COMPENDIUM ON WORK OF INTERNS (VOLUME-II)

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लोकहितार्थ सत्यनिष्ठा
Dedicated to Truth in Public Interest

iCED

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International Centre for Environment Audit and Sustainable Development, Jaipur

About the Research Papers

The research papers in this Compendium are indicative of our ongoing efforts to enhance accountability and inculcate professional excellence within the realms of environmental and sustainable development. We have initiated an Occasional Research Paper (ORP) Series featuring different emerging areas of environment audit and sustainable development in 2022. In line with this, a Compendium (Volume-I) on the work of Interns based on the case studies conducted by interns during the last five years was released in August 2022. This is the eighth Occasional Research Paper, Volume II, of the ongoing ORP series, which showcases the work conducted by interns during the intervening period on diverse environmental issues. This Volume contains three case studies of interns, and is part of iCED's sustained and constant research focus.

Feedback

We strive for constant improvement and encourage our readers to provide their valuable feedback/suggestions. Please send us suggestions, comments, and questions about this compendium series to iced@cag.gov.in

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Foreword

Sustainability of the environment requires every Supreme Audit Institution to constantly upscale its audit focus on an audit of issues related to the environment. Given its cross-cutting, dynamic and multi-disciplinary nature; capacity building and inputs informed by research becomes an essential pre-requisite for human resource management and reporting on public accountability in these areas. Strategic objectives of iCED, inter-alia, include the sharing of knowledge related to the environment among government agencies and public auditors and to undertake research in the area of environment and sustainable development.

In this direction, iCED, apropos of the policy guidance of the Office of the Comptroller and Auditor General of India seeks to encourage internships, provides opportunities to students from Universities and institutions to research at iCED for short durations and provide research inputs in environment-related areas of engagements.

In May 2022, iCED pioneered an Occasional Research Paper Series to conduct a dynamic and research-oriented trajectory to its capacity building efforts. As a part of these efforts, we brought out in August 2022, a compendium of work done by interns at iCED.

In continuation of our effort to promote research activity in the area of environment and sustainable development in iCED, I am happy that young interns at iCED have once again chosen emerging issues i.e. Groundwater usage and its Management, Municipal Solid Waste Management and Pollution caused by Road Dust for their research studies.

This is the second volume of compendium of the work done by the interns at iCED and the eight in the Occasional Research Paper Series of iCED. I hope this compendium will serve as a repository of reference material for auditors working in the field of audit of environment and sustainable development, and also enable them to include new tools, methodologies and approaches. I trust that this compendium will enhance our understanding about the environment and provide a fresh audit perspective for the audit of environment and sustainability-related issues.

As the contributors are young students, sharing their ideas with audit professionals can also be a mode of outreach which can enliven the discourse on an audit of the environment.

It is also worth stressing that the value of these inputs is to bring a spirit of zest-full inquiry from young voices to our structured processes.

We would be delighted to receive your feedback and valuable insights into this compendium.

01 May , 2023 **(Sayantani Jafa)**

Jaipur Additional Deputy C&AG and Director General, iCED

Introduction

The issues of environment and sustainability have emerged as significant subjects in public discourse. It is now widely recognized that without ensuring environmental sustainability, achieving economic stability and ensuring equity and justice would become a formidable challenge. The growing concern for the environment and sustainability has led to more concerted efforts aimed at conserving our natural resources and promoting their sustainable use. Given the dynamic nature of the subject, the field of environment and sustainability is continuously evolving, with new knowledge being added to the repertoire all the time. It is crucial to emphasize the significance of continuous research and its pivotal role in socio-economic development and enhanced understanding of the subject matter. As the field of environment and sustainability continues to evolve, a well-informed research approach remains an indispensable requirement for auditors to draw sound conclusions and provide meaningful recommendations.

In pursuit of its goal to become a global Centre of Excellence in the field of environment and sustainable development, iCED has gained momentum in conducting in-house research through the engagement of interns, young professionals, and Research Associates.

With respect to internship programme in the field of environment and sustainable development, a total of 15 interns have been engaged at iCED since 2017-18. The broad areas covered by the interns in their studies are; Use of Geospatial Technology in Audit, Marine-tourism, Eco-tourism, Plastic waste, Non-Timber Forest Produce (NTFPs), E-Waste, Disaster preparedness, Air Pollution, Pollution caused by dust, Invasive alien species, Hazardous waste, Groundwater usage and its Management, Municipal solid waste management and changes in urban landscape. Accordingly, a Compendium of twelve interns' studies has been prepared and placed on the website of iCED under the Occasional Research Paper Series in the year 2022.

This compendium is a compilation of three case studies conducted by the interns during the period 2021-22 to 2022-23 at iCED. A brief of these case studies is as under:

Theme-1 covers **"Sustainability issues in Groundwater Usage and its Management in Rural Areas"** which comprises the work of **Mr. Viraj Savalaram Rane**. This Paper is an attempt to highlight the issues in management of groundwater, especially in the rural areas of the country through a case study of a village (Jawalarjun and its surrounding areas) in Maharashtra State. In this study, the issue of groundwater depletion, its contamination and groundwater related challenges in rural areas are highlighted. The study suggests some conventional and unconventional methods to overcome these problems of water in rural areas.

Theme-2 highlights aspects of **"Municipal Solid Waste Management"** in three selected cities in India (Indore, Surat and Jaipur) comprising work done by Ms. Swati Jha. Increasing Municipal Solid Waste is a worldwide challenge. This can mainly be attributed to exponential population growth, high urban density, diversified culture, changing dietary habits and lifestyles. This study is an attempt to highlight issues in the implementation of solid waste management in three selected cities (Indore, Surat, and Jaipur). The improper segregation of waste has emerged as the basic problem during this study. Causal Loop Diagrams have been used to analyse systems that have either a negative or positive impact on waste segregation at the source and help in identifying possible solutions to address this issue. Legal/Institutional Framework and broad issues in Implementation in three different cities are also covered in the theme.

Theme-3 brings out "**Pollution caused by Road Dust: A Case study in Delhi and Mumbai",** comprising work done by Ms. Tannu Mittal. Dust pollution has become a major concern in urban environments due to its significant contribution to air pollution. Road dust is a complex mixture of heavy metals, organics, inorganic, mould spores, pollen etc. The movement of any vehicle and wind results in the suspension of dust particles in the air. Under specific meteorological conditions, particles and their associated metals, including fine dust, have a tendency to remain suspended in the air for longer periods. In the developing megacities of India, there is a clear source-pathway-receptor linkage in which individuals often spend a significant amount of their working lives near roadside and engage in activities such as consuming street food. In 2021-2022, study was carried out to analyse the concentration of heavy metals, including copper, zinc, lead, chromium etc. in urban road dust within two cities of India, namely Delhi and Mumbai. The study aimed to assess the pollution levels using various indices such as contamination factor, ecological risk index, and degree of contamination. Furthermore, the study also assessed the health effects associated with the presence of heavy metals in road dust. The research paper has been developed following the guidelines outlined in the United States Environmental Protection Agency (USEPA 2001) regarding road dust and incorporates scientific calculations as part of its methodology.

These contributions may serve as a good source of information in the selective areas and also provide many new inputs/ perspectives/ tools and approaches which can be suitably adopted during various stages of audits, covering the subject of environment and sustainability.

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Theme-1 Sustainability issues in Groundwater Usage and its Management in Rural Areas: A case study of Jawalarjun village, Purandhar Block of Pune District, Maharashtra

1.1 Introduction

Groundwater is fresh water (from rain or melting ice and snow) that soaks into the soil and is stored in the tiny spaces (pores) between rocks and particles of soil. Groundwater is found in two zones, one is an unsaturated zone having water and air in open gaps, or pores, just beneath the land surface and another is a saturated zone which is an area where water is present in all of the pores and rock cracks, which lies beneath the unsaturated zone. The top of the saturated zone (Central Ground Water Board, 2017) is below the land surface (Fish Smart, n.d.) , depending upon the geographic conditions.

Groundwater account for 99 per cent of all non-frozen freshwater. Groundwater is a vital water supply for human beings. It is estimated that of the total groundwater available globally, 36 per cent is used for potable water, 42 per cent for irrigation and 22 per cent for direct industrial and other miscellaneous uses (Global Environment Facility, 2023) . Worldwide, 2.5 billion people depend solely on groundwater resources to fulfil their basic daily water needs (The Groundwater project, 2023) .

India has 17 per cent of the planet's population with only 4 per cent of the earth's freshwater resources (The Economic Times, 2018). After 1960, the Government of India boosted the "green revolution" to ensure food security with increased demand for groundwater for agriculture. The increase in rural electrification has increased modern pump technology, resulting in increase in the number of bore wells and exploitation of groundwater. In the last 50 years, the number of bore-wells in India has increased from 1 million to 20 million, making it the world's largest consumer of groundwater (World water day, n.d.) .

Over the years, there has been a significant shift in the sources of irrigation in India. The share of canals in the net irrigated area has declined from 39.8 per cent in 1950-51 to 23.6 per cent in 2012-13. Alongside, the share of groundwater sources has increased from 28.7 per cent (1950-51) to a whopping 62.4 per cent (2012-13) (Dhawan, 2017) . According to the Ministry of Statistics and Programme Implementation, Government of India, net irrigated area in India got water from tube wells was 46 per cent in 2014-15, whereas irrigation based on canal systems was only 24 per cent during the same period.

The dependence on groundwater in a particular region depends on the demand for water and the availability of water from various sources. Main factors affecting water availability (Cool Geography, n.d.) are**:**

- **Geology** – It has an impact on the location of aquifers and groundwater. Water remains on the Earth's surface in rivers, where rocks are impermeable. This is then transferred elsewhere by rivers.
- **Climate -** Low levels of rainfall and high temperatures lead to water deficits.
- **Rivers** – Due to rain or melting of ice, river systems move huge quantities of water towards seas and lakes.
- **Over-abstraction**- When water is taken from aquifers, groundwater levels fall. If the amount of water taken is greater than the amount of water falling as rain, it is called over-abstraction (BBC, n.d.).

The reason for this research case study is that groundwater levels in the research area are declining on a daily basis because growing agriculture in Jawalarjun village, particularly water-consuming cash crop cultivation, has greatly increased the need for groundwater. The primary goal of this research is to increase groundwater levels through various water conservation methods.

The attention of the government has turned towards the decline of groundwater in this region. Therefore, water conservation works in Jawalarjun village have been done through government schemes like SAGY (Saansad Adarsh Gram Yojana) and social organizations like (Paani Foundation). These include farm ponds, cement Nala bunds, Bandara, tree plantations, etc. (Twitter, 2017) (Paanifoundation, n.d.) (Facebook, 2019). As a consequence, a direct effect was seen on water structures. The water level was very low, but the water level increased after water conservation works.

1.2 Groundwater development

According to the Dynamic Groundwater Resources of India Report 2017 (Ministry of Jal Shakti, 2019), the overall annual groundwater recharge for the entire nation has been estimated at 432 billion cubic metres (BCM), and the total natural discharges work out to be 39 BCM. Hence, the annual extractable groundwater resource for the entire country was 393 BCM. Monsoon rainfall, which account for around 58 per cent of the total annual groundwater recharge, or 252 BCM (*Figure 1 below*), is the main source of groundwater recharge. According to the Dynamic Ground Water Resources of India Report 2017, the nation's annual groundwater recharge has decreased by 15 BCM since the last assessment in 2013 and the amount of groundwater extracted annually for domestic, industrial, and agricultural uses has decreased by 4.35 BCM.

