Nitrates	*0.937*	-
TDS	*0.901*	-
BOD	*0.855*	*0.478*
Ammonical Nitrogen	*0.848*	-
pH	*0.823*	-
TA	-	*0.973*
EC	-	*0.951*
Ca	-	*0.944*
TH	-	*0.919*
Sulphate	-	*0.873*
Magnesium	-	*0.800*
Turbidity	*0.590*	*0.642*
Eigen Value	8.700	3.498
% of variance	62.140	24.984
Cumulative %	62.140	87.123

Table 6.16: PCA loadings of variables of significant principal components for Panchkula city

Parameters	**Rotated Component Matrix**		
	Component 1	**Component 2**	**Component 3**
Calcium	*0.987*	-	-
EC	*0.973*	-	-
TA	*0.958*	-	-
Sulphate	*0.946*	-	-
Magnesium	*0.902*	-	-
TH	*0.860*	*0.402*	-
TDS	-	*0.863*	-
Turbidity	-	*0.863*	-
pH	-	*0.845*	-
BOD	*0.460*	*0.816*	-
Ammonical nitrogen	-	*0.680*	-
Phosphate	-	*0.518*	*-0.458*
Chlorides	-	-	*-0.937*
Fluorides	-	-	*0.926*
Nitrates	-	-	*0.915*
Eigen Value	7.795	3.431	1.956
% of variance	51.966	22.874	13.043
Cumulative %	51.966	74.841	87.884

Hierarchical cluster analysis (HCA)

HCA is the most widely multivariate statistical tool used in environmental studies [138, 182]. It helps in grouping the ground water samples based on the similarities in their chemical composition [182]. In the study, HCA is applied to all the three cities of Chandigarh, Mohali and Panchkula. The classification of ground water samples into clusters is based on a visual observation of the dendogram and is represented in *figures 6.20, 6.21 and 6.22* for Chandigarh, Mohali and Panchkula respectively. A dendogram helps in understanding the correlation among the various elements. HCA was applied to bulk concentrations data using ward's method with Euclidian distances as criterion for formation of the clusters of elements [182]. Ward's method of analysis uses the variance approach to evaluate the distances between clusters and helps to minimize the sum of squares of clusters that can be formed at each step [61, 62, 90]. Grouping of sampling points in accordance with the concentration of constituent's ions is done by cluster study [167].

In this study, for all the three cities the classification of all the ground water samples into clusters is formed. The three different clusters for Chandigarh, Mohali and Panchkula cities are formed: **cluster 1** (sampling sites 1, 11, 7, 10, 13 for Chandigarh; sampling sites 27, 29, 18-19 for Mohali; sampling sites 42, 44, 33-34 for Panchkula), **cluster 2** (sampling sites 9, 15, 6, 8, 5,2 for Chandigarh; sampling sites 26, 30, 25, 20, 22, 16-17 for Mohali; sampling sites 40, 45, 41, 31 for Panchkula) and **cluster 3** (sampling sites 3-4, 12, 14 for Chandigarh; sampling sites 23-24, 21, 28 for Mohali; sampling sites 32, 35-36, 43 for Panchkula). These all respective sites for all the three cities of Chandigarh, Mohali and Panchkula respectively have similar characteristic features which corresponds to low, medium and high pollution region.

In cluster 1, five samples for Chandigarh City and four samples each for Mohali and Panchkula cities respectively are grouped and characterized by low polluted regions. In Chandigarh city, these samples are characterized by low pH, sulphate, magnesium and chloride whereas for Mohali and Panchkula the low values of these samples are characterized in nitrates, ammonical nitrogen, fluorides and phosphates. The ground water which falls under cluster 1 is not much polluted.

In cluster 2, six samples from Chandigarh, seven samples from Mohali and four samples from Panchkula are grouped characterized by moderate polluted region. Members of this cluster have presence of calcium, magnesium, electrical conductivity, biochemical oxygen demand, alkalinity and turbidity. The water samples shows moderate salinity with presence of total dissolved solids. This water can be classified as mixed water type [90].

In cluster 3, four samples each from Chandigarh and Mohali, and seven samples from Panchkula are grouped and characterized by the sites which are closer to the landfill sites and are found to be highly polluted owing to impact from domestic waste. The samples are characterized by presence of high ammonical nitrogen, nitrates, sulphate, hardness, fluorides and total dissolved solids.

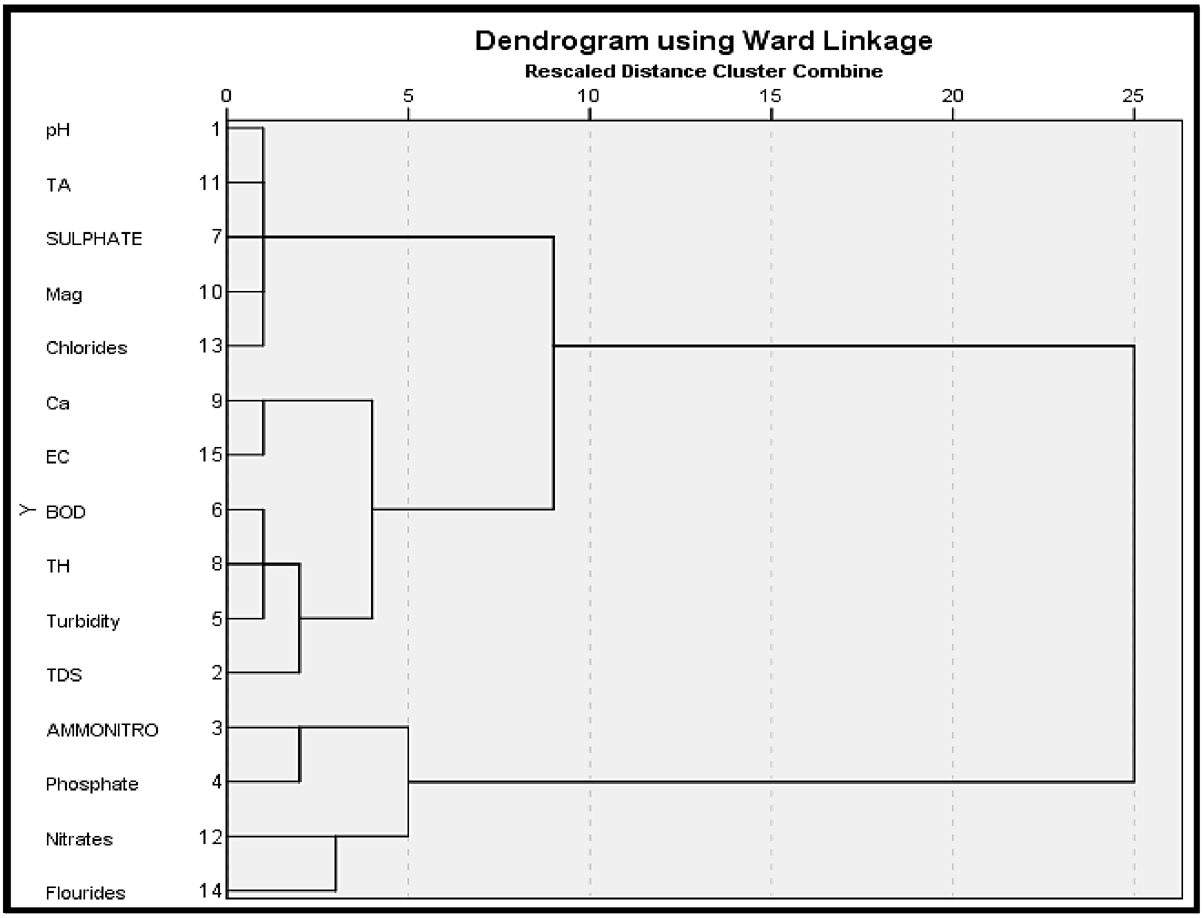


Figure 6.20: Hierarchical dendogram for ground water samples in Chandigarh City

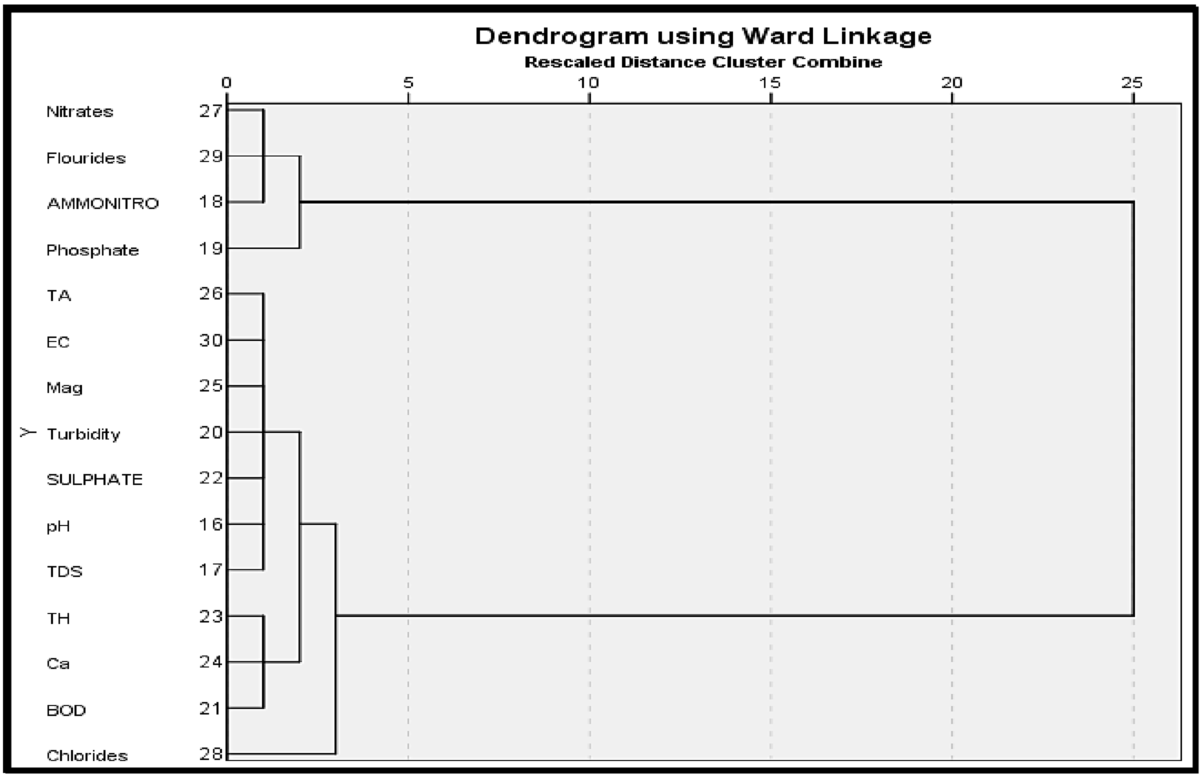


Figure 6.21: Hierarchical dendogram for ground water samples in Mohali

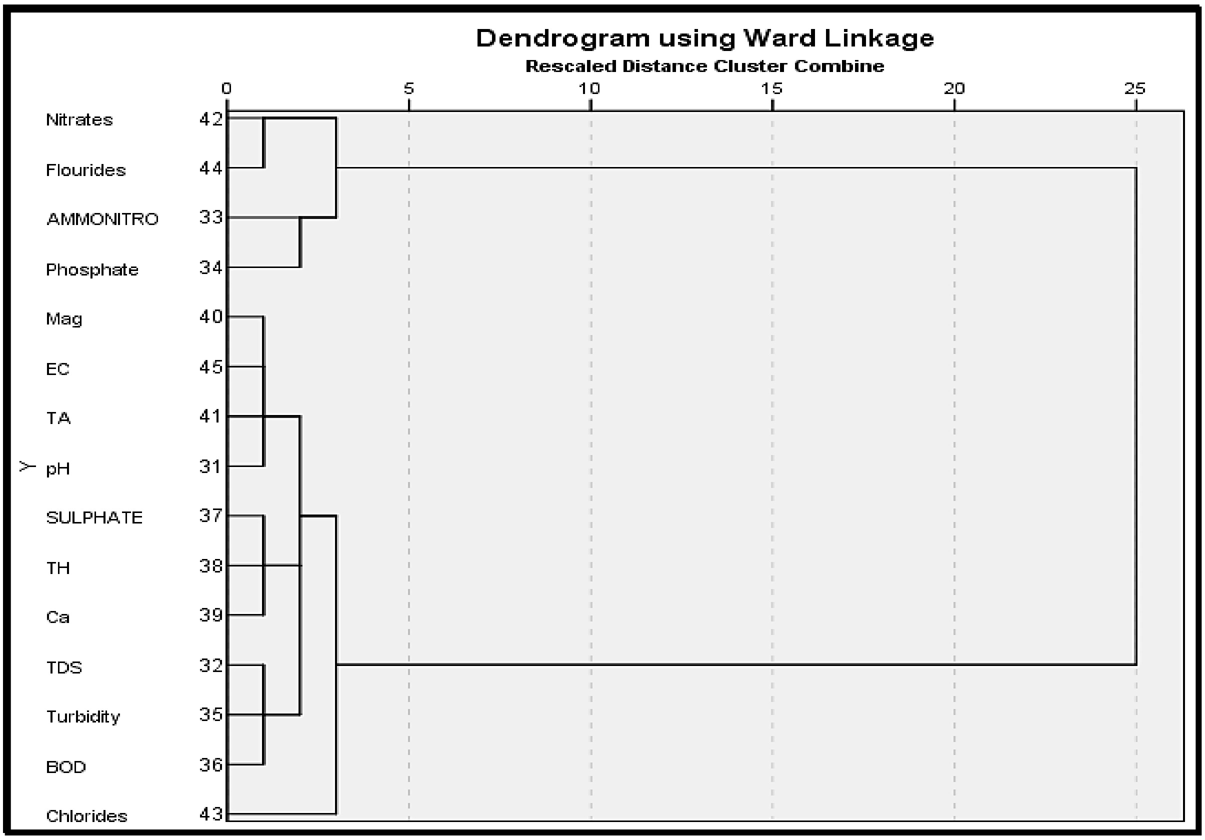


Figure 6.22: Hierarchical dendogram for ground water samples in Panchkula

6.4 Summary and Discussion

The present study reveals the extent to which open dumping of MSW has led to the contamination of the nearby ground water due to percolation of the leachate. The leachate generated affects the ground water quality in the adjacent areas through percolation in the sub-soil. The ground water quality of nearby sites of municipal solid waste landfill sites are of poor quality since they are contaminated due to leachate. The ground water quality improves with the increase in distance from the source of pollution. The WQI indicated the majority of the ground water samples belong to poor quality of water using the OWQI method for the study locations but were classified poor only for Chandigarh while Mohali and Panchkula showed good water quality characteristics using WQI-BIS 10500 method. However, in reality the groundwater conditions for Mohali and Panchkula are on the cusp of being graded 'poor' from 'good' quality as there WQI values are very close to the borderline classifications. It was further concluded that quality of groundwater increased with downstream distances with poor quality being characterized as good quality. Multivariate statistical technique (PCA and HCA) suggests that the components of the PCA accounts for

88%, 87.1% and 87.8% of the total variance in the dataset for Chandigarh, Mohali and Panchkula cities respectively. The components in Chandigarh and Panchkula cities is dominated by high positive loading in electrical conductivity, calcium, magnesium, nitrates and sulphate and for Mohali by fluorides, chlorides, nitrates, total dissolved solids and ammonical nitrogen. Cluster analysis helped to group the sampling sites each for Chandigarh, Mohali and Panchkula into three clusters of similar characteristics. It further helps to examine the quality of water and sources of pollution. In the future, it is recommended to have an engineered landfill sites for each of the three cities which can control the impact of leachate on the ground water.