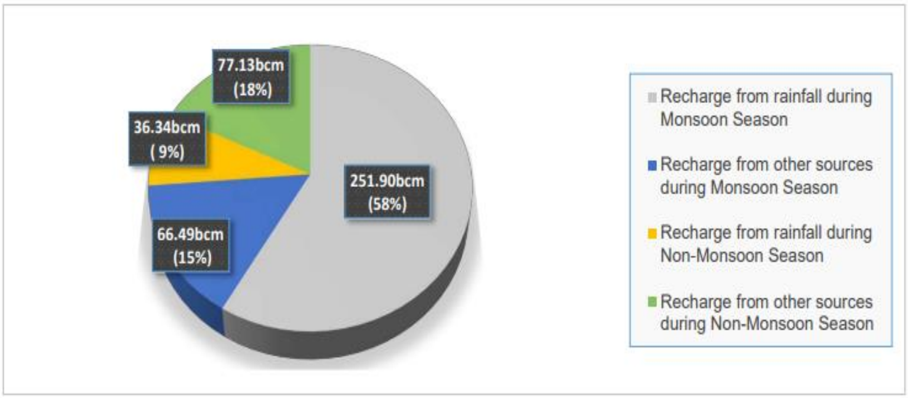


Figure 1 Groundwater resources and extraction scenario in India 2017

The stage of groundwater extraction is very high in Delhi-NCR, Haryana, Punjab, and Rajasthan, where groundwater extraction is more than 100 per cent (Business Standard, 2022) (under over-exploitation stage). It implies that the annual groundwater consumption is more than annual extractable groundwater resources. In the States of Himachal Pradesh, Tamil Nadu and Uttar Pradesh and the Union Territory of Puducherry, the stage of groundwater extraction is 70 per cent and above (under the semi-critical stage). In the rest of the states, the level of groundwater extraction is below 70 per cent (under the safe stage). The 673 assessment units in the country, where yearly groundwater extraction exceeds annual recharge are currently "over-exploited" and the groundwater extraction has reached a high level, i.e. > 85 per cent, 425 assessment units are "dark" or "critical" and the remaining 7091 assessment units have been designated as "safe" with sufficient groundwater supplies for ongoing development.

Maharashtra has one of the higher rainfall rates in the nation. There are 40,785 villages and 45,528 hamlets. Out of the total agricultural land, 28.75 lakh hectares (71 per cent) depend on groundwater for irrigation and only 11.83 lakh hectares (29 per cent) depend on canals. Out of the total consumed groundwater, 85 per cent is for irrigation, 10 per cent for industries, and only 5 per cent is for domestic consumption. Around, 80 per cent need for drinking water in rural areas is met through groundwater (Indiawaterportal, 2015) .

The stages of extraction of groundwater are shown in Figure 2 below:

Stage of Ground Water Extraction	Category
≤70%	Safe
>70% and ≤90%	Semi-Critical
>90% and ≤100%	Critical
> 100%	Over-Exploited

Source: Dynamic Ground Water Resources of India 2017

Figure 2 Stage of groundwater extraction (Ministry of Jal Shakti, 2019)

Over the years, usage of groundwater has increased in areas where the resource was readily available. This has resulted in an increase in overall groundwater development from 58 per cent (under the safe stage) in 2004 to 62 per cent in 2011 (Overview of Ground Water in India, n.d.) (*as illustrated in figure 3 below*).

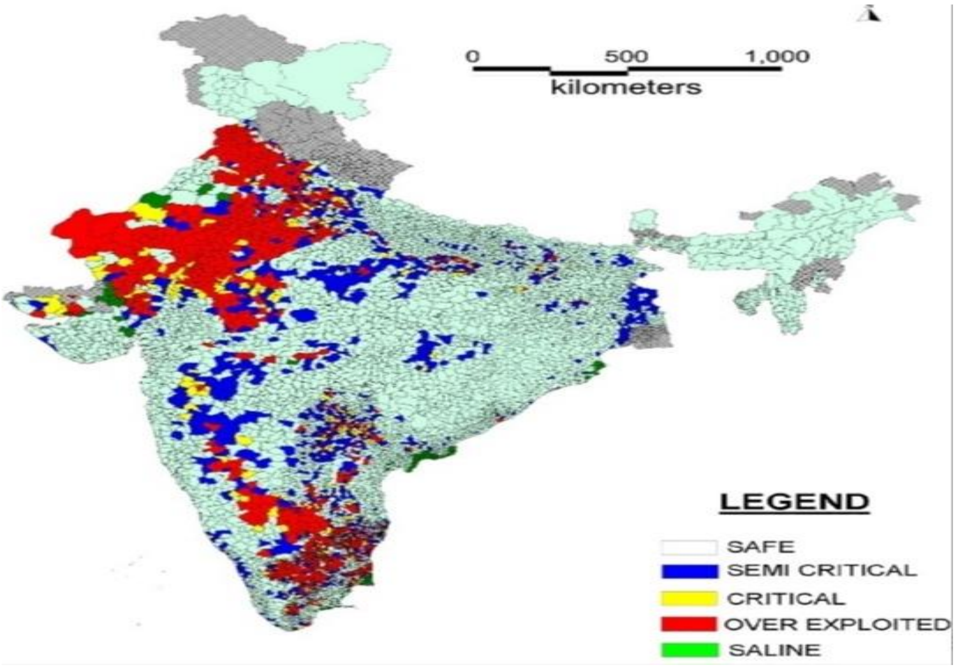


Figure 3 Groundwater Categorization of Assessment (Central Ground Water Board, n.d.)

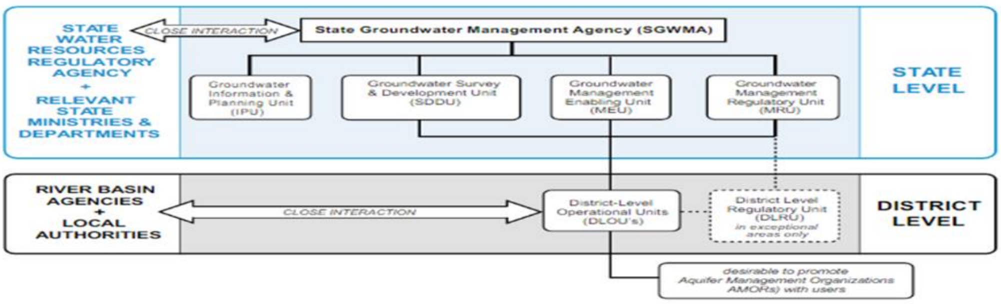
According to the Central Ground Water Board of India (CGWB), 17 per cent of groundwater talukas are overexploited (indicating the frequency upon which water is removed outweighs the frequency with which the Aquifer (Aquifer, n.d.) can recharge).

The study is based on the Jawalarjun village situated in Purandhar taluka/block of Pune District, Maharashtra.

The stage of groundwater development of Purandhar is 94.86 per cent (CGWB, 2013) and categorized as Semi Critical. Groundwater in many villages in Purandhar taluka/block has reached the overexploited level. Purandhar has thousands of dug wells and bore wells through which groundwater has been extracted for the last fifteen years (IndiaWaterportal, n.d.) which has created serious problems. The Groundwater Survey and Development Agency (GSDA) has identified 20 villages in eastern Purandhar as being in the dark zone. The main reasons for the decline in groundwater level in Purandhar taluka are:

- Significant falling rainfall trend of (-) 71.09 mm/year (Central Ground Water Board, n.d.) ,
- Owing to the lack of surface water, farmers have concentrated on groundwater,
- The State government has drilled a large number of bore wells and fitted them with hand pumps/electric motors for the purpose to provide drinking water in rural areas. Yields of bore wells range from 500 to 3,000 lph (2017) (Central Ground Water Board, n.d.) .
- Groundwater development has increased over the period from 84.07 per cent in 2004 to 94.91 per cent in 2011 (Central Ground Water Board, n.d.) and
- Cash crop mainly sugarcane sown by the farmers (5.62 sq.km.) which requires 1500-3000 (Claro Blog, n.d.) litres of water to produce a kilo of sugarcane (Central Ground Water Board, n.d.).

The Maharashtra State Government established the Groundwater Surveys & Development Agency (GSDA) (GSDA, n.d.) during the year 1972. The GSDA is engaged, in the exploration, development, and augmentation of groundwater resources in the State through various schemes. It mainly includes drilling of bore wells/tube wells under the Rural Water Supply Programme, rendering technical guidance under minor irrigation programs by locating suitable dug well sites, strengthening groundwater sources by water conservation measures, artificial recharge projects for induced groundwater, and specific studies related to the periodic status of groundwater availability, protecting the existing groundwater resources through technical assistance under Groundwater Act, etc. The internal structure of GSDA is as under:



1.3 Sustainability in Groundwater Management

'Groundwater sustainability is the development and use of groundwater resources to meet current and future beneficial uses without causing unacceptable environmental or socio-economic consequences' (NGWA, 2023) .

The sustainability of groundwater resources is a function of many factors (Sustainability of Ground-Water Resources, n.d.) , including decline in groundwater storage, reduction in stream flow and lake levels, land subsidence, and changes in groundwater quality. Every ground-water development situation is different, necessitating an analysis tailored to the type of water difficulties encountered, taking into consideration social, economic, and environmental restrictions. Evaluation of hydrological implications of alternative management options is a crucial problem for achieving ground-water sustainability.

Sustainable groundwater management is essential for the conservation of groundwater dependent ecosystems.

1.4 Research Objectives

The objectives of carrying out this study are as follows:

- Analysing the trend of groundwater availability and its exploitation
- Identify groundwater related challenges in rural areas and water conservation practices that increase groundwater including government policies/schemes, social organisations etc. in selected - Jawalarjun village in the Pune district of Maharashtra.

This study is focused on the use of water conservation techniques to save and store water in aquifers, especially in the Pune district of Maharashtra.

1.5 Study Area and Scope

Study Area:

As already explained in the preceding paragraph, Jawalarjun village of Purandhar taluka and its surrounding area in Pune District, Maharashtra is the primary area for research. The Purandhar taluka's headquarters centre, Saswad town, is located about 30 kilometres from the Jawalarjun village. Jawalarjun village can be reached from the Pune-Baramati road (shown in figure 4 below).

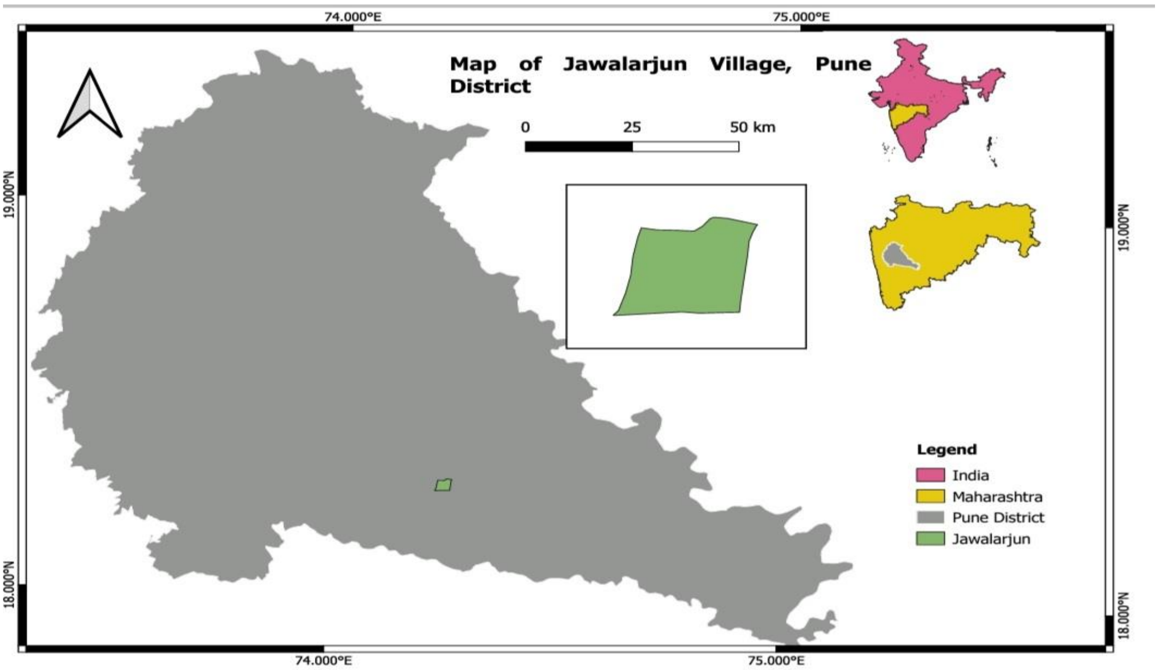


Figure 4 Location map of study area on a regional scale

The Jawalarjun is bounded by the latitudes 18.301 N and the longitudes 74.240 E. The mean average elevation of the village is 643 m above MSL (mean sea level). Pre-monsoon water table elevation in the village is 634.4 m above MSL while post-monsoon water table elevation is 635.1 m above MSL. (CGWB report, 2017) (Central Ground Water Board, n.d.)   .

As per the Population Census 2011 (Censusindia, 2011) , total population of Jawalarjun is 2,347**.** The Average Sex Ratio of Jawalarjun is 984 **(**1,183 are males and 1,164 are females**)**.

As per the census 2011 (Censusindia, 2011), 1,265 were engaged in different work activities. 96.8 per cent of workers describe their work as Main Work (Employment or Earning more than 6 months) while 3.2 per cent were involved in Marginal activity providing livelihood for less than 6 months. Of 1,265 workers, 839 were cultivators owner/co-owner and 232 were Agricultural labourers (Censusindia, 2011).

Physiography (Central Ground Water Board, n.d.)

The area (*figure 5 below*) can be broadly divided as Older Flood Plain (513-560 metres above mean sea level (mamsl)), Region of Denudational origin (550-600 mamsl), Middle-Level Plateau (600-900 mamsl), High-Level Plateau (>900 mamsl) (Mamsl- metres above mean sea level). The western part of the area is occupied by hills, the central part by hillocks and the eastern part by nearly plain terrain with few isolated mounds, divided by valleys of Karha River and other tributaries of Nira River. The region has an average elevation of 516 metres above sea level and a maximum elevation of 1340 metres above mean sea level msl. (GheraPurandhar).

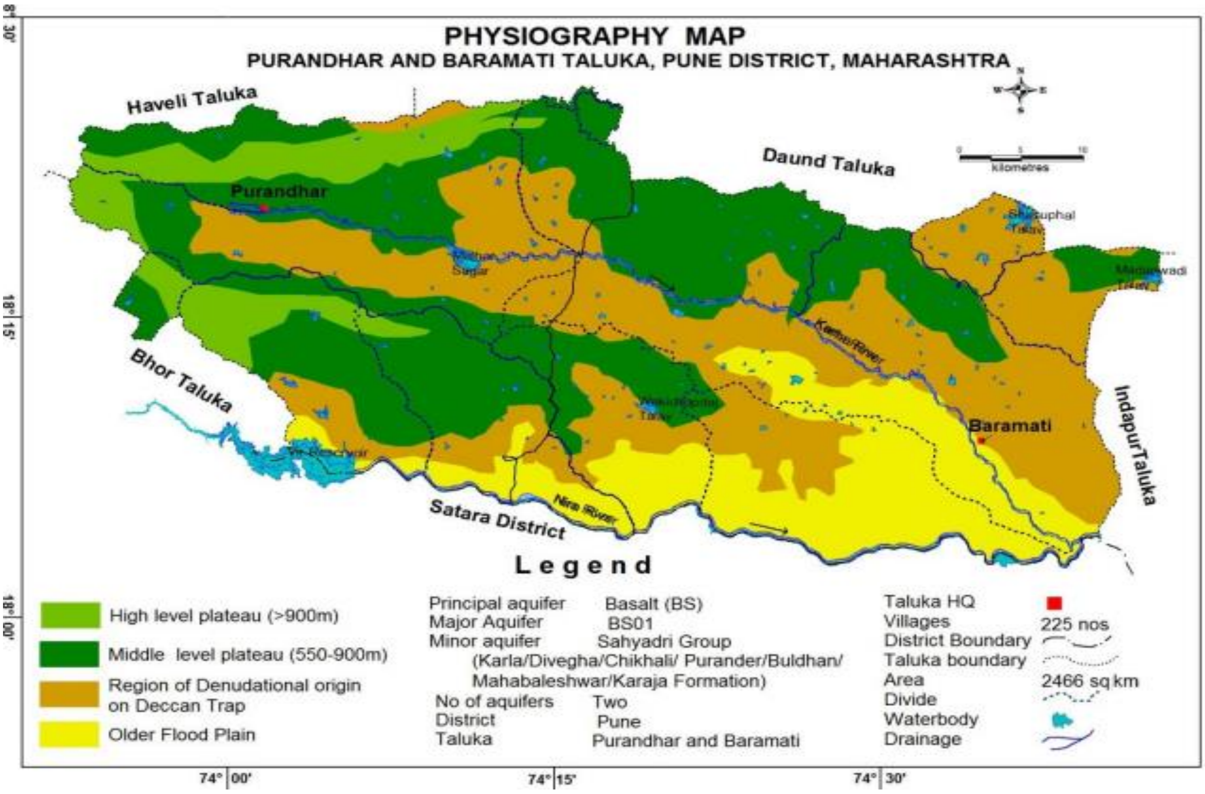


Figure 5 Physiography of Purandhar block5 (Central Ground Water Board, n.d.)

1.6 Methodology

This study focuses on the use of water conservation techniques to save and store water in the aquifers. It discusses, how various climatic factors, such as rainfall and temperature, have affected groundwater development in the Village and various approaches to develop water conservation strategies. The study also covered challenges related to groundwater and the ways to overcome those challenges.

The framework for highlighting sustainable practices to conserve groundwater in rural areas for "**sustainable development**" is outlined in (*figure 6*) the broad steps are enumerated below:

- **Step 1:** To find the problems and issues related to groundwater surrounding the study area (Jawalarjun).
- **Step 2:** Find out methods of water conservation. These mainly consist of conventional and unconventional practices.
- **Step 3:** Find out the water conservation practices in the study area which have been developed with the help of social organizations/ various government schemes.

- **Step 4:** Compare the work done on IWRM (Gwp, n.d.) principle and Dublin (Principles of Integrated Water Resources Management, n.d.) principle with the water conservation practices followed in study area.
- **Step 5:** Analysis of water conservation techniques supported by governmental and social institutions.

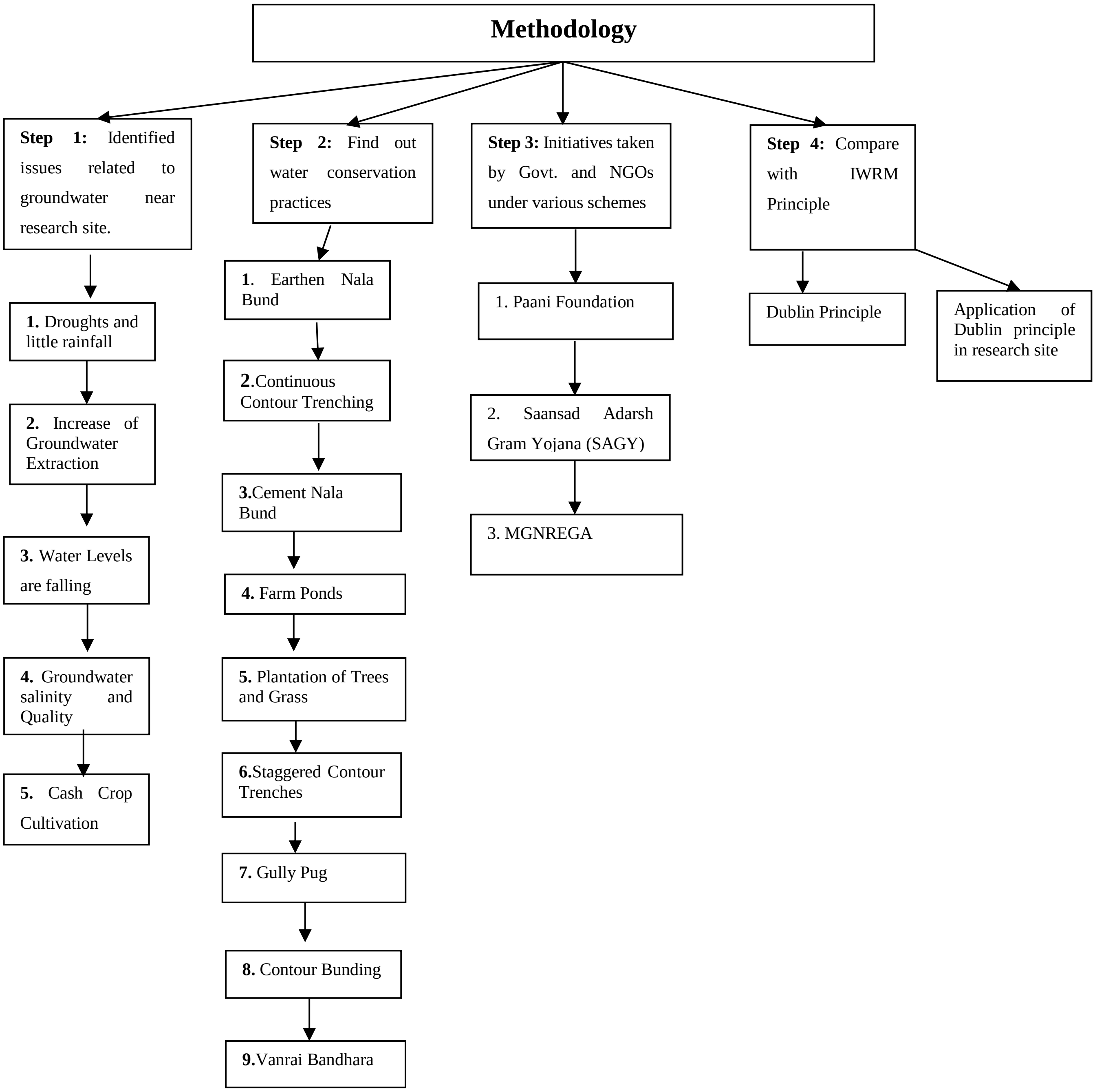


Figure 6 *Framework of highlighting sustainable practices to conserve groundwater in the rural area for "sustainable development" (Self source)*

Study and discussion

1.6.1 Step 1: Identified issues related to groundwater near the research site:

1.6.1.1 Droughts and little rainfall

As per the Aquifer Mapping report 2017 from CGWB, the average annual rainfall of Purandhar taluka for the decade 2006-2016 is 621.48 mm which is indicated in *figure 7*. Purandhar taluka had a significant rainfall falling trend and out of the 11 years, below average rainfall was recorded in 9 years. As a result, the taluka has poor and diminishing precipitation and regular droughts (Central Ground Water Board, n.d.).

Table 1 (Central Ground Water Board, n.d.) –Rainfall in Purandhar

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	**Avg.**
Rainfall in mm	1476	519	497	806	602	609.4	371	574.3	371.3	388.8	270.02	**621.48**

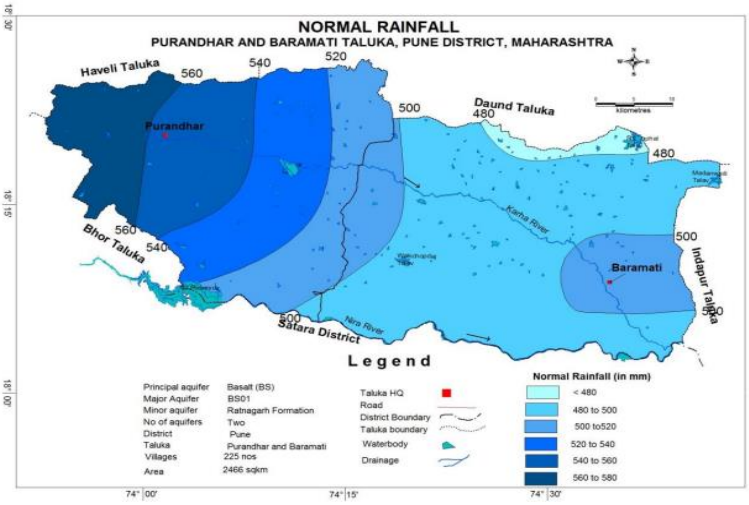


Figure 7 Rainfall trend in Purandhar taluka (Central Ground Water Board, n.d.)