CHAPTER-7

LIFE CYCLE ASSESSMENT OF MSW MANAGEMENT STRATEGIES IN TRICITY

7.1 Introduction

With the rapid increase in population of urban areas, the supervision of environmental and public health sector has been a major challenging task for municipal authorities. The management of MSW is one of the major challenges for Indian megacities [163, 195, 138, 194]. Dumping of MSW into open dumping sites is the most common method used for disposal of waste in most of the cities of India. These dumping sites are serious threats to environment and sustainable development. Therefore, it becomes vital to analyse the effect of MSW disposal at present and what would be the impact under integrated waste management scenarios [5, 195, 219, 220, 130]. Life Cycle Assessment (LCA) can be an important tool to reduce environmental impacts by identifying the most significant causes of these impacts. LCA is a compilation and evaluation of the inputs, outputs and potential environmental impacts of a product or a system throughout its life cycle [104, 219, 221, 222]. The use of LCA had started in 1960's for evaluation of the limitation of raw materials and energy use with the main focus primarily on the energy and resource requirement of the waste [28, 29, 189, 190, 200]. LCA is a useful environmental management tool which attempts toforecast the environmental aspects and potential impacts throughout a waste life, cradle to grave options within a system boundary [99, 169, 188, 173]. Different waste management systems and their various environmental effects can be evaluated using LCA models [22, 23, 134, 192, 220, 221]. LCA process is a systematic approach and consists of the following four major components: (a) goal and definition and scoping that define and describe the product, process or activities, (b) life cycle inventory analysis, (c) life cycle impact assessment and (d) interpretation of results. An explanation of these LCA terminologies is as given in *Table 7.1*. The methodology of LCA with its major components is represented in figure *7.1*.

Table 7.1: Life Cycle Terminology

Goal Definition and Scope	This stage defines the purpose or objective of the study, system boundaries, unit processes and scope of assessment. The functional unit is defined in this stage. The Functional unit is defined as the unit of analysis to be studied and gives a basis for comparison if more than one system or product is being studied.
Life Cycle Inventory Analysis (LCI)	It is the method which accounts for all the inputs and outputs of the system over the life cycle. It includes the raw materials, energy inputs and emissions to environment in the form of air, water and as solid waste which describes the environmental burdens.
Life Cycle Impact Assessment (LCIA)	This stage deals with all the environmental issues caused due to the system viz., ozone depletion, acidification, eutrophication etc.
Life Cycle Interpretation	It evaluates the significance of inputs and outputs of the system cycle. This is the final stage of LCA which reviews all the stages in LCA.

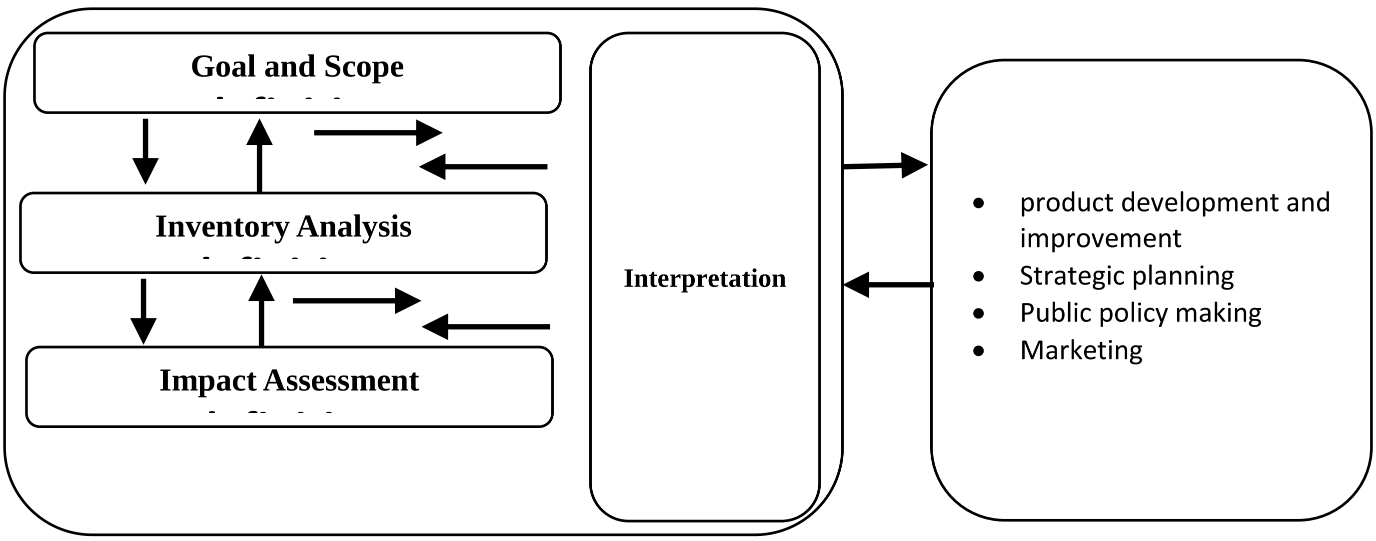


Figure 7.1: Different phases of LCA

The LCA can be used as a tool for assessing environment by comparing and analyzing the environmental impacts of MSW management systems [188, 191]. Hence, in the last decade a number of studies [51, 159, 192,194, 195, 223] have used LCA as a comparative tool for MSW strategies. A study [224] conducted focused on LCA of MSW management of Kathmandu city, compared three different scenarios. The study carried out, determined the best suitable and sustainable MSW management scenario and concluded that scenario comprising of composting and landfilling gave the least environmental impacts. On the similar base, a study accomplished by [43] compared five different scenarios of MSW management as alternative to the current waste management practice in Turkey concluded that the scenario with ablend of recycling and composting is the most environmentally preferred alternative. Research investigated [223] the waste management system of Karaj city and it was concluded from the study that recycling and composting lessen the load of pollutants in the environment. Another research [225] stated that environmental assessment of MSW management scenarios would help to select the most eco-friendly scenarios. An inventory data for different scenarios was presented and it was revealed that the most eco-friendly scenario to be implemented in future would be a combination of anaerobic digestion and incineration.

A study compared [194] six different MSW management scenarios in Yogyakarta, Indonesia and concluded that a combination of gasification and anaerobic digestion is the best option with regard to the environmental impacts. Another research studied [195], five different MSW waste treatment scenarios. Scenario which was a combination of source separation and incineration was found environmental favorable among the rest of the options. This methodology is much in practice in other World countries; however, it is not much used for MSW management in India.

Technological options for MSW management in Delhi [226] were suggested through three different scenarios using LCA approach. It was concluded that sanitary landfilling with energy recovery is the best option to be utilized with respect to reduction in environmental impacts. Similarly, another study [51, 52] conducted in Delhi, evaluated the environmental emissions based on LCA methodology by examining different MSW management options, considering, recycling, composting, incineration and landfilling and also predicted quantity and composition of MSW of Delhi till the year 2024. The results indicate that recycling has least environmental impacts.

Researcher compared [192] six scenarios in Mumbai city, India, and found the recycling, compositing and sanitary landfilling option superior to the other scenarios. Different studies have shown that the impact on environment vary from one city to another because of the different waste composition as well as different environmental conditions. Therefore, the choice of technology may not be the same for all cities.

There are numerous tools for conducting LCA or for supporting the different applications and phases in LCA. A number of LCA softwares or models have been developed for assessment of the products and processes involved, but mainly the models targeted for the waste managementare being made in use [20]. For a good LCA to be performed understanding about the key parameters is essential. The key parameters include the formation of system boundaries and input data [28, 29,158, 191, 220,224, 130]. The models based on LCA include integrated waste management (IWM)-1 and 2, WARM, ORAWARE, WASTED, WIZARD, EASWASTE, SimaPro, Gabi, WRATE, MSW-DST etc. The most commonly and widely used software in the field of MSW nowadays is SimaPro software. This software usually treats the waste as a set of separate fractions and not as a whole mass, which gives it an edge over other used softwares. Other commonly used software for MSW LCA analysis is Gabi software but it faces certain drawbacks like the database need to be downloaded over an again for every process and the available data base sets are decade old in comparison to SimaPro software.

Keeping in view the above, the present study analyses the impacts of different potential MSW management scenarios in Chandigarh, Mohali and Panchkula, respectively using the LCA methodology. Five MSW management scenarios, including the current MSW management system were analysed for each of the three cities. The sensitivity analysis of recycling rate has also been analyzed for Tricity in current waste management situation. The research results can help the decision makers evaluate strategies for the treatment of MSW from an environmental impact point of view. The impact categories analysed are global warming, acidification eutrophication and human toxicity.

7.2 Materials and Methods

7.2.1 MSW management scenarios

In the current study, five scenarios were analysed reflecting different MSW management systems that could be potentially used for Chandigarh, Mohali and Panchkula, respectively as shown in *Table 7.2*. Since, the scenarios are assumed not to influence MSW generation so same amount and composition of MSW are taken in all the scenarios.

Scenario 1(Baseline scenario): Business as usual (BAU) corresponds to the current MSW management practice in Chandigarh, Mohali and Panchkula.

In Chandigarh, out of the total 380 tons per day of MSW generated, approximately 70% is directed to the refuse derived fuel (RDF) plant and rest 30% is dumped in open dumping (OD's) sites. In Mohali and Panchkula, the total 150 tons per day waste generated is directly dumped in OD's. Except for the BAU, all the scenarios assumed were same for Chandigarh, Mohali and Panchkula respectively.

Scenario 2 (Material recovery facility_Sanitary Landfilling-(MRF_SLF): The scenario MRF_SLF will be the simplest approach in future for converting the open dumps into sanitary landfills. This scenario assumes that 20% of the recycled materials are recycled, while rest of the waste is sanitary landfilled (SLF). The recycling rate is based on the recycling rates as assumed at material recovery facilities study in Pune, India (Annepu, 2012). It was also assumed that sanitary landfill is equipped with energy recovery facility with 50% biogas released from the sanitary landfill is collected and then used for generation of electricity and rest would escape to the atmosphere.

Scenario 3 (Material recovery facility_composting_sanitary landfill (MRF_COM_SLF): This scenario explores the potential to reduce the environmental impacts of MSW by assuming that 20% of the recycled materials like glass, paper and plastics is recycled through MRF and rest 80% of the biodegradable is composted (COM) and the remaining fraction is sent for disposal into sanitary landfill.

Scenario 4 (Material recovery facility_composting_anaerobic digestion_sanitary landfill (MRF_COM_AD_SLF): This scenario assumes that along with 20% of the recycled material being recycled, 60% of the biodegradable waste is composted and 20% of the waste is anaerobically digested (AD). The remaining fraction of waste is sent to the sanitary landfill and biogas is used for electricity generation.

Scenario 5 (Material recovery facility_composting_incineration (MRF_COM_INC): Due to presence of high moisture content in waste, this scenario introduced the composting along with MRF and incineration. In this scenario 20% of the recycled materials are recycled and 40% of the biodegradable waste is composted while rest of the waste incinerated.

Table 7.2: Description of scenarios used in LCA of MSW for Tricity

Scenario	Description
Scenario 1: Baseline scenario (BAU)	Business as usual represents the present MSW management practice in Tricity
Scenario 2: Material recovery facility_Sanitary Landfilling (MRF_SLF)	20% recycling + rest of the waste to sanitary landfilling with 50% biogas collection and electricity production
Scenario 3: Material recovery facility_composting_sanitary landfill (MRF_COM_SLF)	20% recycling + 80% of the biodegradable waste is composted (COM) and remaining fraction is sent to disposal into sanitary landfill with 50% biogas collection and electricity production
Scenario 4: Material recovery facility_composting_anaerobic digestion_sanitary landfill (MRF_COM_AD_SLF)	20% recycling+60% composting +20% anaerobic digestion and rest sent to landfill with 50% biogas collection and electricity production
Scenario 5: Material recovery facility_composting_incineration (MRF_COM_INC)	20% recycled through MRF +40% composting and rest is sent to incineration with electricity production

7.2.2 Life Cycle Assessment (LCA)

LCA has been extensively used tool to evaluate solid waste management systems. In the present study, the methodological framework used the International Organization for Standardization (ISO) 14040:2006 methodology for LCA. As per ISO14040:2006 [226] , LCA consists of four phases: Goal and scope definition which defines the purpose of the study, Life cycle inventory which focuses on quantification of energy and mass, Life cycle impact assessment which aims at evaluating the significance of potential environmental impacts of a system, and interpretation of results which helps to reach the conclusion.

7.2.2.1 Goal and Scope Definition

In order to achieve environmental stability the MSW management scenarios were compared in an LCA context. The goal of the study is to assess the environmental impacts of the MSW management system in Chandigarh, Mohali and Panchkula, respectively using LCA methodology. Five scenarios of MSW management that include various treatment, processing and disposal methods were developed in the study and then compared with respect to the environmental burdens like global warming potential (GWP), eutrophication potential (EP), acidification potential (AP) and human toxicity potential (HTP) for each of the three cities of Chandigarh, Mohali and Panchkula. The comparison among the scenarios was done using the MSW composition characteristics as described in Chapter 4.

7.2.2.2 Functional Unit

The functional unit for the comparison of MSW managementsystems used in the present study is one ton of MSW in each of the three cities of Chandigarh, Mohali and Panchkula.

7.2.2.3 System Boundary

The system boundary of study starts with the collection of MSW, transportation of the waste to its treatment and final disposal. The system boundary makes the study easier, helps in comparing options and making decision easier [27, 28, 29, 191]. All the significant processes included within the boundary of the MSW management system are as shown in *figure 7.2*. MSW, energy and mass are the input to the MSW management system and all the outputs considered are air and water emissions, generation of compost, digestate and electricity from the processes. The system boundaries selected for the study include direct emissions viz., emissions associated with different MSW treatment facilities like recycling, sanitary landfilling, composting, anaerobic digestion, incineration and the indirect emissions like fuel requirement and supply of electricity.