As per the CGWB report on the National Compilation Dynamic Groundwater Resources of India 2017

(Ministry of Jal Shakti, 2019), rainfall is the primary and significant source of recharging groundwater. Only the four rainy months from June to September get more than 75 per cent of the yearly rainfall, which causes significant temporal changes. Although, there are large regional fluctuations, the yearly average rainfall of the country is 119 cm while the Northern Parts of Kashmir and Western Rajasthan receive less than 40 cm annual, the places in the Western Ghats and the Sub-Himalayan areas in the North East and Meghalaya Hills receive substantial rainfall of over 250 cm annually. India's rainfall has two noteworthy characteristics: in the north, it decreases westward while in Peninsular India, it reduces eastward before increasing in the coastal region.

The country's yearly groundwater recharge is mostly contributed by rainfall (both monsoon and non-monsoon), which contributes 67 per cent of the total and share of other resources viz. canal seepage, return flow from irrigation, recharge from tanks, ponds, and water conservation structures taken together is 33 per cent (Ministry of Jal Shakti, 2019) .

1.6.1.2 Increase in Groundwater Extraction

The level of groundwater extraction in Purandhar taluka increased from 84.07 per cent to 94.91 per cent between 2004 and 2011 (Central Ground Water Board, n.d.) . Irrigation is the primary driver for groundwater overdraft ranging between 297.09 million cubic per meter (MCM) in 2004 to 302.87 MCM in 2013 (Central Ground Water Board, n.d.).

Factors affecting groundwater exploitation in Purandhar (Central Ground Water Board, n.d.)

Climate change: Except for the south-west monsoon season, the area has a subtropical to tropical temperate climate with hot summers and general dryness all year. Summer months are typically February to May, with maximum temperatures ranging from 30 to 40°C. Rainfall has a coefficient of variation of 35 per cent. Despite excess rainfall in 20 to 25 years between 1901 and 2015, the taluka experienced drought conditions in 25 per cent of the years (Central Ground Water Board, n.d.).

Human Activities: An important factor responsible for groundwater over-exploitation is human activity such as cultivation of cash crops. The sugarcane crop requires a lot of water. Thus, the farmers overuse the water for this crop which endangers the groundwater level (The topic is explained in Para no 3.1.5 - Cash crop cultivation).

1.6.1.3 Falling water levels in Purandhar taluka

Groundwater overexploitation has resulted in a decrease in water levels over time. The declining water level trends >0.2m/year have been observed in the major part of around 1188 Sq.km. (48.2 per cent of the area) during pre-monsoon and 1978 Sq.km during post-monsoon (2007-2016), as shown in *figure 8(a)* and *(b)* (Central Ground Water Board, n.d.)*:*

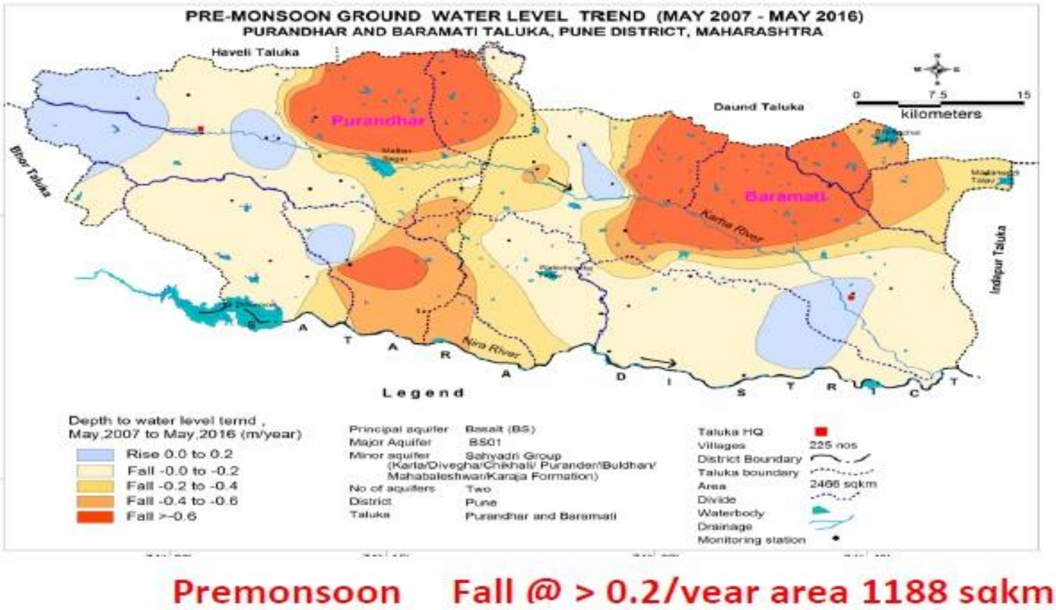


Figure 8(a) Pre-monsoon water level showing in Purandhar taluka (Central Ground Water Board, n.d.)

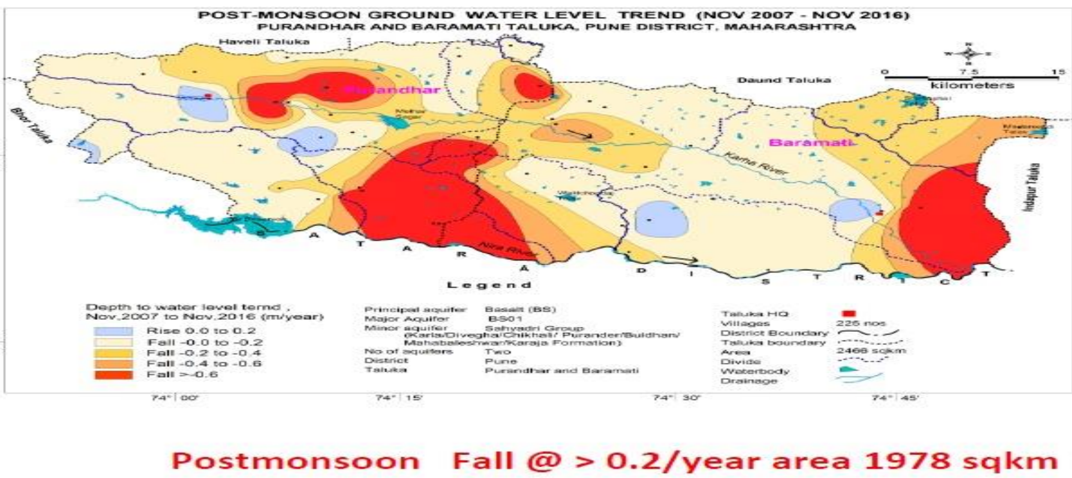


Figure 8(b) Post-monsoon water level showing in Purandhar block (Central Ground Water Board, n.d.)

During the pre-monsoon period, a declining water level trend of > 0.20 m/year was reported in 3300 sq km, (21 per cent of the region), which included parts of Purandhar and some other talukas in Pune District. In parts of Purandhar a significant decline of < 0.20 m/year was reported in the post-monsoon season, encompassing 1395 sq km or 8.9 per cent of the landmass, as Shown in *figure 9* (Central Ground Water Board, 2018):

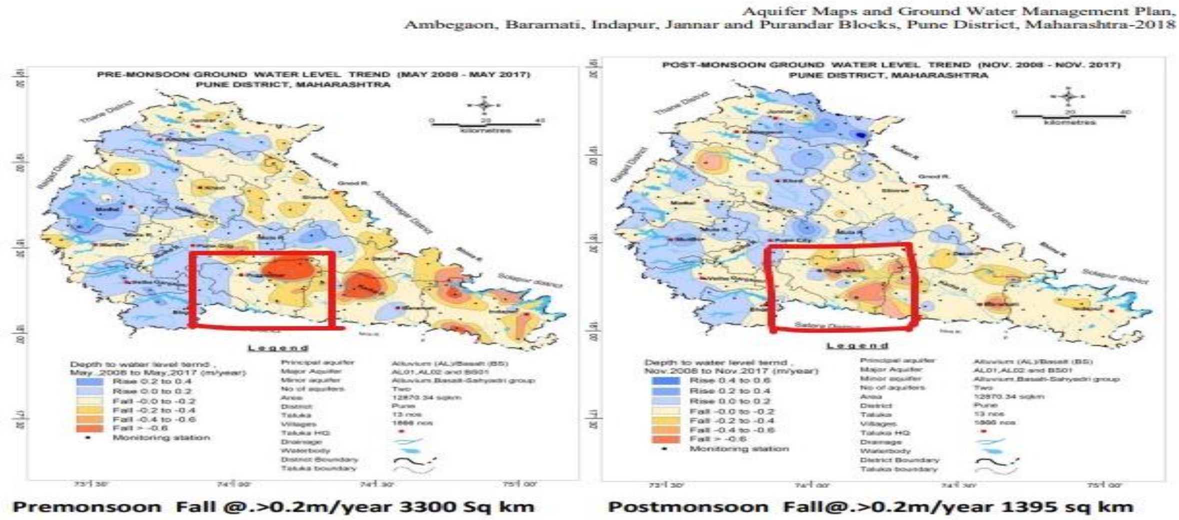


Figure 9 Declining water level

1.6.1.4 Groundwater salinity and water quality

As per a detailed research report (2009) of Advance Centre for Water Resources Development and Management (ACWADAM) in ten villages of eastern Purandhar, it has been observed that alluvial deposits set apart the stretch encompassing the areas of Pimpri and the whole of Pandeshwar village from the surrounding areas dominated by Deccan basalt (aquifer). Groundwater quality issues exist in this location, primarily due to the concentration of dissolved solids and over-exploitation in the village. The difference in groundwater characteristics of two lithological media – basalts and alluvium – causes issues of groundwater salinity. The presence of basalt and alluvium implies the accumulation and movement of groundwater. The recharging mechanisms that occur under such a system are highly complex. The amount of groundwater travelling through the basalts is relatively small, but the velocity of groundwater movement is greater due to fracture induced permeability. (Indiawaterportal, 2010)

As per 2009 data obtained from the ACWADAM, TDS (Total Dissolved Solid) levels in a few wells, such as PP2 in Pandeshwar's nearby village of Jawalarjun, were above 5000 ppm, which is excessive when compared to the permissible limits of TDS for drinking water which are between 50 to 150 ppm (Bisleri, 2020) . TDS levels in Pandeshwar wells were often over 1000 ppm. Some wells also had more significant sodium, chloride, and sulphate concentrations. The land watered by these wells had been eroded due to the salinity in the groundwater. (Indiawaterportal, 2010) .

According to BIS (2012), the ideal limit of nitrate is 45 mg/l. 178 shallow aquifer samples were tested, and 49 of these showed nitrate concentrations over the desired limit of 45 mg/l. The high concentration of Nitrate may be attributable to residential waste and sewage in the areas. Water samples from Jawalarjun and adjacent settlements revealed more than 45 mg per liter of nitrate. Groundwater surrounding Jawalarjun has an extremely high salinity (EC >2250 S/cm), making it unfit for drinking, residential, industrial, or crop irrigation. (Fig. 10) (Central Ground Water Board, n.d.) .

The greatest concentration of fluoride in Aquifer - II (Deeper aquifer) is observed in Waghapur village, Purandhar taluka (4.27 mg/l). Fluoride concentrations above the permissible limit have been found in samples from the deeper aquifer at Purandhar and its surrounding talukas.

RSC (Residual sodium carbonate (Wekepedia, 21)) values of groundwater from the confined aquifer are more than 2.50 meq/l at Saswad - groundwater of these areas was found not suitable for irrigation (*figure 10*) (Central Ground Water Board, 2018).

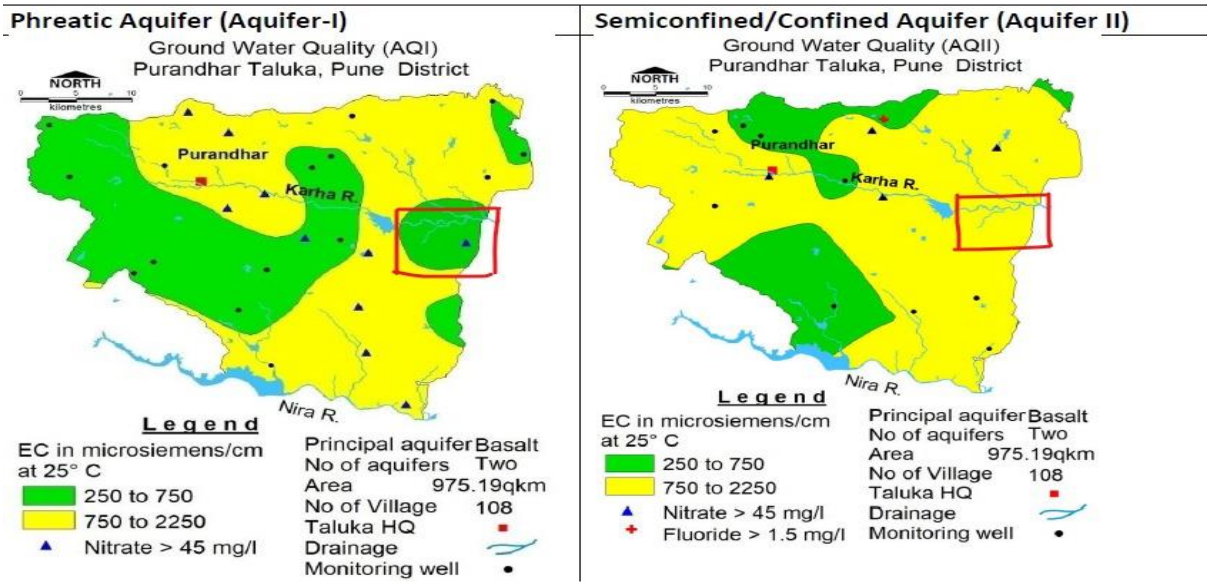


Figure 10 Groundwater quality in Purandhar and Jawalarjun village (Central Ground Water Board, n.d.)

1.6.1.5 Cash Crop Cultivation

After Uttar Pradesh, Maharashtra produces the highest amount of sugarcane in the country. In Maharashtra, this crop covers only four per cent of the agricultural land, yet it uses 71.5 per cent of the irrigation water and 79 per cent of that is planted in areas that are prone to drought. Due to the factories being either owned by or under the authority of the State's officials, sugarcane farming and the sugar industry have enjoyed preferential treatment for decades (The Economic Times, 2015).

As per the Aquifer mapping report 2017 from CGWB, groundwater irrigates the whole sugarcane crop (5.62 sq.km.) in Purandhar. As a result, a large amount of groundwater is bound to maintain the sugarcane crop (Central Ground Water Board, n.d.).

1.6.2 Step 2: Water conservation practices

1.6.2.1 Earthen Nala Bund (ENB) (JournalINX, n.d.)

A bund constructed out of local soil across the stream to check soil erosion to store water and drain out excess water by using a spillway is called Earthen Nala Bund (ENB). It percolates water, raising the surrounding water level in wells and boreholes.

The ENB construction seen in *figure 11(a)* is on the Nala that joins the river Karha as it flows through Jawalarjun village. In this *figure 11(a)* it is seen that water was not collected before the formation of the structure. Water storage started after formation of the structure shown in *figure 11 (b)*. Its direct effect is seen on water structures such as wells and bore-wells shown in *figure 11 (b)*. Before the construction, the water level was extremely low; after the structure, the water level increased.

Utility of ENB

- As a water reserve.
- Water accessibility for the nearby farmers.
- The amount of water in locations vulnerable to drought or water shortages.
- To slow down the water pressure to lessen land degradation.

Figure 11 (a) Earthen Nala Bund at Jawalarjun, Source- Panni Foundation, Satyamev Jayate (2019)
(instagram, n.d.)

Figure 11(b[1]) Water level (After and Before) in Well nearest ENB Structure[2]

1.6.2.2 Continuous Contour Trenching (CCT*)*

Continuous Contour Trenching is a technique which excavates a continuous trench (60 cm wide x 30 cm. deep) which starts from the top to the bottom. The slope and availability of resources determine the distance between the trenches. The contour trench is constructed with an extension of the practice of ploughing fields at the right angle to the slope. CCT is the most appropriate approach for places with little precipitation, hills, and uneven terrain. A berm is formed on the downhill edge of the ditch using the soil excavated from the ditch. Native plants

[1] Self-source
[2] Self source

and lentils are sown in the embankment to stabilize the soil and provide the branches and greenery necessary to capture any silt that might escape from the trench during periods of intense rainfall (EA, n.d.).

The following are the primary purposes of employing the CCT strategy (EA, n.d.) .

- Continuous Contour trench development aids in halting soil erosion.
- It decreases runoff rates which results increasing in percolation rate.
- Rising groundwater levels improve the soil's quality and the region's green cover.
- There has been a rise in drinking water, agriculture and employment.
- In general, it assists in developing degraded lands and improving soil moisture for vegetation.

The Jawalarjun area's geographic location is at a latitude of 18.301° N and a longitude of 74.240° E. The general direction of the slope is from South to North (fig. 2.2.3). Average elevation of the area is about 643 m. above mean sea level in the South to North. Due to such geographical location, CCT works were carried out in the village, as shown in *figure 12*. The water-shed treatment known as CCT performs the function of a speed breaker on flowing water. Dug along contour lines, these trenches work efficiently if created scientifically with the right tools. Its direct effect is seen on water structures such as wells and bore-wells. The water level was very low, but the water level increased after formation of the structure.

Figure 12 Continuous contour Trenching (CCT) in Jawalarjun Village, Source- Panni Foundation, Satyamev Jayate (2019 (Facebook, 2019) ***)***

1.6.2.3 Cement Nala Bund

An important watershed intervention is the Cement Nala Bund (CNB) which is built on the mainstream/Nala. A CNB is a bund/obstruction constructed across the Nala or stream by using cement concrete to obstruct and store the flowing water. CNBs are also referred to by a few other names pukka bund, check dam, weir etc. CNB prevents soil erosion, expands the irrigation area and slows the rate at which water erupts from the surface. It increases the amount of groundwater and raises the water depth in the wells under dam's catchment area (Indian Institute of Technology Bombay, 2019).

Figure 13 (a) shows the construction of the CNB structure on the Karha River in Jawalarjun before and during the construction work.

Figure 13 (a) CNB Structure on Karha River (Before and After) structure[3]

It can be seen in *figure 13(a)* that water accumulation started after the construction of the structure.

Figure 13 (b) Water level (Before and After) in nearest the well of CNB structure at Jawalarjun village

(Green Foundation, n.d.)

Figure 13 (b) shows the low water level in the well before the construction of CNB. The water level increased after the construction of Cement Nala Bund.

[3] Self source

1.6.2.4 Farm Ponds

Farm ponds are constructed to collect and store rainwater and include drainage systems that direct runoff to the pond. Too much water is drained onto the surrounding terrain via pond outlets. Pond water is frequently utilised for agricultural irrigation.

One of the primary advantages of agricultural ponds is that it reduces farmers' dependency on groundwater or rainfall. They help farmers resist climate change by providing a water supply during dry seasons. Additionally, Farm ponds enhance soil moisture levels, restore groundwater supplies, and recharge borehole water sources. (Green Foundation, n.d.)

Farm ponds are divided into four varieties based on their location and source of water (CRIDA, 2012):

1. Excavated or dug-out ponds
2. Ponds on the ground/surface pond
3. Ponds that are fed by a spring or a creek
4. Off-stream storage ponds.

Only surface ponds are located in the research site.

Local soil qualities, geography, drainage capabilities, infiltration and precipitation patterns etc. play an important role in determining the site for the farm pond. Choosing a decent site is one of the most important aspects of creating agricultural ponds.

Surface Pond

Surface ponds are created to gather runoff from the surrounding farmland into a nearby depression or the lowest part of the farm, requiring little to no excavation aside from building the earthen barrier that encloses the water body. These are feasible in agricultural areas with undulating topography and severe erosion. Such agricultural ponds do not require inlets, but rather they must have outlets in the earthen bund to discharge the excess flow (CRIDA, 2012). *figure 14* shows the farm pond under construction and after construction in Jawalarjun. Water reserves is seen after creation of the farm pond. It had a direct effect on groundwater levels (which showed an increase).

Figure 14[4] Farm Pond (Shet Tale) in Jawalarjun Village, (Water level). Before and after of structure[5]

Suggested Conventional water conservation practices for Jawalarjun Village

a) Staggered Contour Trenches (Better Mahatma Gandhi NREGA, n.d.) - Staggered contour trenches are trenches dug in a trapezoid shape with a top width of 1.0 meters, and a bottom width of 1.0 meters, and a depth of 0.6 meters. The soil removed is used to create a berm just downhill from the trench. The trenches should be dug perpendicular to the slope (along the contours). They can either be continuous or staggered, such that they are 3 meters long, with 1-meter gap between every section, and 3 meters between every row.

b)Gully Plug (Sswm-solutions-bop-markets, n.d.) - Gully plugs, also known as check dams, are primarily constructed to stop erosion and deposit contaminants and silt. A check dam (sometimes called a gully plug) is a minor, partial, or full-sized dam constructed across a drainage ditch, swale, or channel in order to slow down targeted flows for a particular design range of storm events. It helps in recharging shallow wells.

c) Contour Bunding (IndiaAgroNet.com, n.d.) - Contour Bunding are carried out in many parts of India- notably in Maharashtra, Gujarat, Tamilnadu, Karnataka and Andhra Pradesh. It consists of building earthen embankments across the slope of the land, following the contour as closely as possible. A series of such bunds divide the area into strips and act as barriers to the flow of water, thus reducing the amount and velocity of the runoff.

d) Vanrai Bandhara (IJSRD, n.d.) - Vanrai bandhara or Bunds are constructed over streams or small rivers using gunny bags that have been filled with adjacent sand or dirt. This luggage is correctly sealed and positioned to resemble a wall barrier. This is a movable construction placed along a waterway to collect water and slow down the flow of the stream to enhance the water infiltration level.
Immediately following the most recent rainfall, vanrai bandharas are constructed to prevent runoff and hold water

[4] Self source
[5] Self source

1.6.2.5 Plantation of trees and grass

Choosing plants to conserve water (University of Delaware, n.d.)

Plant selection is one of the most crucial element in creating a drought-tolerant landscape. Other than concern about plant's size, texture, colour and other physical characteristics, focus should be on significance of the plant for overall ecology. Planting trees around the structure helps prevent run-off. There are various structures for water conservation in Jawalarjun village (CCT, Farm ponds, ENB, CNB, etc.) and trees have been planted around them.

Figure 15 shows tree plantation activity in Jawalarjun village. This activity was implemented under the *Paani Foundation* workshop. Students, NGOs and villagers participated in the workshop and planted trees.

Figure 15[6] Plantation of trees in Jawalarjun Village[7]

1.6.3 Step 3: Government and NGOs initiatives for water conservation

1.6.3.1 Paani Foundation (Paanifoundation, n.d.)

Work at the Paani Foundation (Paanifoundation, n.d.) is focused on mobilising the public to address the drought. The *"Satyamev Jayate Samruddha Gaon Spardha",* a bigger competition to change rural ecological and rural economic conditions, was established in 2020 and has ever since grown in popularity.

[6] Self-source by intern

[7] Self source

From 2016 to 2019, the Paani Foundation held the "*Satyamev Jayte Water Cup*" event, in which thousands of villages participated to accomplish the best work in water and soil conservation. The tournament became a venue for the village communities to address the drought issue constructively.

Two major pillars of the competition,

1. Training and
2. Shrama-Daan or volunteer work.

Figure 16(a) and *16(b)* shows celebrities and women's self-help group (SHG) participating in volunteer work in Jawalarjun village during the *Satyamev Jayate Water Cup competition*. Over the years, the work done by the villages participating in the *Satyamev Jayate Water Cup* has increased the storage capacity of water by more than 550 billion litres. (Paani Foundation, n.d.)

Figure 16(a)[8] ***Volunteer work by Bollywood celebrities in Jawalarjun village***[9]

Figure 16(b) Volunteer work by Mahila Bachat Gat (Self Help group) in Jawalarjun Village[10]

Figure 16(c) below shows the students and NGOs participating in water conservation programmes under the volunteer work in Jawalarjun village.