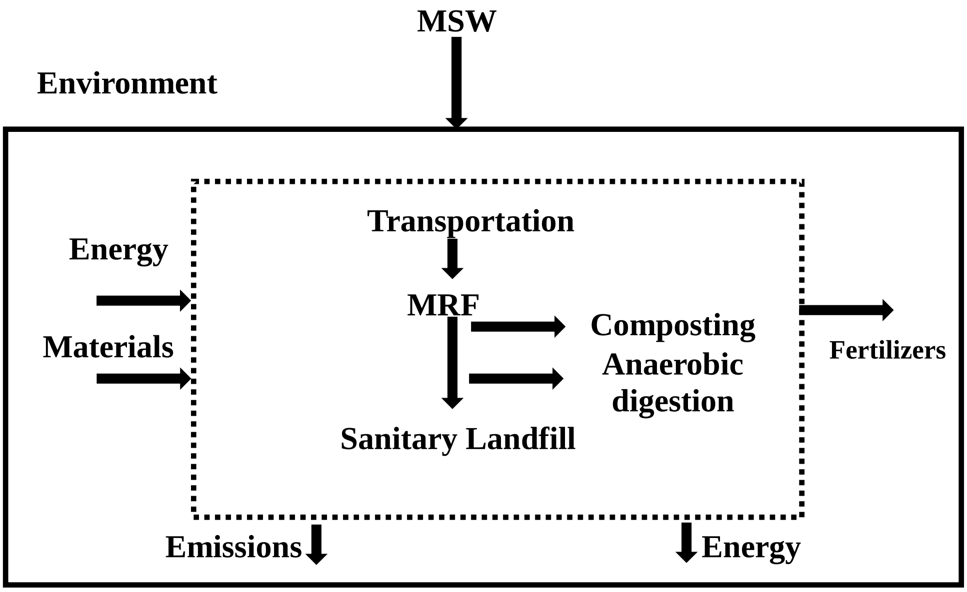


Figure 7.2: System boundary of MSW management system for Tricity
(MRF: material recovery facility, MSW: municipal solid waste)

7.2.3 Life Cycle Inventory Analysis (LCI)

LCI denotes the compiling of a specific set of inputs and outputs related with a product or process [20, 73, 227]. It helps to predict the environmental performance. LCI is a phase of data collection related to all the inputs and outputs of the study. LCI aims at classifying and measuring the environmental interventions related to the study [194, 195]. The LCI data used in the present study was collected from on-site investigations, different references [20, 28, 29, 73, 226, 194, 195, 68,189, 190, 192, 121,219, 220, 222, 225, 228], data from the municipal authorities (population, waste generation, waste processing and transportation) in each respective city and the database Ecoinvent 2.2. Until now, no relevant life cycle inventory data bases are available and with addition to this a very little public data in regard with MSW management system are available. The attainment of adequate LCI data in the present study turned out to be very difficult due to absence of any data and research studies in the study area related to LCA. The data for energy consumption, input, resource recovery, emissions of pollutants to water and air were computed for all the scenarios. The major components of LCI are identified at each stage starting from MRF, composting, landfilling, thermal processes to final landfilling.

The input data's are those that are derived from the non-renewable sources like fuel, which is required in transportation and management of waste. The direct and indirect emissions considered in the study were taken from various literatures, references and data base of SimaPro version 8.3.0, Eco-Indicator 99 (H) and Eco-Invent methodand included the inputs from the recycling facilities, composting, sanitary landfilling, anaerobic digestion, incineration and supply of electricity and fuel requirement respectively.The inventories of resource use and by-products for various processes are as represented in *Table 7.3*.

Table 7.3: Life Cycle Inventories for Tricity

Inputs	Value	Units
Landfill[a]		
Diesel	3	Lt^{-1}
Net electrical efficiency	20	%
Material Recovery Facility [b]		
Diesel	3.21	Lt^{-1}
Electricity	3.2	kWh t^{-1}
Composting[c]		
Diesel	0.52	Lt^{-1}
By-products		
Compost	130	Kgt^{-1}
Anaerobic Digestion[d]		
Net Electrical Efficiency	20	%
By-products		
Digestate	100	Kgt^{-1}
Incineration[e]		
Net Electrical Efficiency	20	%
By-products		
Ash	140.8	Kgt^{-1}

[[a]195, 192, 121; [b]222, 195; [c]51, 219;[d]73, 195; [e]194, 195, 194, 192]

The data used for the current study were population of the Tricity, waste characteristics, and rate of waste collection and data of dumping site. The MSW composition of Chandigarh, Mohali and Panchkula, respectively has been considered as given in Chapter 4 to check the influence of MSW composition on total environment profile of each scenario in each case for each city. Transportation of MSW to the disposal site is also included in the system boundary. Three different types of vehicles (tractor trolleys, dumpers and compactors) are used for transportation of MSW to the final disposal site in Tricity. The emissions from the transportation of waste from Chandigarh, Mohali and Panchkula, respectively were obtained from the database of SimaPro software version 8.3.0, Eco-Indicator 99 (H) and Eco-Invent methodand literature and have been described in *Table 7.4*.

Table 7.4: Emissions from transportation of MSW in Chandigarh, Mohali and Panchkula

Substances	**Emissions (gt^{-1})**		
	CHD	**MOH**	**PKL**
PM	115.86	112.28	114.82
CO_2	156.79	191.32	142.11
NO_x	103.21	141.61	98.63

In open dumping, the direct CO_2 emission is of biogenic origins which were not considered for greenhouse gas (GHG) emissions. The emissions suh as particulate matter (PM), nitrous oxide (N_2O), nitrogen oxides (NO_x), ammonia (NH_3) and Sulphur oxides (SO_x) have been obtained from the data base of SimaPro, literature [195, 228]. The emissions to water in the form of total nitrogen (N) and phosphorous (P), chromium (Cr),cadmium (Cd), arsenic (As), copper (Cu), lead (Pb), zinc (Zn), mercury (Hg) and nickel (Ni) were attained from previous studies [188, 192, 195] and the data base of the SimaPro software version 8.3.0, Eco-Indicator 99 (H) and Eco-Invent method. The inventory data of the environmental emissions from the production of 1MJ of electricity and production of mineral fertilizer (SimaPro version 8.3.0, 222, 225] are as shown in *Table 7.5* and *7.6.*

Table 7.5: Environmental emissions resulting from production of 1MJ of electricity (Indian Grid and 1 Liter (L) of Diesel

	Electricity grid mix (Indian grid) (MJ)	Diesel (L)
Global warming potential (GWP)	0.281	0.374
Acidification potential (AP)	0.00289	0.00176
Eutrophication potential (EP)	0.000212	0.000182
Human toxicity potential (HTP)	0.10	0.05

[SimaPro software version 8.3.0 database, 2015, 225]

Table 7.6: Environmental Emissions from production of mineral fertilizers

Mineral Fertilizer	Global warming potential (GWP) $kgCO_2$ eq kg^{-1}	Acidification potential (AP) $kgSO_2$ eq kg^{-1}	Eutrophication potential (EP) $kgPO_4^{3-}$ kg^{-1}	Human toxicity potential (HTP) Kg1, 4-DB eq kg^{-1}
Nitrogen	4.7	0.0376	0.0202	0.0188
Potassium	0.2	0.0412	0.0319	0.042
Phosphorous	0.09	1.89E-3	1.1E-3	0.031

[SimaPro software version 8.3.0 database, 2015; 225]

For sanitary landfilling, the data used for estimation of gases, transportation and production of electricity has been obtained from various literatures [129, 158, 222, 225, 194, 192, 195, 73] and the data base of SimaPro version 8.3.0, Eco-Indicator 99 (H) and Eco-Invent method.

The emissions processes and estimation from composting and anaerobic digestion were based on the studies as described in literature [3, 6, 104, 121, 158, 227, 192, 225] and SimaPro version 8.3.0 database and Eco-Indicator 99 (H) method.

7.2.4 Life Cycle Impact Assessment (LCIA)

LCIA is the phase of LCA which intends at understanding and associating the inputs and outputs with particular environmental issues. It is composed of several mandatory elements that convert the LCI result to indicator result. So far at present, necessary information in order to perform LCIA and scientific methods for long term assessment does not exist. The important elements of LCIA are: classification and selection of impact categories (selected on the basis of goal and scope of study), characterization (assigning of impact indicators), normalization and weighting (converting indictor results to impact categories).

In the present study, the emissions accounted for inventory stages have been allocated into four impact categories: global warming, acidification, eutrophication and human toxicity. As per the basic model for LCA (ISO 14040:2006) [226], the impact categories and indicators considered are as follows:

- **Global warming potential (kg CO_2 eq t^{-1})**- In LCA methodologies, the greenhouse effect is quantified by using global warming potential for substances having the same effect as CO_2 in reflection of heat radiations. It is generally expressed as CO_2 equivalents. The global warming potential of a product or process can be estimated by calculating the amount of greenhouse gases emitted per functional unit.
- **Acidification potential (kg SO_2 eq t^{-1})** -The primary contributors to acidification are oxides of nitrogen, sulfur and ammonia. Acidification potential is quantified by using the acidification of substances having same effect as SO_2 in reflection of acidification. It is expressed as SO_2equivalents i.e., potentials relative to SO_2.
- **Eutrophication potential (kg PO_4^{3-} eq t^{-1})** –Eutrophication or nutrient enrichment leads to oxygen depletion. Major contribution to the impact category is from nitrogen and phosphorous. Mostly the loading of nitrogen and phosphorous is due to the discharge from the municipal or sewage and agriculture. The total eutrophication potential expresses the emissions from a substance as an equivalent emission of the reference substance PO_4^{3-}.

- **Human toxicity potential (kg 1,4-DB eq t^{-1})**–In context of LCA, the human toxicity covers many effects like acute toxicity, corrosive effects, allergenic effects, irritation effects, carcinogenic effects, genotoxic effects, irreversible damage, organ damage, toxicity to reproductive system and neurological disorders in a single parameter. The equivalence factors are quantified for emissions to different sections as: air emissions, water emissions and soil emissions and exposure via various mediums like air, water and soil.

The LCIA was constructed for the study using SimaPro software version 8.3.0 and expressed with the Eco-indicator 99 (H) method. Eco-indicator 99 method is a multi-step aggregating method which helps in leading result of a single number [194] and helps in making the comparison between different MSW management scenarios.

7.2.5 Life Cycle Interpretation

This is the final stage of LCA that includes the reviewing of all the stages during LCA. All the data was analysed and the findings were combined with the defined goal and scope of the study.

Review of LCA software used for MSW management in Tricity

There are many examples of the software tools used to support LCA assessments. The programs like SimaPro, Gabi, Integrated waste management models (IWM-1, 2), environmental assessment of solid waste systems and technologies (EASEWASTE), waste resources assessment too, for environment (WRATE), waste-integrated systems for assessment of recovery and disposal (WISARD) and organic waste research (ORWARE) to name a few have been used to evaluate existing as well as model new waste management systems.

In the present study, SimaPro software packages were used. SimaPro was developed by PRé Consultants with a goal of making more fact based studies. SimaPro software version 8.3.0 (PRé Consultants 2015) is a professional tool which helps in monitoring the sustainability performance of a product or process. It was developed for an integrated waste management, life cycle analysis, carbon and water foot printing, product design, generating environmental product declarations, determining key performance indicators and sustainability reporting. The MSW stream in its life cycle is followed in this software. SimaPro database is structured in three main parts: project data, library data and general data. It develops the complex life cycles hence saving lot of time. Each of the stages in the life cycle of MSW management scenarios is represented and stored in the software: goal and scope definition, data quality profile, process data, product storage data, impact assessment methods and data on results interpretation. SimaPro software is fully complaint with ISO 14040/14044 providing complete LCI and LCIA capabilities. A life cycle of a product or process is modeled as a collection of assemblies (collection of waste, substances, chemicals, processes and materials), processes, and waste, treatment and disposal scenarios. Multiple libraries of databases are available in the software containing predefined materials, substances, processes, wastetreatments for products and various impact assessment methodologies which can be used for formation of a model for a particular study. The data entry in the software is done in following steps:

1) Inspect goal and scope
2) Inspect the processes in database
3) Analyze the environmental profile of a product or process
4) Generation of process network
5) Analyzing full life cycle
6) Comparing products or processes in production stage
7) Compare life cycles
8) Perform sensitivity analysis
9) Inspect of select the method
10) Inspect the interpretation section

The input information related to the composition of MSW from Tricity was entered in the SimaPro software version 8.3.0. On the basis of the data entered, the software calculated emissions based on various scenarios making use of Eco-indicator 99 method and Ecoinvent database and various literatures.

7.2.6 Sensitivity Analysis to Recycling Rates

The sensitivity analysis is used to check the strength of LCI stage with the main aim to identify how the final results are influenced by uncertainties in the data and to calculate the results of LCA in order to assess its reliability [194, 192]. The sensitivity analysis identifies sensitive parameters and assess whether a small change in an input parameter would induce a large change in the impact category. For sensitivity analysis, firstly the identification of the main assumptions are made and then calculation of the results along with confirmation of whether the conclusion changes is performed.

In the present study, input parameters for sensitivity analysis focus on the recycling rate. Recycling is the important parameter in MSW management as resource recovery and reduction of waste can be obtained efficiently through recycling. In regard with the resource recovery; the recycling represents the opportunities for increasing the utilization of materials and thus reducing the need for production of virgin materials. Studies [71, 75, 219, 194, 195, 192] have shown that the economic impact of recycling includes an evaluation of current recyclable market value of materials and market trends. The results concluded that most economic and environmental friendly recycling rate is 50%. The environmental implications of recycling depend upon the substance being recycled and for what purpose. For the present study, the materials considered for the recycling are paper, plastics, glass, metals, leather and textiles and the total amount of these recyclable materials for MSW composition for Chandigarh, Mohali and Panchkula are 15%, 13% and 14% respectively. The impact of the different recycling rates of 10%, 50% and 90% on each scenario was analysed.

7.3 Results and Discussion

7.3.1 Quantification of Environmental Impacts

SimaPro software version 8.3.0 was run for each of the scenario for Chandigarh, Mohali and Panchkula based on the data collected at the inventory analysis stage. The environmental emissions under different scenarios for Chandigarh, Mohali and Panchkula are presented in *Table 7.7, 7.8* and *7.9* respectively. The emissions considered are GHG's (CO_2, CH_4 and N_2O), particulate matter (PM), acidic gases (SO_x, NO_x and NH_3), total nitrogen (N) and phosphorous (P), dioxins, cadmium, copper, lead, nickel, chromium, arsenic, zinc and mercury in both water and air emissions.

One of the main goals of the waste disposal system is to minimize the stream of waste entering the landfills. When the MSW is directly sent to the landfill, without giving any prior treatment, it undergoes anaerobic decomposition leading to release of high amount of gases like methane, nitrous oxides, nitrogen oxides, carbon monoxide and carbon dioxide. The biodegradable fraction in MSW also releases large amount of nitrogenous and phosphorous compounds. They all contribute towards the global warming, acidification, eutrophication and human toxicity. The ratio of the landfilled waste to the waste generated act as an indicator of the efficiency of the waste disposal system. The results of global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP) for Chandigarh, Mohali and Panchkula, respectively are displayed in *figures 7.3- 7.6*. The results of all the environmental impacts are symbolized as (a) for Chandigarh, (b) for Mohali and (c) for Panchkula respectively.