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8 Self source
9 Self source
10 Self source

Figure 16 (c)[11] Volunteer work under Water conservation by Students and NGOs[12]

Workshop under Paani Foundation

Nisargachi Dhmaal Shala from education to action

The Paani Foundation's workshop for kids in Maharashtra's Zilla Parishad schools is called "**Nisargachi Dhamaal Shala** (Paanifoundation, n.d.) " ("Fun School for Nature"). Its goal is to educate students about critical environmental challenges and motivate them to take immediate action. Students learn about topics such as climate change, water scarcity, and water conservation through games, movies, and studies.

In *figure 16 (d)* shows students and NGO members participated in the workshop “Nisargachi Dhamaal Shala” in Jawalarjun village under the tree- plantation program.

Figure 16 (d)[13] Tree- plantation under activity of the workshop by Students and NGOs[14]

[11] Self source
[12] Self source
[13] Self source
[14] Self source

1.6.3.2 Saansad Adarsh Gram Yojana (Saansad Adarsh Gram Yojna, n.d.)

Prime Minister Shri Narendra Modi shared his vision for Saansad Adarsh Gram Yojana on its launch. Saansad Adarsh Gram Yojana (SAGY) was established on October 11, 2014 with the goal of bringing Mahatma Gandhi's full vision of an ideal Indian village to reality while taking into consideration the current environment. Under SAGY, each Member of Parliament adopts a Gram Panchayat and guides its holistic development, emphasising social development with infrastructure. The development of SAGY villages strives to create model villages by ensuring that all plans have been integrated and adequately implemented in order of priority.

SAGY supported water conservation projects on the Karha River and its tributaries in the village, which mostly comprised of a Cement Nala Bund structure. This development work has benefited not only the people of the village but also the surrounding villages. Due to this water conservation structure, the water level of wells and bore-wells in the village has increased. This has greatly benefited the agriculture industry. Figure 17 shows series of Cement Nala Bund under SAGY.

Figure 17 Series of Cement Nala Bund (Kolhapur padhatiche Bandhare) at Jawalarjun under the SAGY[15].

[15] Self source

MGNREGA and Water Conservation (PIB Delhi, 2019) : - MGNREGA has become the main force that is driving water conservation efforts all across rural India during the last five years. The initiative has developed from merely mitigating rural distress to a focused drive to increase rural incomes through Natural Resource Management (NRM) projects. As a result, approximately 75 per cent of the activities permitted under the Act now directly benefit water security and conservation initiatives. The major works taken up under NRM include check dam, ponds, renovation of traditional water bodies, land development, embankment, field bunds, field channels, plantations, contour trenches etc. Mission Water Conservation Guidelines were developed in collaboration with the Ministries of Water Resources, River Development & Ganga Rejuvenation, and Department of Land Resources to focus on the dark and grey blocks where groundwater levels were quickly declining. The funds of MGNREGA, dovetailed with State funds have led to the following very successful State level schemes.

1.6.4 Step 4: Comparison with IWRM Principle

1.6.4.1 Integrated Water Resource Management (IWRM)

As per the Technical Committee of the Global Water Partnership (GWP) (IWA Publishing, 2012) , Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (IWA Publishing, n.d.). Social equality, economic efficiency, and environmental sustainability are the three principles that form the basis of IWRM (Technical Committee, n.d.) .

Economic efficiency makes scarce water resources go as far as possible and to allocate water strategically to different economic sectors and uses.

Social equity to ensure equitable access to water and the benefits from water use, between women and men, rich people and poor, across different social and economic groups both within and across countries. This involves issues of entitlement, access and control.

Environmental sustainability to protect the water resources base and related aquatic ecosystems, and more broadly to help address global environmental issues such as climate change mitigation and adaptation and sustainable energy and food security.

1.6.4.2 Dublin Principles (IWRM) of The International Conference on Water and the Environment (ICWE 1992) **(UNESCO-IHE Institute of water education, 2014)** and its applications in research area (Jawalarjun village**)**

First Dublin's Principle: 'Water is a finite, vulnerable and essential resource which should be managed in an integrated manner' - Despite the implementation of water conservation measures in the region, growing groundwater usage in Jawalarjun village has created a threat to the availability of drinking water due to large-scale agricultural growth. Chemical fertilizers used in agriculture have increased water pollution, affecting humans and their livestock. Farmers' usage of chemical fertilisers did not decline, and their use of organic fertilisers remained minimal. Therefore, the first principle appears to be ignored in Jawalarjun village.

Second Dublin Principle: 'Water resources development and management should be based on a participatory approach, involving all relevant stakeholders' -

The concept of a participatory approach (2018-19) in water conservation works in Jawalarjun village was adopted by the *Paani Foundation* (*Satyamev Jayate Water Cup Competition, 2019*). The water conservation work of the *Paani Foundation* saw the participation of all stakeholders from the government, NGOs, students and women as well as the rich and poor in the community.

This indicates that Dublin's second IWRM-related principle has appropriately been complied with in Jawalarjun Village.

Third Dublin Principal: 'Women play a central role in the provision, management and safeguarding of water' -

Women are playing a big role in water conservation work in Jawalarjun village since 2019 which may be seen in *fig. 16 (b) and 16 (c)*. Hence, the third Dublin principle, affiliated with IWRM was found to be followed here.

Fourth principle of Dublin: 'Water has an economic value and should be recognised as an economic good, taking into account affordability and equity criteria'-

If farmers want to irrigate their fields during the summer season they have to devote significantly to water conservation works in Jawalarjun village under SAGY. Dublin's fourth principle, which is affiliated with IWRM was found to be followed in the research area.

1.7 Observations

During the study, it was observed that:

- Water level of the wells/bore-wells situated near the farm ponds have increased in Jawalarjun village.
- Water level of the wells and bore-wells has increased due to the construction of Earthen Nala Bund in the village.
- The construction of the CCT has contributed to the accumulation of rainwater during the monsoon season. As a result, the farmers have more water for irrigation and prevent soil erosion in the village.
- The construction of the Cement Nala Bund structure has raised the surface water level in Jawalarjun village. As a result, farmers who did not have enough water to cultivate cash crops began cultivating sugarcane and other crops, which improved their economic situation.
- However, tree plantation has contributed immensely in preventing soil erosion and development of a sustainable eco-system. Though there is no example demonstrating the direct impact of tree planting on increasing groundwater.

The above-mentioned observations have already been explained in detail in "**Water Conservation practices**" part of paper.

The efforts being made in Jawalarjun Village have resulted in a significant rise in surface water as well as groundwater. The agriculture in the Jawalarjun village benefited and farmers began to produce more crops, thus increasing their income.

1.8 Limitations of study

The study relies on secondary sources of data, including publications like books, newspapers, and other research papers. The absence of meteorological data presented a significant challenge for study. The meteorological data in these rainfall figures are generally collected at large taluka sites (blocks) or specific division regions where rain gauges are installed. As a result, obtaining reliable and authentic data for a specific village/ small area was difficult.

Furthermore, data uniformity is not maintained by different sources i.e. the central government, state government and gram-panchayat.

1.9 Significance of Study

1.9.1 Food security and groundwater management

The population of India is growing fast. It is estimated that it will increase from 361 million in 1951 to 1.7 billion by 2050 (Wekepedia, n.d.) . Food security could become a serious concern in future.

An increase in water scarcity, pollution, and competition for water resources will add a new dimension to our country's food insecurity (Pro Bono India, n.d.) . Climate changes will also play a vital role in ensuring food security.

In the Jawalarjun village, groundwater conservation practices adopted by the villagers/farmers helped them sustain agricultural productivity This study may also help prevent falling groundwater levels in other parts of the country by adopting water conservation practices highlighted in the study.

1.9.2 Poverty alienation and ground water management

In rural India, groundwater is the primary source for drinking and irrigation because of its easy availability, reliability and little capital cost.

Out of the total working population in the Jawalarjun village, 839 were cultivators (owner or co-owner) and 232 were agricultural labourers (Census India, n.d.) . Therefore, this indicates that agriculture and related activities are a significant source of livelihood in the village and sustainable groundwater management has a vital role to reduce poverty.

1.9.3 Drinking water security

Drinking water is an issue in some areas of the Jawalarjun village. Pressure challenges develop, particularly at high altitudes while providing water via pipelines. In such areas, there is no water supply by the pipe. Drinking water, particularly in the summer season, is a major concern in isolated regions.

Groundwater levels in such remote regions can be increased by water conservation methods. The water level of dug wells and bore-wells in these places can be raised in this manner. Furthermore, it can address the issue of drinking water in such isolated regions.

1.9.4 Importance for Audit

Points incorporated in the study may be helpful for auditors. The research study can be useful in understanding the development of an aquifer's water balance by taking into account the flow system's natural conditions. Further, the study with pan-India information availability can also serve as a source of information for CAG’s audits to ascertain groundwater challenges particularly in rural areas, groundwater management, groundwater regulation implementation and targets under the United Nations mandated Sustainable Development Goal 6 that addresses water-related issues.

1.10 Conclusion

The objective of this study is to underline the threats to sustainability of groundwater resources and promote water conservation in rural areas. It highlights different factors affecting groundwater and approaches used for its management in the selected site for this study.

Various traditional water conservation practices (CCT, ENB, Farm Pond, Plantation, CNB etc.) in Western Maharashtra (Pune District) were highlighted as these are mainly less expensive and therefore, beneficial for the small farmers. For example, the main advantage of the Earthen Nala Bund structure in Jawalarjun is its low cost, as the soil, sand, stone etc. are all freely available.

As previously discussed in the introduction of this research paper about the significance of groundwater for drinking and irrigation, the study can be useful for groundwater management with expanding population, particularly in rural areas.

Theme-2: Municipal Solid Waste Management in three selected cities in India (Indore, Surat and Jaipur): Legal/Institutional Framework and broad issues in Implementation

2.1 - Solid Waste Management: Introduction and Approach

2.1.1 Introduction

Over the years, there has been continuous migration of people from rural areas to towns and cities. With the growing urbanization Solid Waste Management (SWM) has emerged as one of the most critical development challenges in urban India. In India, the volume of waste generation has been increasing rapidly over the last few decades. According to the "Swachhata Sandesh Newsletter" by the Ministry of Housing and Urban Affairs (MoHUA), as of January 2020, per day 147,613 Metric Tonnes (MT) of solid waste is generated from 84,475 wards (Singh, 2020). According to the 12th Schedule of the 74th Constitution Amendment Act of 1992 (India, 1993) urban local bodies (ULBs) are responsible for keeping cities and towns clean (Singh, 2020).

One key aspect of efficient Solid Waste Management (SWM) is "Waste Segregation." It is now mandatory for waste generators to deposit their waste in colour-coded bins—blue for dry waste and green for wet waste—to ensure proper recovery, reuse and recycling. This reduces the burden of Solid Waste Management (SWM) on Urban Local Bodies (ULBs) significantly (Singh, 2020). In 2016, Centre for Science and Environment (CSE) published "*Not in My Backyard: Solid Waste Management in Indian Cities*". This book examined the problem of Municipal Solid Waste in the country and brought out the need for a paradigm shift in management. It recommended that India must not use scarce and prized land for disposing of waste. Instead, waste should be treated as a resource and a strategy must be designed for material recovery and reuse. But what was also clear is that the material recovery is not possible without segregation and that this sorting of waste streams is best done at the household level or at source (Niti Aayog, CSE, 2021).

2.1.2 What is Waste?

2.1.2.1 Definition of Waste

As per United Nations Statistics Division, waste (Divisions) can be defined as materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose. Wastes may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities (Divisions). For more details, refer to Massive Open Online Course (MOOC) on Auditing Waste Management, National Audit Office-Estonia.

2.1.2.2 Classification of Waste (INTOSAI WGEA)

A. Waste can be classified based on source i.e.:

- Who/what generated the waste?
- Substance (what is it made of?)
- Hazard properties (how dangerous is it?)
- Management (who handles it?) or a mix of these concepts (*fig. 18 below*).