Table 7.7: Emissions under each scenario for Chandigarh

	Scenario				
	OD(BAU)	**MRF_COM_SLF**	**MRF_SLF**	**MRF_COM_INC**	**MRF_COM_AD_SLF**
Emissions to air					
Carbon dioxide, fossil (kg)	71.63	4.40	9.90	44.22	5.58
Methane (kg)	0.19	0.03	0.01	0.10	0.02
Nitrogen oxides (kg)	0.79	0.15	0.48	1.01	0.27
Ammonia (g)	0.26	0	0	0.01	0
Sulfur dioxide (kg)	0.24	0.08	0.48	0.95	0.19
Arsenic (µg)	13.69	2.07	1.65	7.52	1.53
Cadmium (µg)	1.89	0.66	0.73	1.36	0.55
Chromium (µg)	1.19	0.04	0.01	0.48	0.02
Copper (mg)	99.42	15.83	25.77	66.90	17.18
Dioxins (µg)	1.65E-04	0.83E-06	0.43E-05	0.91E-05	0.51E-05
Nickel (mg)	39.39	5.62	8.63	30.14	5.78
Zinc (mg)	97.45	15.72	22.43	142.95	14.66
Lead (mg)	130.13	10.41	9.18	77.74	8.05
Mercury (mg)	3.63	0.30	0.20	5.81	0.28
Particulate Matter, < 2.5µm (µg)	90.18	7.11	16.96	41.33	6.36
Carbon dioxide, biogenic (kg)	1.76	1.47	1.84	1.32	0.96
Emissions to water					
Total Nitrogen (kg)	0.35768	0.09527	0.30547	0.57081	0.39441
Total Phosphorous (kg)	0.20548	0.01314	0.03141	0.13011	0.04727
Arsenic (µg)	73.58	15.82	22.30	165.23	12.68
Cadmium (µg)	20.24	7.36	7.45	78.24	5.68
Chromium (µg)	10.28	0.56	1.79	7.71	0.93
Copper (µg)	1.40	0.31	0.03	2.21	0.21
Lead (µg)	8.21	23.80	8.38	123.71	15.73
Mercury (µg)	7.06	0.40	1.28	4.91	0.35
Nickel (µg)	7.35	0.30	0.49	3.88	0.21
Zinc (µg)	1.40	0.55	0.75	4.83	0.48

Table 7.8: Emissions under each scenario for Mohali

Scenario					
	OD(BAU)	**MRF_COM_SLF**	**MRF_SLF**	**MRF_COM_INC**	**MRF_COM_AD_SLF**
Emissions to air					
Carbon dioxide, fossil (kg)	71.63	27.40	29.90	44.22	5.581
Methane (g)	70.19	25.03	27.01	43.10	4.02
Nitrogen oxides (g)	69.07	24.01	26.04	41.10	3.02
Ammonia (g)	130.60	50.37	48.54	140.96	63.31
Sulfur dioxide (g)	128.51	48.05	46.76	137.40	61.29
Arsenic (µg)	126.89	43.66	45.73	135.36	59.55
Cadmium (µg)	125.19	41.04	45.01	134.48	58.02
Chromium (µg)	124.42	39.83	44.77	133.90	57.18
Copper (mg)	123.50	36.03	44.16	132.24	57.16
Dioxins (µg)	122.63	32.30	43.20	131.81	56.28
Nickel (mg)	120.13	27.41	42.18	129.74	54.05
Zinc (mg)	119.45	22.72	40.43	127.95	52.66
Lead (mg)	119.45	22.72	40.43	127.95	52.66
Mercury (mg)	121.39	30.62	42.63	130.14	55.78
Particulate Matter, < 2.5µm (µg)	90.18	7.11	16.96	41.33	6.36
Carbon dioxide, biogenic (g)	1.76	1.47	1.84	1.32	0.96
Emissions to water					
Total Nitrogen (kg)	0.35768	0.09527	0.30547	0.57081	0.39441
Total Phosphorous (kg)	0.20548	0.01314	0.03141	0.13011	0.04727
Arsenic (µg)	73.58	15.82	22.30	165.23	12.68
Cadmium (µg)	20.24	7.36	7.45	78.24	5.68
Chromium (µg)	10.28	0.56	1.79	7.71	0.93
Copper (µg)	1.40	0.31	0.03	2.21	0.21
Lead (µg)	8.21	23.80	8.38	123.71	15.73
Mercury (µg)	7.06	0.40	1.28	4.91	0.35
Nickel (µg)	7.35	0.30	0.49	3.88	0.21
Zinc (µg)	1.40	0.55	0.75	4.83	0.48

Table 7.9: Emissions under each scenario for Panchkula

Scenario					
	OD(BAU)	**MRF_COM_SLF**	**MRF_SLF**	**MRF_COM_INC**	**MRF_COM_AD_SLF**
Emissions to air					
Carbon dioxide, fossil (kg)	716.37	440.01	390.90	442.28	550.81
Methane (g)	710.98	410.35	350.12	432.08	535.22
Nitrogen oxides (g)	680.53	390.25	300.74	411.60	505.38
Ammonia (kg)	1.02	0.10	0.50	1.91	0.50
Sulfur dioxide (g)	0.94	0.08	0.48	1.55	0.39
Arsenic (µg)	98.69	14.07	47.65	139.52	17.53
Cadmium (µg)	93.89	13.66	47.73	137.36	16.55
Chromium (µg)	91.19	13.04	47.01	135.48	16.02
Copper (mg)	89.42	12.83	46.77	133.90	15.18
Dioxins (ng)	87.00	12.00	46.16	132.00	1.50E+01
Nickel (mg)	81.39	10.62	43.63	125.14	13.78
Zinc (mg)	79.45	9.72	43.43	123.95	13.66
Lead (mg)	85.13	11.41	45.18	131.74	15.05
Mercury (mg)	83.63	11.30	44.20	128.81	14.28
Particulate Matter, < 2.5µm (µg)	7.11	90.18	16.96	41.33	6.36
Carbon dioxide, biogenic (kg)	5.79	0.40	0.85	1.01	0.32
Emissions to water					
Total Nitrogen (kg)	0.35768	0.09527	0.30547	0.57081	0.39441
Total Phosphorous (kg)	0.20548	0.0131	0.03141	0.13011	0.04727
Arsenic (µg)	73.58	15.82	22.30	165.23	12.68
Cadmium (µg)	20.24	7.36	7.45	78.24	5.68
Chromium (µg)	10.28	0.56	1.79	7.71	0.93
Copper (µg)	1.40	0.31	0.03	2.21	0.21
Lead (µg)	8.21	23.80	8.38	123.71	15.73
Mercury (µg)	7.06	0.40	1.28	4.91	0.35
Nickel (µg)	7.35	0.30	0.49	3.88	0.21
Zinc (µg)	1.40	0.55	0.75	4.83	0.48

Global Warming Potential (GWP)

Figure7.3 represents the global warming potential for different scenarios assessed for Chandigarh, Mohali and Panchkula, respectively. The baseline (BAU) scenario for all the three cities have found to be contributing maximum green-house gas (GHG) emissions (CHD- 75.63 kg CO_2 eq t^{-1}; MOH- 73.10 kg CO_2 eq t^{-1} and PKL- 731.89 kg CO_2 eq t^{-1}) which is owed to the high emission of methane generation along with other anthropogenic gases and biogenic and fossil carbon dioxide. The biogenic carbon dioxide contributes lesser to greenhouse gas emissions as they are a part of carbon cycle. It can be comprehended from the figures that open dumping scenario (BAU) in all the three cities is producing greenhouse gaseseven more than the assumed incineration scenario as in incineration the greenhouse gases emerge due to burning of fossil or anthropogenic carbon dioxide from plastics, textiles or leather which tends to generate lesser methane as compared to the ones generating from open dumping sites.

BAU was followed by scenario 5: MRF_COM_INC having GHG emissions (CHD- 46.32 kg CO_2 eq t^{-1}; MOH- 45.12 kg CO_2 eq t^{-1} and PKL- 451.35 kg CO_2 eq t^{-1}).

Scenario 3: MRF_COM_SLF produces the least GHG emissions (CHD- 5.03 kg CO_2 eq t^{-1}; MOH- 4.45 kg CO_2 eq t^{-1} and PKL- 59.62 kg CO_2 eq t^{-1}) as due to the benefits generated from the process of composting the biological processes leads to removal of methane from the global warming potential.

This Scenario was followed by scenario 2: MRF_SLF (CHD- 10.40 kg CO_2 eq t^{-1}; MOH- 9.97 kg CO_2 eq t^{-1} and PKL- 58.77 kg CO_2 eq t^{-1}) and scenario 4: MRF-COM_AD_SLF (CHD- 5.87 kg CO_2 eq t^{-1}; MOH- 5.63 kg CO_2 eq t^{-1} and PKL- 83.43kg CO_2 eq t^{-1}).

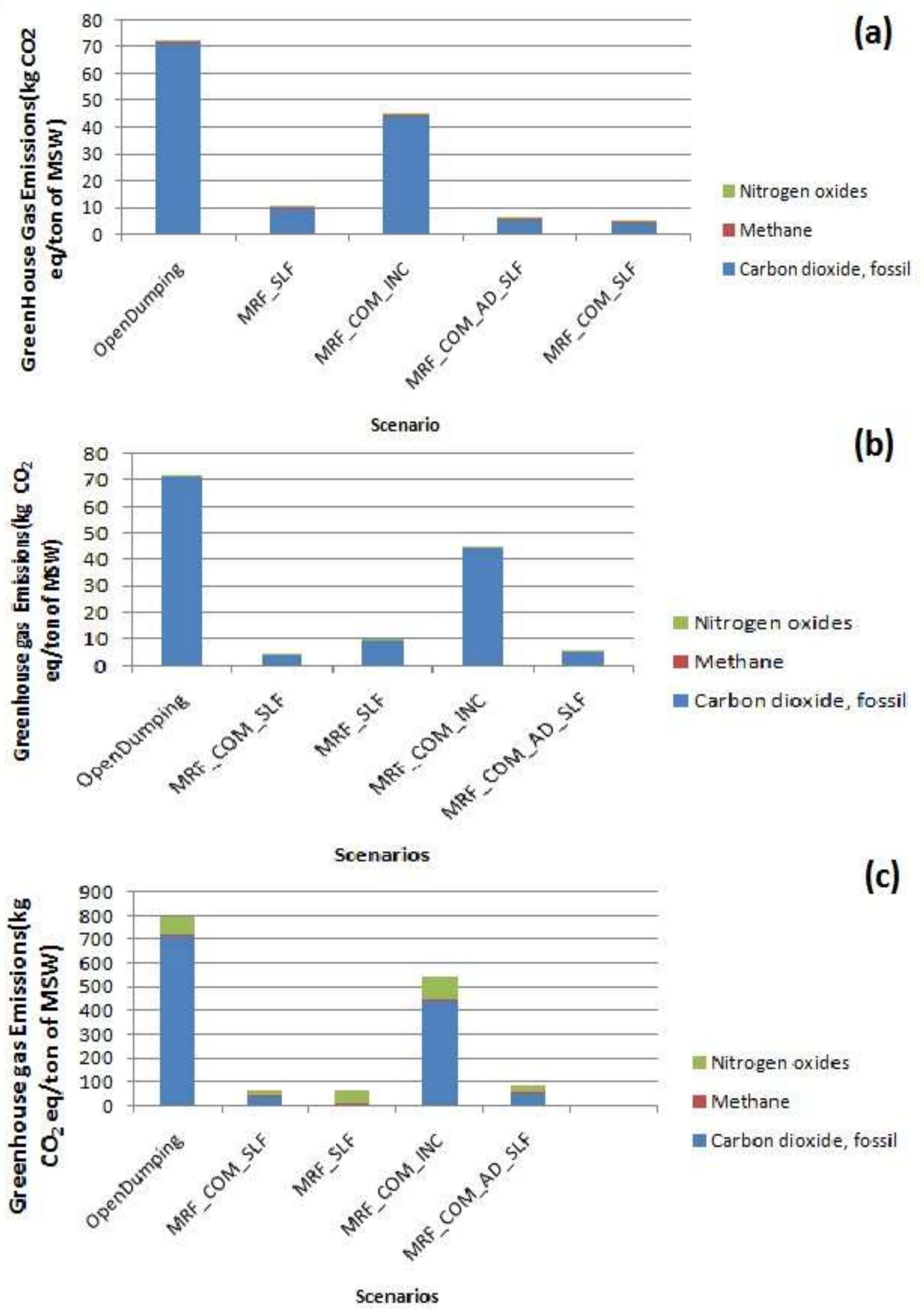


Figure 7.3: Global warming potential under different scenarios for (a) Chandigarh, (b) Mohali and (c) Panchkula

Acidification Potential (AP)

Figure 7.4 represents the acidification potential (AP) for each scenario in Chandigarh, Mohali and Panchkula, respectively. Acidification is an environmental problem mainly caused due to SO_x, NO_x and NH_3 gases and is expressed as kg SO_2 eq t^{-1}. Acidification increases the leaching and mobilization of metals and causes adverse impacts on environment.

The maximum acidification impacts were detected in scenario 5: MRF_COM_INC (CHD- 1.989 kg SO_2 eq t^{-1}; MOH- 1.98 kg SO_2 eq t^{-1} and PKL- 1.95 kg SO_2 eq t^{-1}). As in incineration process due to the combustion of MSW, most of the sulfur and nitrogen compounds present in MSW get converted to SO_x and NO_x gases which in turn lead to high acidification. Major contribution is from N_{Ox} emission due to the presence of mineral fertilizers and characteristic properties of MSW.

This was followed by scenario BAU (CHD- 1.30 kg SO_2 eq t^{-1}; MOH- 1.066 kg SO_2 eq t^{-1} and PKL- 1.12 kg SO_2 eq t^{-1}) as mixed MSW is dumped in the open dumping sites of all the three cities, moreover due to absence of any facilities for the resource recovery causes more environmental impacts. Leachate generated in the open dumping sites with the production of harmful gas like hydrogen sulfide (H_2S) also act as a contributor to the acidification potential.

These were followed by Scenario 2: MRF_SLF (CHD-0.980 kg SO_2 eq t^{-1}; MOH- 0.980 kg SO_2 eq t^{-1} and PKL- 0.91 kg SO_2 eq t^{-1}) and scenario 4: MRF_COM_AD_SLF (CHD- 0.46 kg SO_2 eq t^{-1}; MOH-0.46 kg SO_2 eq t^{-1} and PKL- 0.5 kg SO_2 eq t^{-1}).