Figure 18 *Origin of waste (INTOSAI WGEA, n.d.)*

B. Two main waste categories (*fig. 19 below*) can be established based on the distinct legislation and policy instruments usually in place: Non-Hazardous or Solid Waste; and Hazardous Waste. Such a classification is also used in the Basel Convention. Hazardous waste is usually regulated at the national level, while non-hazardous is regulated at the regional or local (municipal) level (INTOSAI WGEA).

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989, which came into force in 1992. It is the most comprehensive global environmental agreement on hazardous and other types of wastes. With 190 Parties, it has nearly universal membership (Source-Basel Convention). It regulates the transboundary movements of hazardous wastes and other wastes and obliges its Parties to ensure that such wastes are managed and disposed of in an environmentally sound manner. The convention covers toxic, poisonous, explosive, corrosive, flammable, ecotoxic and

infectious wastes. Parties also have an obligation to minimize the quantities that are transported, to treat and dispose of wastes as close as possible to their place of generation and to prevent or minimize the generation of wastes at source. (Source- United Nations Environment Programme)

Figure 19 Types of Waste Image source - *(INTOSAI WGEA)*

(a) **Hazardous waste** (INTOSAI WGEA, n.d.) is waste that has been identified as potentially causing harm to the environment and human health and therefore needs special, separate treatment and handling. Special kinds of hazardous waste include:

(i) **E-waste** is waste from electric and electronic equipment such as end-of-life computers, phones, and home appliances.

(ii) **Medical waste** originates from the human and animal healthcare systems. Medical waste can be infectious, toxic, or radioactive or contain bacteria and harmful microorganisms (including those that are drug-resistant).

(iii) **Radioactive waste** contains radioactive materials.

(b) **Non-hazardous/solid waste** is all waste that has not been classified as hazardous: paper, plastics, glass, metal and beverage cans, organic waste, etc. However, it can have serious environmental and health impacts if left uncollected and untreated.

2.1.3 Generation of Municipal Solid Waste (MSW)

2.1.3.1 Municipal Solid Waste generation in the world

As per data provided by the World Bank in its report "What a Waste 2.0", at least 33 per cent of 2.01 billion tonnes of municipal solid waste generated annually, not managed in an environmentally safe manner. Worldwide, waste generated per person per day averages 0.74

kilograms but ranges widely, from 0.11 to 4.54 kilograms. High-income countries generate about 34 per cent, or 683 million tonnes, of the world's waste. Global annual waste generation is expected to jump to 3.4 billion tonnes over the next 30 years, up from 2.01 billion tonnes in 2016 (The World Bank, n.d.).

2.1.3.2 Municipal Solid Waste (MSW) generation, collection and transportation in India

As per a report on Solid Waste Management titled "Compliance of Municipal Solid Waste Management Rules, 2016 and other environmental issues" submitted by the Central Pollution Control Board (CPCB) before the National Green Tribunal in October 2021 on the basis of information received by 29 States/UTs (CPCB, 2021), status of MSW has highlighted as under:

- Total Quantity of MSW generated is 150858.951 Tonnes Per Day (TPD)
- Total Quantity of MSW collected is 144300.54 TPD
- Total Quantity of MSW segregated & transported is 97357.713 TPD
- Total quantity of MSW processed is 94435.318 TPD
- Total Quantity of MSW disposed of in secured landfill site is 11772.4538 TPD
- Gap in Solid Waste Management is 44651.1792 TPD

The quantity of Municipal Solid Waste processed was 62.6 per cent of the total waste generated in these States/UT, 7.8 per cent of Municipal Solid Waste (MSW) was landfilled and the gap in Solid waste management in 29 States was 45071.771 Tonnes Per Day (TPD) which is 29.6 per cent of the waste generated in these States/UTs (CPCB, 2021).

With mere 18 per cent waste treatment capacity in 2014, India's waste management efficiency was extremely critical and posed huge challenges towards the environment. From 18 per cent waste processing in 2014 to 70 per cent in 2021, we have come a long way.

Source: (Niti Aayog, CSE, 2021) *WASTE-WISE CITIES Best practices in municipal solid waste management*

2.1.4 Implications of improper solid waste management (INTOSAI WGEA)

Waste can cause different problems that may have a negative impact on people's health and well-being and on the environment. Here is an overview of the most important and frequent issues:

2.1.4.1 Air emissions

Air emissions are mainly produced by fumes from the burning of waste and also landfill gases. A significant proportion of greenhouse gas emissions related to waste is released into the air during the degradation of organic matter in landfills (INTOSAI WGEA).

2.1.4.2 Health impact

Waste that is not properly managed is a serious health hazard and leads to the spread of infectious diseases like Tuberculosis, pneumonia, diarrhoea, tetanus, whooping cough etc. Toxic components such as Persistent Organic Pollutants (POPs) pose particularly significant risks to human health and the environment as they bio-accumulate through the food chain and certain chemicals, if released untreated (e.g. cyanides, mercury, and polychlorinated biphenyls), are highly toxic and exposure to them can lead to disease or death.

2.1.4.3 Harmful effects on terrestrial and aquatic ecosystems

Human and ecosystem health can be adversely affected by all forms of waste. For example, terrestrial and aquatic ecosystems have experienced negative impacts from nutrient pollution and chemical toxins. Additionally, soil and health of the local population are highly vulnerable to damage caused by irrigation with the usage of waste water.

2.1.4.4 Soil contamination

Hazardous substances may enter the soil as water trickles from contaminated sites, leaching chemicals, fertilisers, or pesticides. Contaminated soil can damage flora and fauna directly and also indirectly by releasing toxic components into the food chain. Ingesting, inhaling, or touching contaminated soil may have a serious adverse impact on humans and animals.

2.1.4.5 Surface and groundwater

Precipitation or surface water seeping through waste absorbs hazardous components from landfills, agricultural areas, feedlots, etc. and carries them into surface and groundwater. Contaminated groundwater poses a great health risk, as it is often used for drinking, bathing and recreation, as well as in agricultural and industrial activities. The contamination of surface and groundwater may cause damage to wetlands and their ability to support healthy ecosystems and control flooding.

2.1.4.6 Marine pollution

Marine pollution constitutes a significant threat to marine life, fisheries, mangroves, coral reefs and coastal zones. Approximately, 80 per cent of this pollution derives from land-based sources, such as pesticides, persistent organic pollutants, heavy metals from mining and electronic waste, radioactive substances, wastewater, industrial discharges and marine litter. In regard to the latter, plastic waste is a growing concern as it spreads across the world’s oceans. Marine pollution also includes oil spills, discharges of oily waste from ships and untreated sewage.

2.1.5 Objectives

1. A preliminary study of the Legal and Institutional framework for Municipal Solid Waste Management (MSWM) in India.

2. Identify the principal problem of effective MSW Management in the cities of Indore, Surat and Jaipur and finding possible solutions by using Causal Loop Diagrams (CLD).

2.1.6 Methodology

- Literature review on Municipal Solid Waste Management.
- Comparative study of waste management in cities of Indore, Surat and Jaipur to understand the challenges and loopholes based on available literature and data.
- Use of Causal Loop Diagrams for representation of the one major problem and their solutions.

2.2 - Framework for Municipal Solid Waste Management in India

2.2.1 Evolution of Municipal Solid Waste Management (MSWM) in India

For waste management in India, its administration and regulation is governed by the Ministry of Environment, Forests and Climate Change (MoEF&CC), the Ministry of Urban Development (MoUD), the National Environmental Engineering Research Institute (NEERI), the Central Pollution Control Board (CPCB), and State Pollution Control Boards (SPCBs) and ground-level implementation responsibility lies with Urban Local Bodies (ULBs). Some major steps have been taken by the Government of India (GOI) for solid waste management in India during the last two and half decades (Ahmad, 2016).

Major Landmarks in Waste Management

- **National waste management committee**: The main objective of the committee constituted in 1990 was to identify the recyclable contents in solid waste picked up by rag-pickers.
- **Strategy Paper**: A manual on Solid Waste Management has been developed by the MoUD in collaboration with the National Environmental Engineering Research Institute (NEERI) in August, 1995.
- **Policy Paper**: MoUD and the Central Public Health and Environmental Engineering Institute prepared a strategy paper for the treatment of wastewater, appropriate hygiene, SWM, and efficacy in drainage system.
- **Master plan of Municipal Solid Waste**: A stratagem was formulated by the combined efforts of the MoEFCC, CPCB, and ULBs to develop a master plan for SWM with emphasis to biomedical waste in March, 1995.
- **High Powered Committee**: In 1995, a High-Powered Committee constituted to encompass a long-term strategy for the SWM using appropriate technology.
- **Municipal Solid Waste (Management and Handling) Rules, 2000** (Amended from time to time).

2.2.1.1 Waste Framework

Public sector- Government (Centre, State, and ULBs): Municipal solid waste management in India is managed at three tiers: local governments, state governments, and the central government (*Fig. 20*). The principal implementing entity accountable for all actions at the field level is the urban local bodies. At the policy-making and financial levels, the central and state governments provide support. The Urban Local Bodies (ULBs) are typically in charge of providing solid waste collection and disposal services.

The establishment of a system for door-to-door collection of segregated solid waste and separate collection facilities, waste processing, material recovery facilities, transportation, and disposal is the responsibility of urban local governments. Once the waste is collected or left out for collection in their authorised area, the ULBs are deemed lawful owners (Priti & Mandal, 2019). They are also in charge of setting up different types of bins (dry and wet), garbage deposition facilities for residential hazardous waste and integrating waste pickers and waste collectors to make solid waste management more manageable.

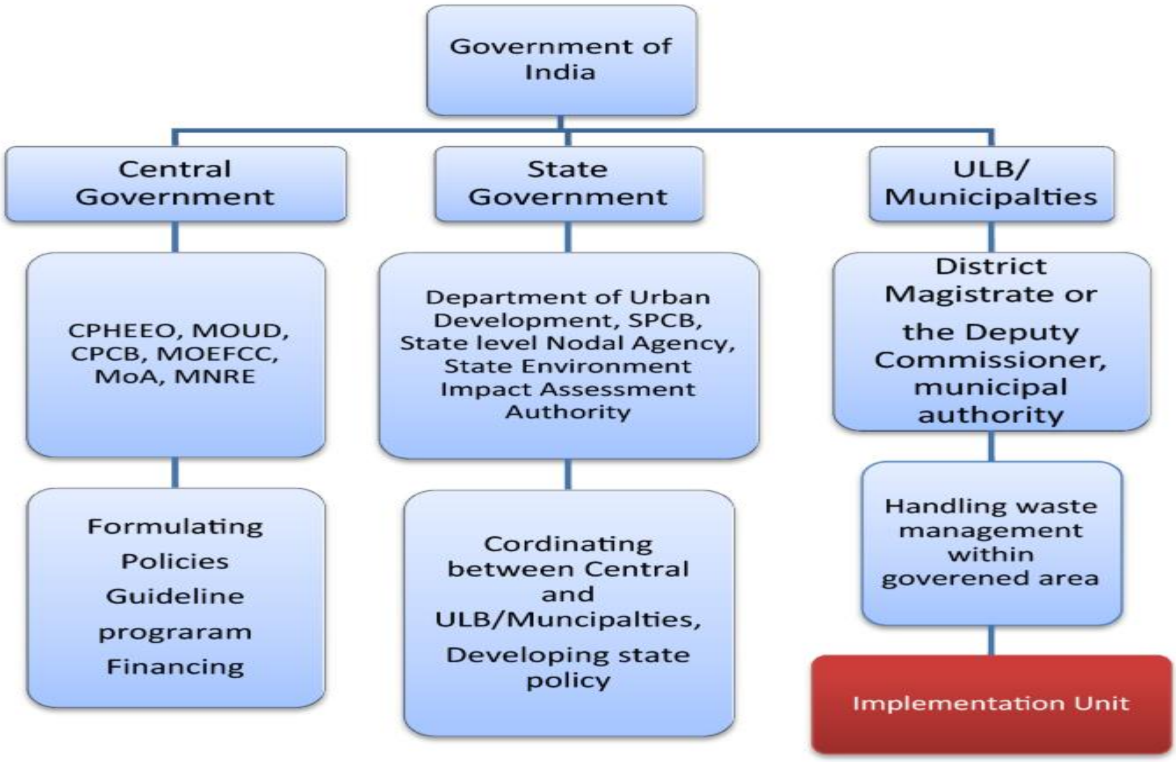

Figure 20 Governance structure for municipal waste management

Review on evolution of municipal solid waste management in India, Journal of Material Cycles and Waste Management (Mandal, 2019)

Private sector and Non-Governmental Organisations (NGOs): The Private Sector and Non-Governmental Organisations (NGOs) provide Municipal Solid Waste Management services under contractual agreements with municipalities by developing an infrastructure for waste collection, transportation, treatment, and disposal, resulting in efficient maintenance and cost-effective service provision. NGOs serve as a communication link between the corporate and public sectors, promoting awareness programs and engaging with communities to better understand implementation difficulties, gaps, and challenges.