Least acidification environmental impacts were observed in scenario 3:MRF_COM_SLF (CHD- 0.17 kg SO_2 eq t^{-1}, MOH- 0.28 kg SO_2 eq t^{-1} and PKL- 0.19 kg SO_2 eq t^{-1}) due to the environmental benefits by a combination of composting and material recovery. The compounds of sulfur and nitrogen get oxidized in the lesser amount resulting in lower emissions of SO_x and N_{Ox} gases.

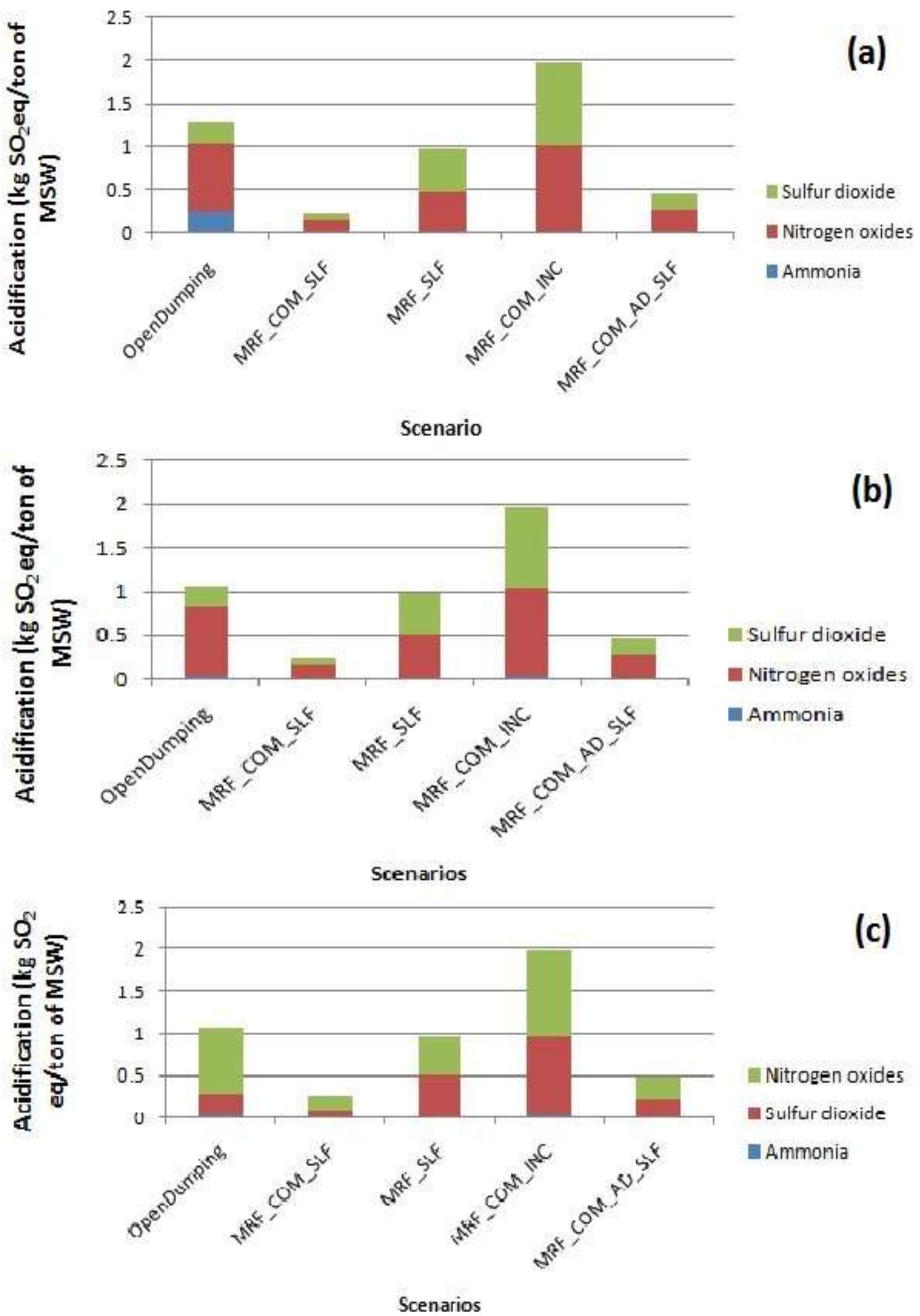


Figure 7.4: Acidification potential under different scenarios for (a) Chandigarh, (b) Mohali and (c) Panchkula

Eutrophication Potential (EP)

Eutrophication is the phenomenon of excess loading of nutrients due to waste, chemical fertilizers, discharged waste water, which triggers the algal growth. It is expressed as kg PO_4^{3-} eq t^{-1}. Nitrogen and phosphorous are the major substances in waste which are key contributor to eutrophication potential. Due to their increased activity, the action of microorganism increases, causing increased consumption of oxygen. Presence of excessive nitrogen can make ground water unfit for use.

Figure 7.5 represents the nutrition enrichment potential or eutrophication potential for each scenario in Chandigarh, Mohali and Panchkula, respectively. It was observed that maximum eutrophication potential was shown in scenario 5: MRF_COM_INC (CHD-0.7009 kg PO_4^{3-}eq t^{-1}; MOH- 0.6995 kg PO_4^{3-}eq t^{-1} and PKL-0.7110 kg PO_4^{3-}eq t^{-1}) due to harmful emissions during the combustion process. It was followed by the scenario BAU (CHD- 0.5001 kg PO_4^{3-} eq t^{-1}; MOH- 0.5009 kg PO_4^{3-}eq t^{-1} and PKL-0.5010 kg PO_4^{3-}eq t^{-1}).

The presence of maximum eutrophication in BAU is attributed to the dumping of MSW in open dumping sites with no provision of liner systems or treatment or collection facility. The biological processes occurring inside the dumping sites leads to the emission of nitrogen and phosphorous compounds. These compounds dissolve along with the leachate and cause more environmental impacts. It was followed by scenario 4: MRF_COM_AD_INC (CHD-0.4416 kg PO_4^{3-}eq t^{-1}; MOH-0.4365 kg PO_4^{3-}eq t^{-1} and PKL- 0.4520 kg PO_4^{3-}eq t^{-1}) and scenario 2: MRF_SLF (CHD-0.3368 kg PO_4^{3-}eq t^{-1}; MOH-0.3151 kg PO_4^{3-}eq t^{-1} and PKL-0.3471 kg PO_4^{3-}eq t^{-1}).

Scenario 3: MRF_COM_SLF produced least eutrophication potential impacts (CHD-0.1084 kg PO_4^{3-}eq t^{-1}; MOH-0.1182 kg PO_4^{3-}eq t^{-1} and PKL-0.1052 kg PO_4^{3-}eq t^{-1}) due to the source separation as well as presence of impermeable synthetic bottom liners in sanitary landfills. Sanitary landfills also help in isolating the waste, thus, minimizing the amount of water entering and gases escaping from the waste.

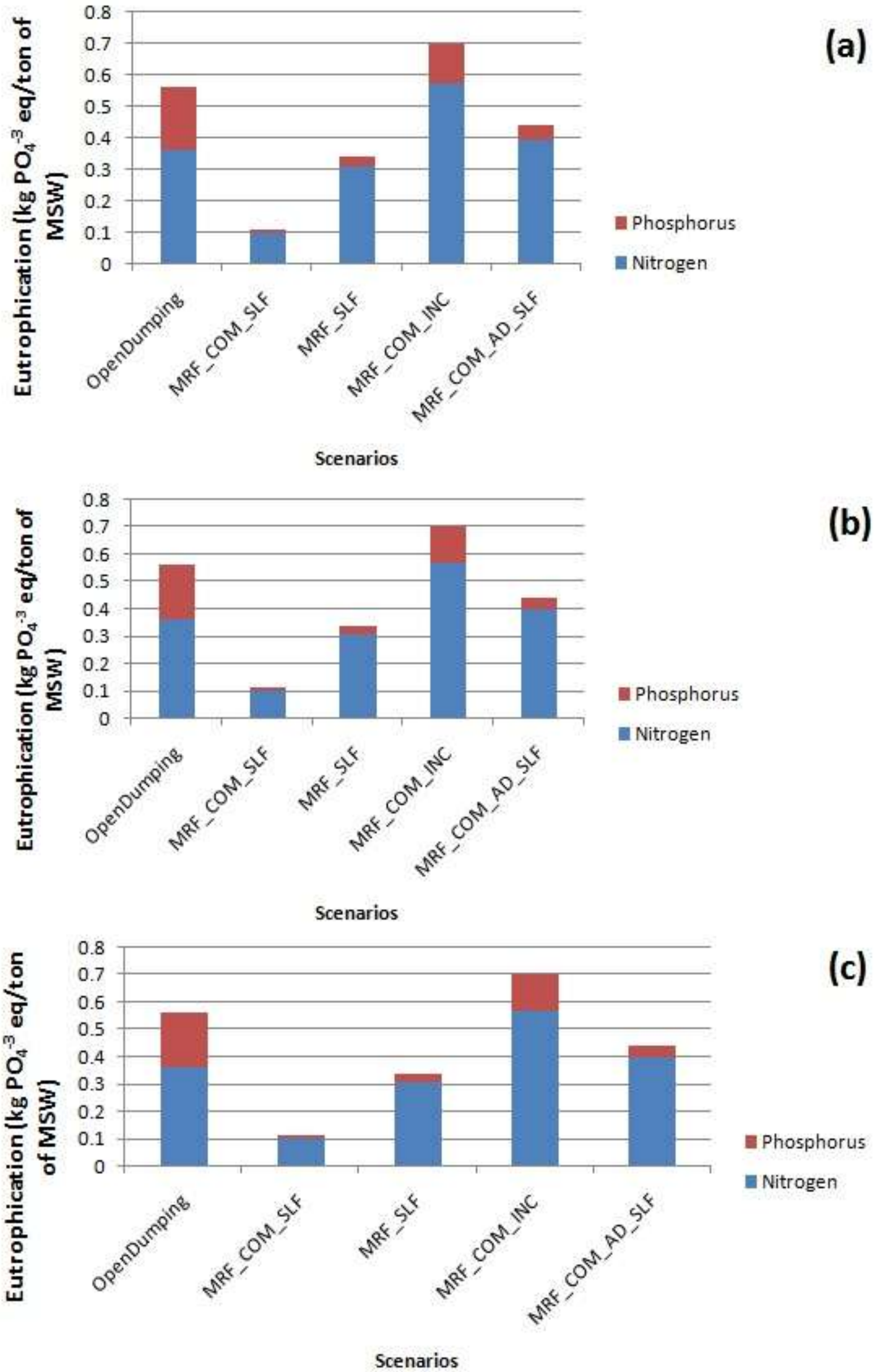


Figure 7.5: Eutrophication potential under different scenarios for (a) Chandigarh, (b) Mohali and (c) Panchkula

Human Toxicity Potential (HTP)

The last impact category was human toxicity potential (HTP) and is expressed as kg 1, 4-DB eq t^{-1}. *Figure 7.6* presents the human toxicity potential for each scenario in Chandigarh, Mohali and Panchkula, respectively. It is an index which evaluates the potential of a unit chemical released in environment. Human toxicity is mainly caused by pollutants like SO_x, $NO_{x,}$ particulate matter, lead, dioxins, copper, chromium, nickel, cadmium, mercury and zinc.

Maximum human toxicity impact was observed in BAU (CHD- 388.12 kg 1, 4-DB eq t^{-1}; MOH-756.43 kg 1, 4-DB eq t^{-1} and PKL- 510 kg 1, 4-DB eq t^{-1}) owing to the absence of any recovered resources and separation facilities in any of the three cities. Unsegregated MSW is sent to these open dumping sites which have no provision of collection and treatment facility for leachate and absence of proper synthetic liner systems. The leachate generated from these sites tends to percolate into ground water thus leading to emission of high toxicity potential.

Scenario 5: MRF_COM_INC also generated high human toxicity potential (CHD- 335 kg 1, 4-DB eq t^{-1}; MOH-620 kg 1, 4-DB eq t^{-1} and PKL- 499.89 kg 1, 4-DB eq t^{-1}) owed to the emissions from heavy metals during the combustion process. It was followed by scenario 2: MRF_SLF (CHD- 53.7 kg 1, 4-DB eq t^{-1}; MOH-170 kg 1, 4-DB eq t^{-1} and PKL-168.1 kg 1, 4-DB eq t^{-1}) and scenario 4: MRF_COM_AD_SLF (CHD-49.9 kg 1, 4-DB eq t^{-1}; MOH-98.9 kg 1, 4-DB eq t^{-1} and PKL-97.6 kg 1, 4-DB eq t^{-1}).

Least human toxicity effects were observed in scenario 3: MRF_C0M_SLF (CHD-50 kg 1, 4-DB eq t^{-1}; MOH-70 kg 1, 4-DB eq t^{-1} and PKL-50 kg 1, 4-DB eq t^{-1}) which reveals the environmental benefits of material recovery and composting which lead to lesser emissions of toxicity causing agents along with the sanitary landfilling.

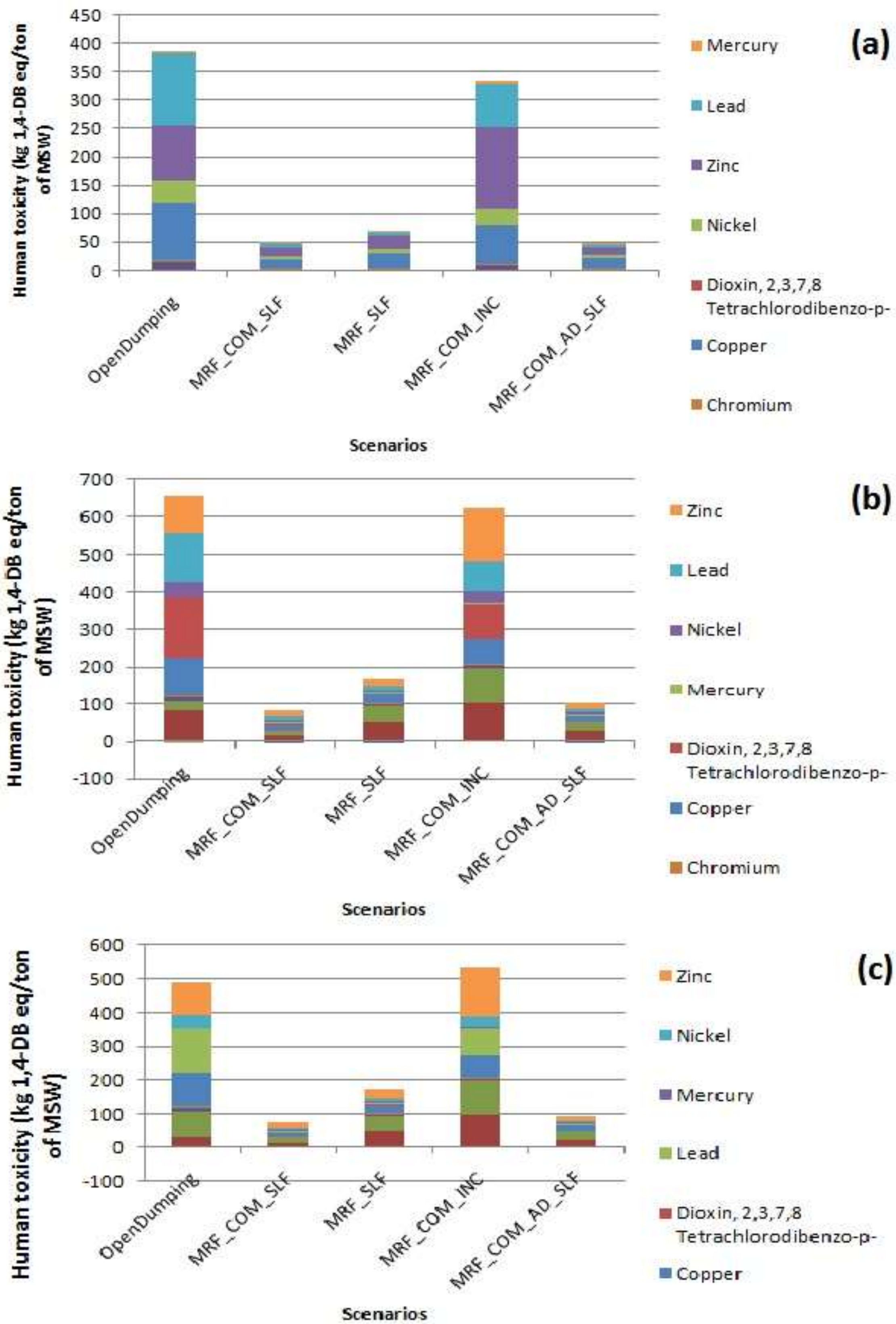


Figure 7.6: Human Toxicity potential under different scenarios for (a) Chandigarh, (b) Mohali and (c) Panchkula

Tricity generates 680 tons per day of MSW, with Chandigarh contributing 380 tons per day, Mohali and Panchkula 150 tons per day respectively. The final disposal method of MSW in all the cities is open dumping which makes the effective waste management a highly challenging task. The results of the environmental LCA under the five scenarios have shown that the least environmental impacts were generated in scenario 3: MRF_COM_SLF. The scenario revealed that with effective use of source separation and resource recovery, composting and sanitary landfilling method, maximum benefits could be generated along with lesser environmental impacts. The global warming potential (GWP), human toxicity potential (HTP), eutrophication potential (EP) and acidification potential (AP), all the environmental impacts studied have shown least values in this scenario. Under scenario 3:MRF_COM_SLF, minimum global warming potential was generated in Chandigarh while low emissions from acidification potential, eutrophication and human toxicity potential were observed in Panchkula.

The present, BAU, MSW disposal scenarios for Chandigarh, Mohali and Panchkula, projects maximum environmental consequences. The reason for this is the absence of liner systems, material recovery systems, dumping of unsegregated MSW and absence of leachate collection and treatment systems. The GWP and HTP are extreme in this case. Therefore, this is the least considered option in terms of environmental consequences.

Table 7.10, 7.11 and *7.12* gives the summary of the environmental impacts for scenario: BAU and scenario 3: MRF_COM_SLF for Chandigarh, Mohali and Panchkula, respectively showing the reduction in level of environmental impacts if the current open dumping is replaced with the combination of material recycling, composting and sanitary landfilling. It can be observed from the tables (*7.10, 7.11 and 7.12*), that highest environmental impacts in terms of AP and EP were being generated from Chandigarh city due to more generation of MSW as compared to Mohali and Panchkula. GWP was majorly being generated from Panchkula waste as compared to the emissions from Chandigarh and Mohali as many a times the incidents of illegally burning of waste are being reported in Panchkula city. Scenario 3 shows that Panchkula city generates lowest emissions in terms of acidification potential; eutrophication potential and human toxicity potential while in terms of global warming potential lowest emissions were generated in Mohali city. As Chandigarh is generating more quantity of waste in comparison to the other two cities, so it produces more emissions to environment as compared to Mohali and Panchkula in scenario 3.

Table 7.10: Comparison of environmental impacts (BAU and Scenario 3) for Chandigarh

Environmental Impacts	**Chandigarh**	
	BAU	**Scenario 3**
Global Warming Potential	75.63 kg CO_2 eq t^{-1}	4.5 kgCO_2 eq t^{-1}
Acidification Potential	1.30 kg SO_2 eq t^{-1}	0.980 kgSO_2 eq t^{-1}
Eutrophication Potential	0.5001 kg PO_4^{3-}eq t^{-1}	0.108 kgPO_4^{3-} eq t^{-1}
Human Toxicity Potential	388.12 kg 1, 4-DB eq t^{-1}	0.42 kg 1, 4-DB eq t^{-1}

Table 7.11: Comparison of environmental impacts (BAU and Scenario 3) for Mohali

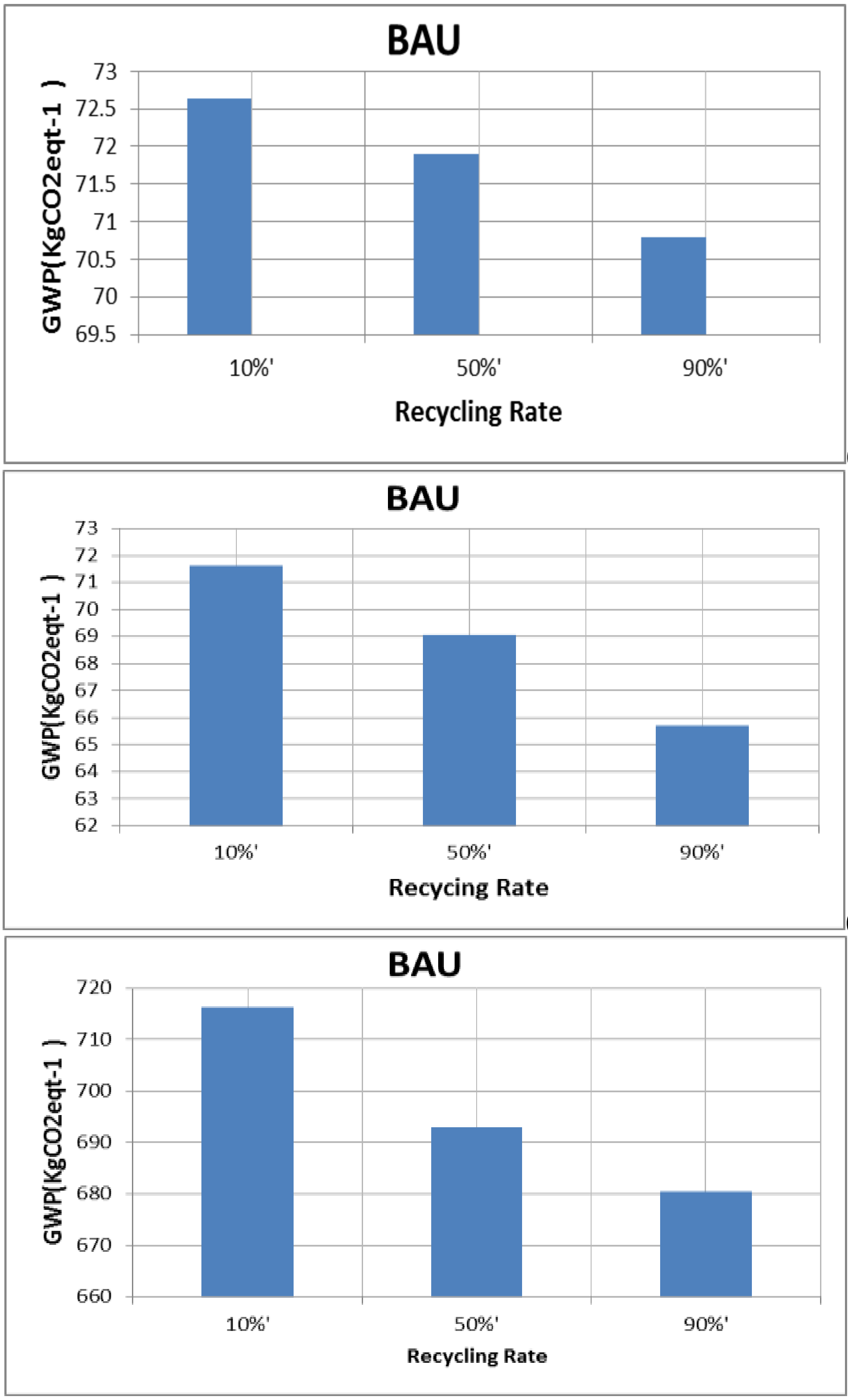
Environmental Impacts	**Mohali**	
	BAU	**Scenario 3**
Global Warming Potential	73.10 kg CO_2 eq t^{-1}	4.4 kgCO_2 eq t^{-1}
Acidification Potential	1.066 kg SO_2 eq t^{-1}	0.980 kgSO_2 eq t^{-1}
Eutrophication Potential	0.5009 kg PO_4^{3-}eq t^{-1}	0.1182 kgPO_4^{3-} eq t^{-1}
Human Toxicity Potential	756.43 kg 1, 4-DB eq t^{-1}	0.56 kg 1, 4-DB eq t^{-1}

Table 7.12: Comparison of environmental impacts (BAU and Scenario 3) for Panchkula

Environmental Impacts	**Panchkula**	
	BAU	**Scenario 3**
Global Warming Potential	731.89 kg CO_2 eq t^{-1}	59.62 kgCO_2 eq t^{-1}
Acidification Potential	1.12 kg SO_2 eq t^{-1}	0.910 kgSO_2 eq t^{-1}
Eutrophication Potential	0.5010 kg PO_4^{3-}eq t^{-1}	0.105 kgPO_4^{3-} eq t^{-1}
Human Toxicity Potential	510 kg 1, 4-DB eq t^{-1}	0.41 kg 1, 4-DB eq t^{-1}

7.3.2 Sensitivity Analysis

The impact of different recycling rates on the life cycle emissions were analysed for Chandigarh, Mohali and Panchkula for the baseline scenario (BAU). In the analysis the recycling proportions of paper, plastics, metals, textiles and leather were assumed to be recycled from 10%, 50% and 90%. The results showed that recycling rate will considerably lower the life cycle emissions from the MSW management systems in all the three cities. The results of global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP) for Chandigarh, Mohali and Panchkula, respectively are displayed in *figure 7.7 to 7.10*. The results of all the parameters are symbolized as (a) for Chandigarh, (b) for Mohali and (c) for Panchkula respectively.



(a)
(b)
(c)

Figure 7.7: Effect of recycling rate on global warming potential under BAU scenario for (a) Chandigarh, (b) Mohali and (c) Panchkula

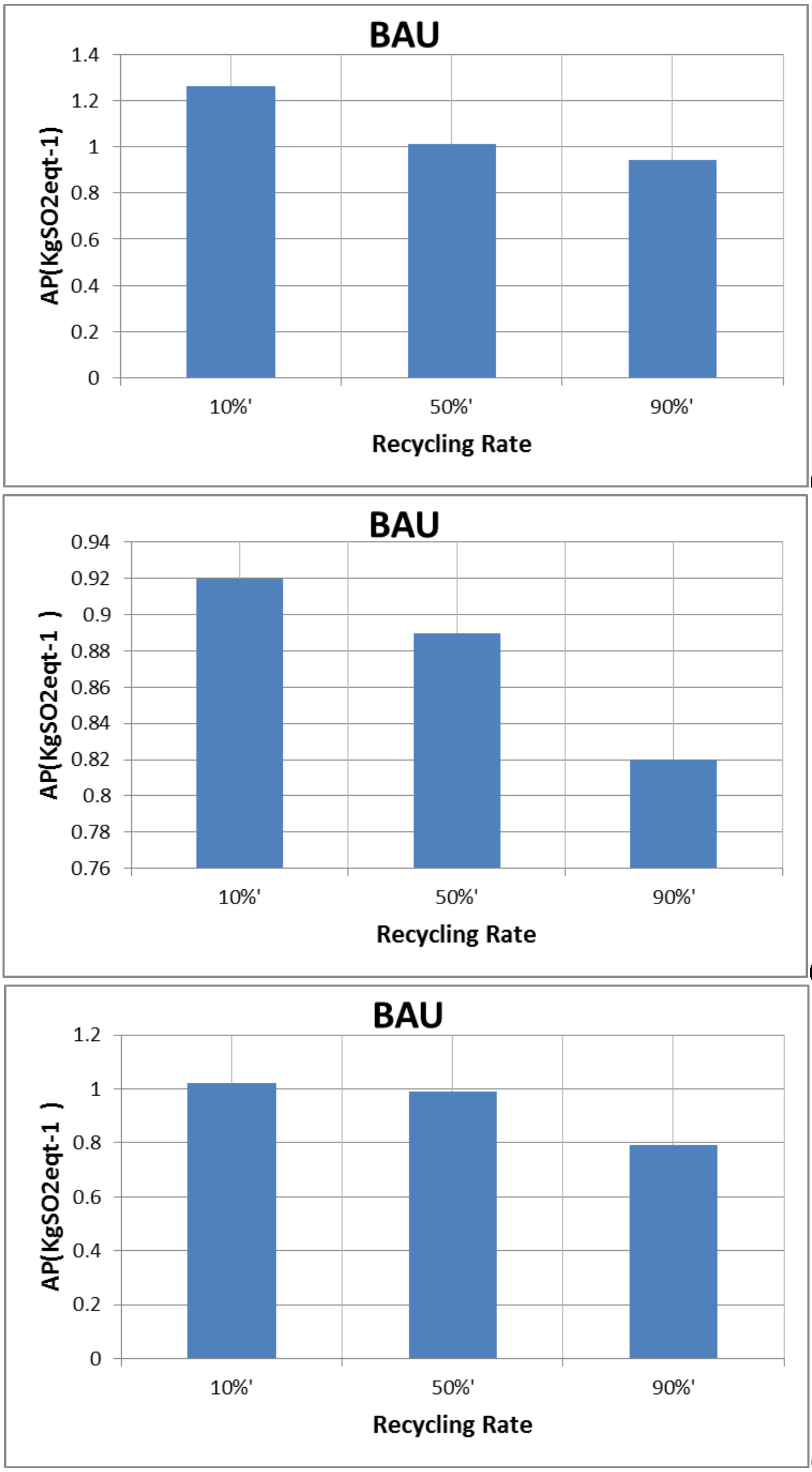
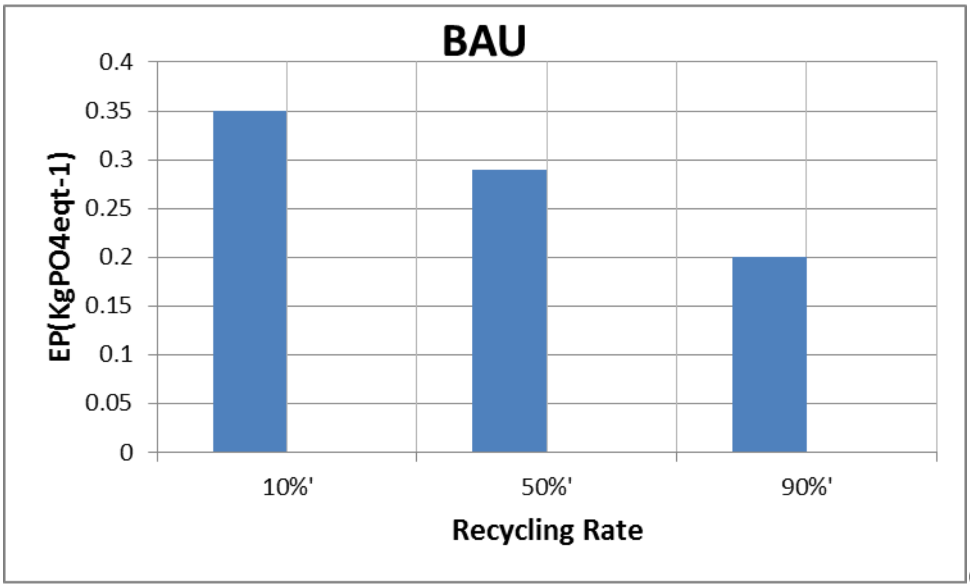
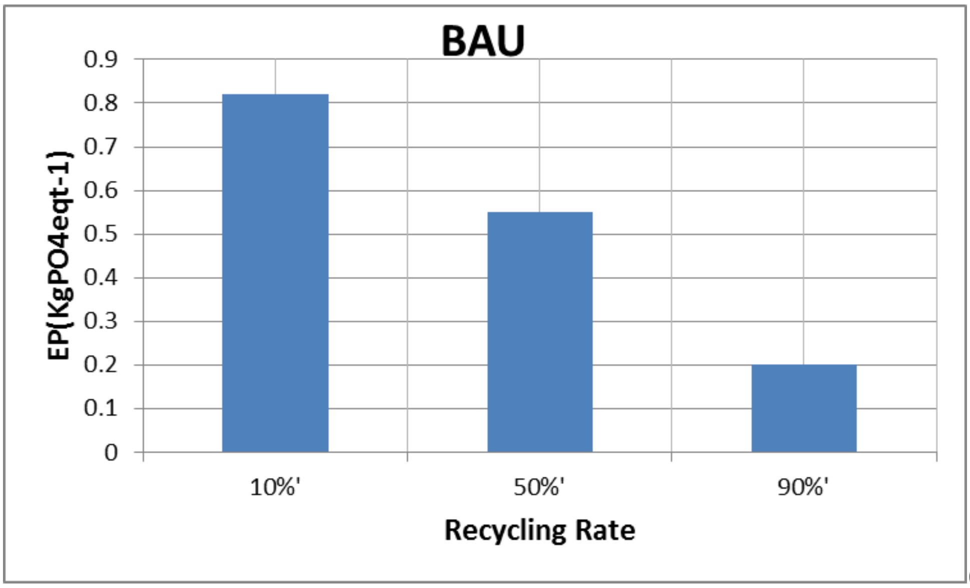


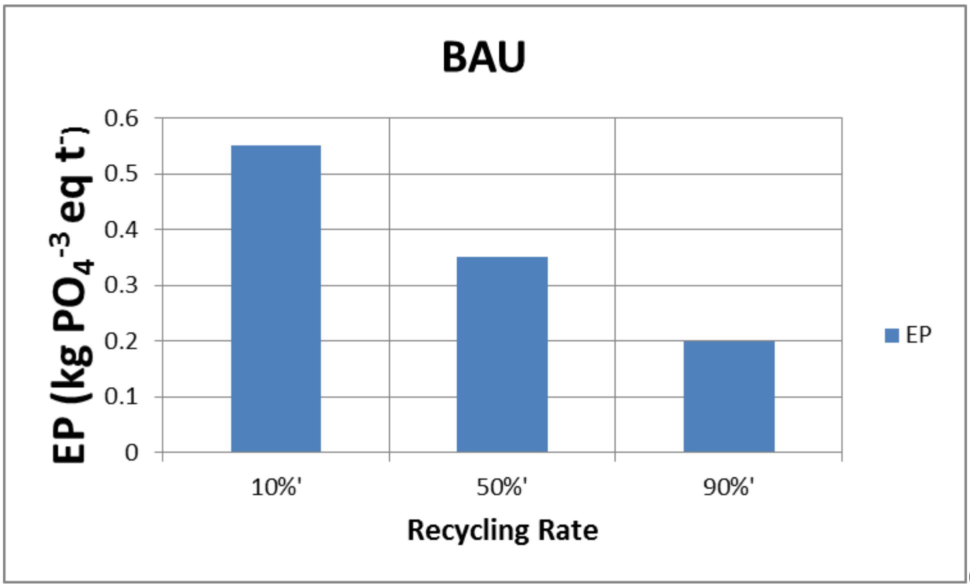
Figure 7.8: Effect of recycling rate on acidification potential under BAU scenario for (a) Chandigarh, (b) Mohali and (c) Panchkula



(a)



(b)



(c)

Figure 7.9: Effect of recycling rate on eutrophication potential under BAU scenario for (a) Chandigarh, (b) Mohali and (c) Panchkula

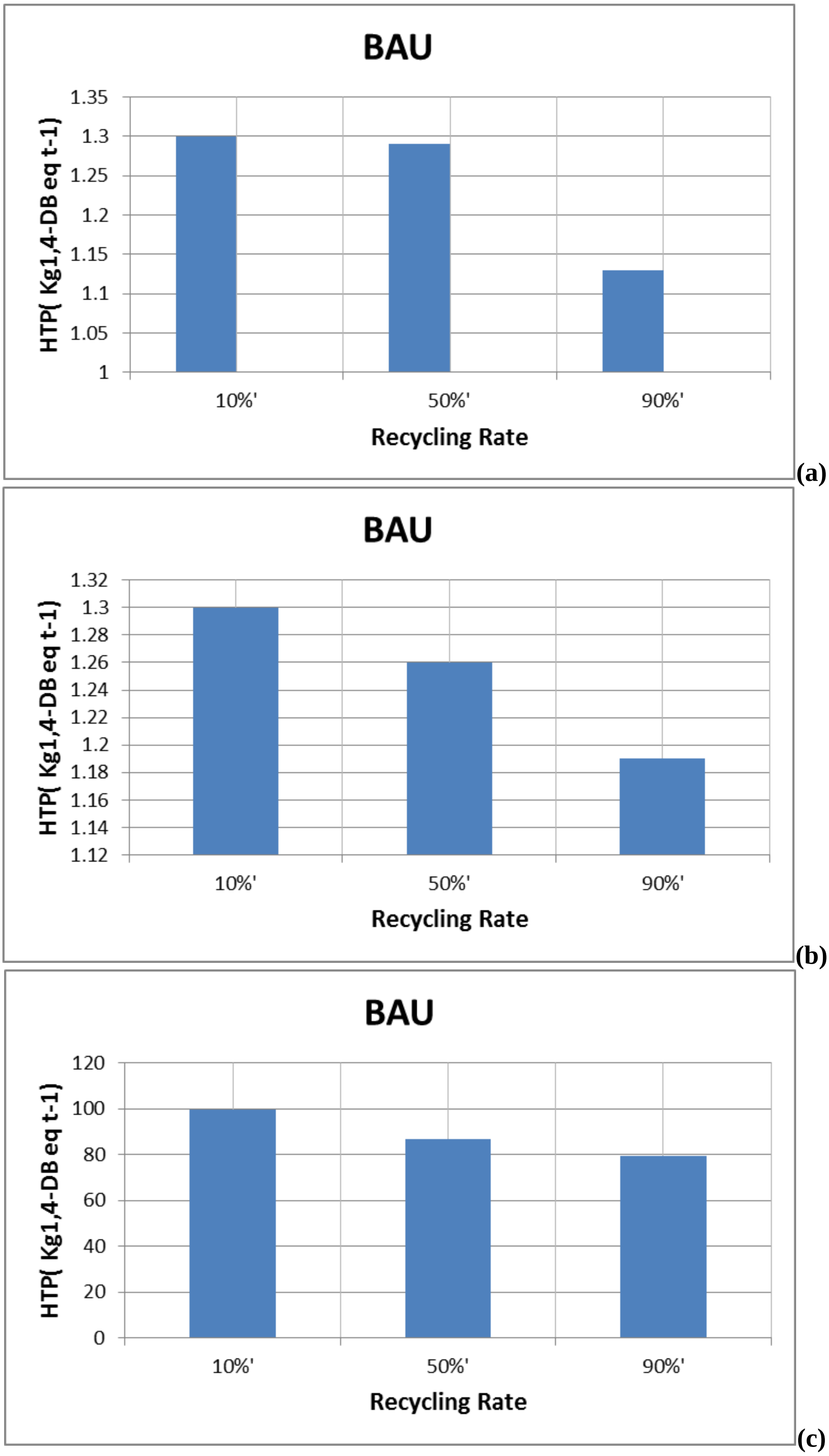


Figure 7.10: Effect of recycling rate on human toxicity potential under BAU scenario for (a) Chandigarh, (b) Mohali and (c) Panchkula

It is depicted from the results that the total environmental benefits will increase as rate of recycling increases. If the recycling rate is increased form 10% to 90%, the environmental impacts as compared with present scenario would reduce and are shown in *Table 7.13*.

Table 7.13: Environmental Impacts in the BAU for sensitivity analysis at 10%[(a)] and 90%[(b)]

	GWP	AP	EP	HTP
Chandigarh	72.63 kg CO_2 eq t^{-1a} TO 70.79 kg CO_2 eq t^{-1b}	1.26 kg SO_2 eq t^{-1a} TO 0.94 kg SO_2 eq t^{-1b}	0.35 kg PO_4^{-3} eq t^{-1a} TO 0.20 kg PO4 $^{-3}$ eq t^{-1b}	1.30 kg 1,4-DB eq t^{-1a} TO 1.13 kg 1,4-DB eq t^{-1b}
Mohali	71.63 kg CO_2 eq t^{-1a} TO 69.07 kg CO_2 eq t^{-1b}	0.92 kg SO_2 eq t^{-1a} TO 0.82 kg SO_2 eq t^{-1b}	0.82 kg PO_4^{-3} eq $t^{-1\,a}$ TO 0.20 kg PO4 $^{-3}$ eq t^{-1b}	1.30 kg 1,4-DB eq t^{-1a} TO 1.19 kg 1,4-DB eq t^{-1b}
Panchkula	716.3 kg CO_2 eq t^{-1a} TO 680.53 kg CO_2 eq t^{-1b}	1.02 kg SO_2 eq t^{-1a} TO 0.79 kg SO_2 eq t^{-1b}	0.35 kg PO_4^{-3} eq t^{-1a} TO 0.20 kg PO4 $^{-3}$ eq t^{-1b}	99.60 kg 1,4-DB eq t^{-1a} TO 79.45 kg 1,4-DB eq t^{-1b}

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

7.4 Summary and Discussion

The life cycle assessment (LCA) is used as a tool to compare the different MSW management system options and to determine the best possible and feasible system for Chandigarh, Mohali and Panchkula. The most feasible system considered is the one which produces least environmental impacts. In the study, five scenarios were considered for different impact categories viz., global warming potential, acidification potential, eutrophication potential and human toxicity potential to evaluate the potential for reducing the environmental impacts in Chandigarh, Mohali and Panchkula, respectively. Under the present conditions of MSW management system in Tricity are producing- global warming (CHD-75.63 kg CO_2 eq t^{-1} ; MOH-73.10 kg CO_2 eq t^{-1} ; PKL-731.89 kg CO_2 eq t^{-1}), acidification (CHD-1.30 kg SO_2 eq t^{-1} ; MOH-1.066 kg SO_2 eq t^{-1} ; PKL-1.12 kg SO_2 eq t^{-1}), eutrophication (CHD-0.5001 kg PO_4^{3-} eq t^{-1} ; MOH-0.5009 kg PO_4^{3-}eq t^{-1} ; PKL-0.5010 kg PO_4^{3-}eq t^{-1}) and human toxicity (CHD-388.12 kg1, 4-DB eq t^{-1} ; MOH-756.43 kg1, 4-DB eq t^{-1} ; PKL-510 kg1, 4-DB eq t^{-1}) environmental impacts. Among the proposed scenarios, the scenario 3; with the combination of material recovery recycling, composting and sanitary landfilling has the least environmental impacts. Results have shown that integrated MSW management with environmental benefits can be achieved with the introduction of recycling the valuable recovered resources (paper, plastics, metals etc.), composting and with energy recovery. The sensitivity analysis for the recycling rate reveals that there is reduction in environmental impacts if the recycling rate is increased from 10% to 90%. Recycling of valuable resources makes a significant contribution by reducing the environmental impacts. Since there are no research studies and data focusing on LCA of MSW in Chandigarh, Mohali and Panchkula, the use of detailed LCA for analyzing the different MSW management systems makes it possible for the municipal authorities of the respective cities of Chandigarh, Mohali and Panchkula to work towards improving the present management system.

CHAPTER -8

CONCLUSIONS AND RECOMMENDATIONS

8.1 General

This chapter comprises the summary of observations and conclusions derived from the field and laboratory investigations performed to meet the objectives of the study.

8.2 Conclusions

- The daily average solid waste production in Tricity is about 680 tons per day. The Municipal Corporations of Chandigarh, Mohali and Panchkula respectively are responsible for the overall management of the MSW which includes the collection of the waste from the households, storage of the waste, transportation of the waste to the final disposal sites. The collection efficiency of 90% is achieved in Chandigarh and around 70% and 60% is achieved in Mohali and Panchkula respectively.
- The Municipal Corporations of respective cities of Chandigarh, Mohali and Panchkula aims at providing a daily collection routine but lack of proper trained manpower, insufficient bin capacity leads to overflowing bins and odor problems emanating from different sectors in these cities.
- The sanitation sweepers and workers, who collect and transfer the waste, work under unhygienic conditions. Most of them generally suffer from parasitic diseases like jaundice, diarrhea and trachoma.
- The Municipal Corporations of Chandigarh, Mohali and Panchkula have been provided with total of 112, 17 and 25 conservancy vehicles respectively for transportation of MSW. The less number of vehicles in Mohali and Panchkula further leads to low collection efficiency and transportation of waste. Majority of the vehicles used for transporting the waste to the disposal sites in Chandigarh, Mohali and Panchkula are old and wearied out. Use of such vehicles increase operation and maintenance costs and reduces the transfer efficiency and also adds up to the air and noise pollution. The collection and transfer system in all the three cities is carried out in a disorganized manner without following any organized approach. This leads to highly reduced efficiency.

- It has been determined that no PPP initiatives for SWM systems exist in either of the satellite towns (Mohali and Panchkula) unlike the Chandigarh city. There is only one designated dumping site in each of the cities of Chandigarh, Mohali and Panchkula and which are operational since 30 years, 20 years and 15 years respectively. The present dumping sites in Chandigarh, Mohali and Panchkula are non-engineered landfill sites and thereby no controls measures exist to prevent percolation of leachate in the groundwater. Such uncontrolled leachate percolation poses tremendous health hazards from toxic metals.
- Although, the existing practices of waste management in Tricity indicates the practice of door-to-door collection with the presence of temporary transfer stations, regular monitoring agencies and effective street sweeping ‘manually and mechanized’ which gives these cities an edge over the other tier-II cities (Ludhiana, Amritsar, Jalandhar, Dehradun, Jaipur, Pune and Lucknow), however, certain insufficiencies have been observed in the existing waste management system which needs immediate attention.
- The ‘*wasteaware*’ benchmarks parameters for Chandigarh, Mohali, Panchkula, Surat and Lahore shows that Chandigarh, Mohali and Surat have very good collection efficiencies as compared to Panchkula and Lahore which showed ‘low-medium’ and ‘medium’ index on wasteaware benchmark indicators respectively. The major difference between Chandigarh, Mohali, Panchkula, Surat and Lahore is in the disposal methods and in the efficiency of *3R method*, while Surat scores a ‘Low/Medium’ index for environmental controlled waste treatment and disposal method, Chandigarh, Mohali and Panchkula scores ‘Low’ index. This is because the disposal sites are open dumps without provision of liner systems to prevent the percolation of leachate in groundwater thereby contributing to environmental hazards. Further, Chandigarh, Mohali, Panchkula scores ‘Low’ index in the *3R* methodology (reduce, reuse and recycle) as no recycling facilities exists in these cities.
- The total evaluation based on matrix method showed that quantitative parameters and qualitative parameters for Chandigarh, Mohali and Panchkula have showed 46%, 44% and 38% of overall weightage. The matrix method for evaluation showed the quantitative parameters (Chandigarh – 40%, Mohali – 37% and Panchkula – 27%) was significantly less than the qualitative parameters (Chandigarh – 55%, Mohali – 55% and Panchkula – 55%) for Chandigarh, Mohali and Panchkula which shows same level of government efficiency across the Tricity. The main difference between

categorization of scores between Surat and Chandigarh, Mohali and Panchkula is primarily due to increased scores for Surat cities for better environmental control facilities (2 and 2E) and recycling facilities (3, 3R). Interestingly, no recycling facilities exist for Chandigarh, Mohali and Panchkula. The quantitative parameters were significantly less than the qualitative parameters for Chandigarh, Mohali and Panchkula. The overall classification of the three cities was in the low categories. The overall classification of the three cities was in the low categories. Interestingly, governance factors for all the Indian cities were equal with 55% of weightage.

- Characterization of the waste from the Tricity region denotes that the physical characterization of the MSW from Chandigarh, Mohali and Panchkula from all the socio-economic groups indicate high percentage of organic matter ranging from 24.1 to 59% of the total MSW followed by inert with composition ranging from approximately 22 to 33% in the waste stream of various socio-economic groups. The MSW collected from the low income group (LIG) areas contained maximum organic fraction for all the three cities since such socio-economic groups consume more organic fractions in their diet. The high content of inert fraction in the Tricity region is predominantly due to continuous unrestrained practice of combining street sweeping waste and construction and demolition waste with MSW. Presence of inert along with the MSW must be controlled as it spoils the processing of biodegradables as well as recyclable materials. It was observed from the results that major fractions of inorganics were generated from commercial, institutional and high income group (HIG) areas suggesting the use of more packaged and disposable products in these sectors. In this study, two more categories including institutional and commercial were incorporated. This is because over the period of time it has been observed in the Tricity area that there has been rapid growth of MSW generated from institutional (universities, colleges, coaching centers) with about 10% in Chandigarh, 6% in Mohali and 6% in Panchkula and commercial (shopping complexes, malls and restaurants, local markets) and are now responsible for accounting for about 10% in Chandigarh and 7% each in Mohali and Panchkula of the total MSW generated in the Tricity region.
- Chemical characterization of the waste from the three cities also specified combined average ash content of low income group (LIG) from all the three cities was reported to be 27.7% (25.94% in Chandigarh, and 27.51% in Mohali and 29.9% in Panchkula).

The ash content of the MSW of the three cities was observed to be high due to large amount of inert material in waste samples. Moisture content was highest in LIG areas of all the three cities indicating presence of higher fractions of vegetables and other putrescible constituents. Moisture content of the MSW for Chandigarh, Mohali and Panchkula were observed to be in range of 42 to 59%, 34 to 57.7% and 35 to 44% respectively. The calorific value of the MSW of Chandigarh, Mohali and Panchkula was found to be significantly high in HIG (2508 kcal/kg in CHD, 2208 kcal/kg in MOH and 1500 kcal/kg in PKL) followed by the commercial area (2200 kcal/kg in CHD, 2186 kcal/kg in MOH and 2218 kcal/kg in PKL) and lowest in LIG (1008 kcal/kg in CHD, 1005 kcal/kg in MOH and 1123 kcal/kg in PKL). This is primarily due to the presence of higher combustible fractions of waste in HIG and commercial sector in comparison to LIG wherein more organic fraction and higher moisture content was observed.

- Based on the MSW characterization from Chandigarh Mohali and Panchkula, it is suggested that due to presence of high percentage of organic matter (24.1% to 59%) a single existent technology like RDF cannot lead to complete management of waste, but there is a need to adopt integrated technologies for the treatment of different fractions of waste, and hence for these cities a combination of composting, vermicomposting and bio-methanation plant, would help in achieving a better solid waste management system. Although, the inorganic content (48.2%) after separation from the organic fraction can be processed in RDF plant.
- The leachate derived from municipal solid waste dumping sites of all the three cities of Chandigarh, Mohali and Panchkula exhibits exceedingly high values for all physico-chemical and biological parameters analyzed. The concentrations of tested parameters including pH, TDS, COD, BOD, chlorides, NH_3-N, Cu and Ni exceeded the permissible limits for all the three dumpsites for the entire monitoring campaign as specified by the Municipal Solid Waste Management and Handling Rules, 2016 (MoEF Gazette of India, 2016) for discharge of leachate samples in inland surface waters, public sewers and land disposal. For the study locations, the average pH of the leachate samples from all the three dumping sites over the entire monitoring campaign varied from 9.2 for Chandigarh and 8.9 for Mohali and Panchkula indicating highly alkaline nature and that all the three dumping sites were in methanogenic phase and can be classified as '*old or matured*' landfill sites and thereby nearing the end of their

lifespan. The high average concentrations of major ions and heavy metals in the leachate depicted that these open dumping sites are a potential source of human and environmental hazards. Leachates produced from these dumping sites are heterogeneous in nature due to a mixture of various harmful chemicals. High concentrations of heavy metals were detected in the leachate samples, like copper which was primarily due to the dumping of toxic waste like metal scrap, batteries, toxic medicines, paints etc.

- The quantitative analysis for PAHs in the leachate samples showed benzo (a) pyrene-toxic equivalence quotient (BaP-TEQ) ranging from 54.71×10^{-8} to 305.031×10^{-8} mg/l. The level of toxicity established on the basis of CR for leachates is ML>PL>CL due to the presence of high concentrations of PAH's. The cancer risk varied from 4.88×10^{-8} to 27.3×10^{-8} which was less than cancer risk (CR) potential of 10^{-6}. Methyl tetrazolium (MTT) assay for cytotoxicity was carried out in Neuro-2a cell lines to further evaluate the potential toxicity of the leachate samples. The MTT EC_{50} (Effective Concentrations) values ranged from 9.99 to 15.46% affirming the significant cytotoxic effect of leachates on Neuro-2a cell line. The results indicated that though there was no cancer risk by the PAHs present in the leachate samples but the presence of other contaminants may individually or collectively cause cytotoxicity in the mammalian cells. The results of the MTT assay put forward that the leachate from all the three dumping sites of each Chandigarh, Mohali and Panchkula cities contained significant load of toxicants.

- LPI values indicates the contamination potential due to leachate produced from the landfill sites in the particular areas and act as an important tool for identifying and measuring the hazards caused due to percolation of the leachate in soil strata as well in aquifers. The calculated LPI values obtained for Chandigarh, Mohali and Panchkula dumping sites were 26.15, 27.02 and 27.88 respectively. These LPI values are much higher than the standard LPI value of the treated leachate disposal limit of 7.378 to inland surface water. Higher values of LPI signify that leachate produced from all these three dumping sites of Chandigarh, Mohali and Panchkula is highly contaminated and proper treatment techniques must be ensured before discharging the leachate. All the three dumping sites do not have any provision of base liners or leachate collection and treatment systems.

- The ground water quality of nearby sites of municipal solid waste landfill sites are of poor quality since they are contaminated due to leachate within the vicinity of 5 km. The moderately high concentrations of EC, TDS, CL^-,SO_4^{2-}, NH_3-N etc. in ground water near landfill deteriorates its quality for drinking and other purposes. The ground water quality improves with the increase in distance from the source of pollution. Leachate percolation in the ground water can be a result of composition of leachate, rainfall, depth and distance from the source of pollution. Ground water samples collected from the close vicinity of dumping sites were found to be more contaminated that that of the farther away samples (>3km). Further, presence of coliforms in some of the samples of ground water confirms that infiltration of leachate into the ground water has deteriorated the quality. The ground water quality improves with the increase in the distance of the sampling sites from the source of pollution i.e. dumping site.
- The WQI of ground water samples from all the three cities of Chandigarh, Mohali and Panchkula were performed using OWQI and BIS 10500 method. The average WQI over the three monitoring campaigns for Chandigarh, Mohali and Panchkula was 74, 60 and 72 respectively using the OWQI. The results obtained from (OWQI) shows that the existing groundwater quality from the Tricity Region is 'poor quality'. As per BIS 10500, the groundwater quality for Chandigarh was poor quality (130) but for Mohali (97) and Panchkula (92) were classified as good quality. However, the groundwater quality for Mohali and Panchkula is very close to being graded poor as the WQI values are on the borderline conditions. Seasonal variation showed that for all the monitoring campaigns poor quality of water existed till downstream distance of 2 km after which the quality of the water increased to good. The WQI results revealed that the ground water samples from the nearby location to the dumping sites are affected due to leaching of ions from the leachate. With the increase in downstream distance of the groundwater sources from the dumpsite the WQI and also the quality of the groundwater keeps on improving. A simple regression analysis between LPI and WQI for the three sites was found to be 0.35 for Chandigarh, 0.58 for Mohali and 0.22 for Panchkula respectively.
- Multivariate statistical technique (PCA and HCA) suggests that the components of the PCA accounts for 88%, 87.1% and 87.8% of the total variance in the dataset for Chandigarh, Mohali and Panchkula cities respectively. The components in

Chandigarh and Panchkula cities is dominated by high positive loading in electrical conductivity, calcium, magnesium, nitrates and sulfates and for Mohali by fluorides, chlorides, nitrates, total dissolved solids and ammonical nitrogen. Cluster analysis helped to group 15 sampling sites each for Chandigarh, Mohali and Panchkula into three clusters of similar characteristics. It further helps to examine the quality of water and source of pollution.

- The life cycle assessment (LCA) is used as a tool to compare the different MSW management system options and to determine the best possible and feasible system for Chandigarh, Mohali and Panchkula. The most feasible system being the one which produces least environmental impacts. Among the proposed scenarios, the scenario 3; with the combination of material recovery recycling, composting and sanitary landfilling has the least environmental impacts. Results have shown that integrated MSW management with environmental benefits can be achieved with the introduction of recycling the valuable recovered resources (paper, plastics, metals etc.), composting and with energy recovery. The present, BAU, MSW disposal scenarios for Chandigarh, Mohali and Panchkula, projects maximum environmental consequences. The reason for this is the absence of liner systems, material recovery systems, dumping of unsegregated MSW and absence of leachate collection and treatment systems. Highest environmental impacts in terms of AP and EP were being generated from Chandigarh city due to more generation of MSW as compared to Mohali and Panchkula. GWP was majorly being generated from Panchkula waste as compared to the emissions from Chandigarh and Mohali as many a times the incidents of illegally burning of waste are being reported in Panchkula city.

- Scenario 3 shows that Panchkula city generates lowest emissions in terms of acidification potential; eutrophication potential and human toxicity potential while in terms of global warming potential lowest emissions were generated in Mohali city. As Chandigarh is generating more quantity of waste in comparison to the other two cities, so it produces more emissions to environment as compared to Mohali and Panchkula in scenario 3.

- The sensitivity analysis identifies the sensitive parameters and assess whether a small change in an input parameter would induce a large change in the impact category. The input parameters for sensitivity analysis focus on the recycling rate. The impact of different recycling rates on the life cycle emissions were analysed for Chandigarh, Mohali and Panchkula for the baseline scenario (BAU). In the analysis the recycling proportions of paper, plastics, metals, textiles and leather are assumed to be recycled from 10%, 50% and 90%. The results showed that recycling rate will considerably lower the life cycle emissions from the MSW management systems in all the three cities.

8.3 Recommendations

- Recruitment and training of additional sanitary workers should be carried out to increase collection efficiency. Segregation of waste should be carried out for the collected wastes generated from Tricity and this can be achieved by sensitizing residents regarding the benefits of source segregation and its role in waste management along with set up of formal recycling unit for Tricity.
- Color coding of bins should be promoted as this will help to segregate the garbage into different fractions like organic, inorganic, inert fraction and hazardous materials.
- Regular medical check-ups of sanitation workers should be done and they must be motivated to use protective measures while handling waste.
- New sites must be considered for construction of these engineered landfill sites as the present dumpsites are nearing the end of their lifespan capacity.
- Based on the MSW characterization from Tricity, it is suggested that a single existent technology like RDF cannot lead to complete management of waste, but there is a need to adopt integrated technologies for the treatment of different fractions of waste, and hence for these cities a combination of composting, vermi-composting and bio-methanation plant, would help in achieving a better management system.
- Leachate collected near the dumping site could be extracted and treated so as to prevent its percolation into the groundwater.
- Regular monitoring of water should be done to study the long term effect of dumping site on groundwater quality.

8.4 Scope of Future Work

- An attempt can be made to evaluate the impact of MSW leachate on the properties of soil at the dumping sites of Tricity.

- A study can be undertaken to design an engineered sanitary landfill for Tricity having leachate collection and treatment facilities along with air pollution monitoring.
- A cost effective approach for dumping site rehabilitation can be performed.
- In order to have a holistic view of MSW management economic evaluation of the costs and benefits of the MSW proposed scenarios can be performed.

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