Informal sector: Garbage pickers and waste buyers work in the informal Municipal Solid Waste sector; gathering, sorting, and segregating waste before selling it.

2.2.1.2 Process flow of Municipal Solid Waste Management

Over the past few years, there has been a rapid shift in the strategic direction of waste management in the country. The flagship programmes of the Government of India – the **Swachh Bharat Mission** (**SBM**), the Atal Mission for Rejuvenation and Urban Transformation (**AMRUT**), and the Smart Cities programme – have all created an enabling environment to drive this transformation.

- The Swachh Bharat Mission (SBM) 2.0, launched on September 01, 2021, is based on a clear strategy for solid waste management in cities – a strategy that focuses on source segregation, processing of waste (biodegradable and non-biodegradable), and minimising the waste that is sent to landfill sites. According to the guidelines of SBM 2.0, only the inert waste and process rejects – not exceeding 20 per cent of the total waste can be sent to landfill sites. These are waste materials which are not suitable for either biodegradable or non-biodegradable waste treatment processes. It, therefore, works towards a zero-landfill city concept in the country (Atin Biswas, 2021).
- The purpose of the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) is to
    - ensure that every household has access to a tap with an assured supply of water and a sewerage connection.
    - increase the amenity value of cities by developing greenery and well-maintained open spaces (parks).
    - reduce pollution by switching to public transport or constructing facilities for non-motorized transport (e.g., walking and cycling).
- The Smart Cities Mission's objective is to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of 'Smart' Solutions. The focus is on sustainable and inclusive development and the idea is to look at compact areas and create a replicable model which will act like a lighthouse to other aspiring cities (Affairs, 2022).

2.2.1.3 Components of Municipal Solid Waste Management

The Table 1 below gives a depiction of various components (GoI, 2021) of Solid Waste management systems:

Table No. 1

Sl.No.	Components	Description
1.	Source Segregation	Source Segregation of waste at the place of its generation in the following categories is fundamental to Municipal Solid Waste Management (MSWM): • Biodegradable wastes (wet waste - food waste, fruits & vegetables and parts thereof, meats, etc.) • Non-biodegradable wastes (dry waste - plastics, paper, cardboard, rags, glass, metal, wood, and inert waste, etc.) • Sanitary waste and disposables thereof • Domestic hazardous wastes (such as aerosol cans, paint material, discarded medical supplies, etc.) • Construction & Demolition waste (C&D) • Generators of E-waste (including fluorescent and mercury-containing bulbs & lamps) shall not mix e-waste with any other waste but deposit the same at the e-waste collection centre.
2.	Door-to-Door Collection	Collection of solid waste from the doorstep of households, apartments, housing societies, shops, commercial establishments, offices, institutional or any other non-residential premises, including a collection of such waste from entry gate or a designated location on the ground floor in a housing society, multi-storied building or apartments, large residential, commercial or institutional complex or premises;
3.	Separate Transportation	Transportation of the segregated waste collected from source premises in specially designed, partitioned and covered transport vehicles, to the respective processing facilities.
4.	Waste Processing	Processing of different fractions of Municipal Solid Waste (MSW) i.e., dry, wet, Construction & Demolition and plastic as per "Solid Waste Management Rules 2016". Processing is to be done differently for different categories of waste.
5.	Wet Waste	• Home / Family sized Decentralized Composting Community /larger Decentralized (Less than 5 TPD) composting facilities.

		• Bio-methanation - most suited for segregated wet waste like food waste from hotels/restaurants, and waste from dairies, vegetable markets, meat/fish markets etc.
6.	Dry Waste	• Material Recovery Facility (MRF) is a facility where non-compostable solid waste can be temporarily stored and processed by authorized agencies for further segregation, sorting, and recovery of recyclables/non-recyclables/inert fractions such as segregation of plastic, glass, metal, paper, clothes, etc. Recyclable fractions like plastics and metals are to be sent to authorized recyclers. • The non-recyclable/ combustible waste is to be sent to the Waste to Energy plant/ Cement Kilns as Refuse Derived Fuel (RDF). • Incinerators: Sanitary napkins and Diapers are to be separated, specially marked, and sent to a bio-medical waste/ waste electricity plant for incineration. • Waste to Electricity plants: The combustible fraction of waste out of MRF/ Processing Facilities which is non-recyclable and has a calorific value of 1,500 Kcal per kg and above can be used in waste to electricity plants.
7.	Sanitary Landfill	Only the inert waste (mostly from street sweeping) and process reject (in no case should this exceed 20 per cent of total waste) which are not suitable for any of the above dry and wet waste treatment processes can be sent to sanitary landfills. It is recommended that Sanitary Landfills (SLFs) are set up as separate business entities levying tipping/ gate fee as per the quantity and quality of waste received at the facility. Free use of Sanitary Landfill (SLF) / LF may not be allowed, to increase the processing & recycling efficiency by the Urban Local Bodies (ULBs) and its contractors.
8.	Construction & Demolition (C&D)	Construction & Demolition (C&D) waste is generated whenever construction/ demolition activity takes place such as building roads, bridges, highways, flyovers, subways and redevelopment of old structures. It consists mostly of inert, non-biodegradable material such as concrete, soil, steel, wood & plastics, bricks & mortar etc. C&D Waste is sorted into different streams and sent to C&D waste processing plant.
9.	Bulk Waste Generators	All Bulk waste generators have to manage their own wet waste and also make their own arrangements for dry waste management.

10.	User Fee	Suitable User Fee and relevant penalty provisions need to be notified by all Urban Local Bodies (ULBs) as per Rule 15 (ze) (zf) of SWM Rules 2016 on the lines of advisory circulated by the Ministry of Housing and Urban Affairs (MoHUA).

2.3 - Case Study of Municipal Solid Waste Management in Indore, Surat and Jaipur

2.3.1 Case Studies of Municipal Solid Waste (MSW) Management with respect to Indore, Surat and Jaipur

The city of Indore has consistently held the top position in cleanliness for the past five years, from 2017 to 2021. It has been recognized as a role model in the field of Municipal Solid Waste (MSW) management in India. As per the rankings of the “All India Swachh Survekshans”, the city of Surat has been working towards achieving an efficient MSW Management and is somewhere at a middle stage where it may perform much better in the coming years, whereas, comparatively the city of Jaipur has ample scope of improvement at every stage of MSW Management.

2.3.1.1 Indore

City Profile

Figure 21 City map of Indore

The city of Indore, is located at the GPS coordinates of 22° 43' 10.4448" N and 75° 51' 27.8172" E. It is among the million+ population cities of India with a population of 32,76,697 (2011). It is the commercial capital of the State of Madhya Pradesh. The city has an area of 3898 Sq. Km. Indore has been divided into

19 zones and 85 wards. Each ward has, on average, 6,000 households and 600 commercial establishments (part of 88 notified commercial areas) (Smart City Indore). The waste composition of Indore may be categorized into three broad categories given in *fig. 22*.

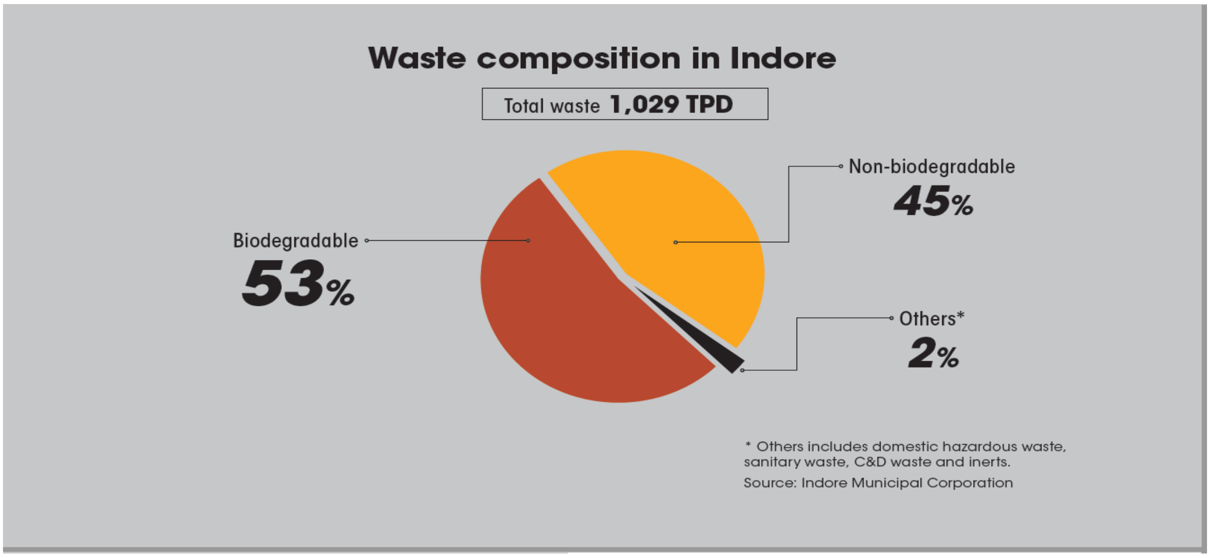

Figure 22 Waste Composition in Indore (Niti Aayog, CSE, 2021)

As per the report "Waste-Wise Cities" by NITI Aayog and Centre for Science and Environment (CSE) (2021), the city of Indore generates a Municipal Solid Waste of 1,029 tonne per day (TPD), excluding Construction and Demolition Waste (C&D waste) and inert (392.4 g per person per day). Nearly, 2854 sanitation workers and 829 vehicles are engaged in these cleaning arrangements to cover 100 per cent of households. Based on the Swachh Survekshan ranking (Star Rating for Garbage-Free Cities) parameter, the absence of community bins and garbage-vulnerable points serves as strong indicators of an efficient solid waste management system. Indore has zero number of community bins as well as zero number of garbage-vulnerable points (Niti Aayog, CSE, 2021). Indore city has been recognized for its successful implementation of segregation at the source and effective waste management practices. Indore is also the first city to receive Water Plus Certification in the nation, in addition to being Open Defecation Free.

<u>Background and Evolution</u>

As per the report "Waste-Wise Cities" by NITI Aayog and Centre for Science and Environment (CSE) (2021), a pilot operation for the door-to-door collection waste system was implemented by Indore Municipal Corporation (IMC) in December 2015. After the success of a pilot project in October 2016, the door-to-door collection was extended to the entire city, along with a campaign to promote source segregation. Indore started using separate containers for sanitary and hazardous waste in 2017 (Niti Aayog, CSE, 2021).

Figure 23 Compartmentalized vehicle for collection of biodegradables, non-biodegradable, domestic hazardous, electronic and sanitary wastes (Niti Aayog, CSE, 2021)

Status as per Swachh Survekshan

As per the "All India Swachh Survekshan" the city of Indore has been ranked as number one in the last consecutive years from 2017 to 2021. It is the most consistent performer and has shown an impressive work in the field of Municipal Solid Waste Management.

Game Changer

There are a number of factors responsible for a consistent performance by the city of Indore in the Swachh Survekshan. As per the report "Waste Wise Cities" by NITI Aayog, behavioural change is the major "Game Changer" in the mission of Indore Municipal Corporation. Municipal officials and public representatives have been actively involved in conducting joint visits and road shows to raise awareness about waste segregation and to encourage citizens to participate in the process. Religious and community leaders are also involved in the form of "Swachhagrahis" who talk about the importance of cleanliness and participated in mass road-sweeping exercises to spread awareness. The Indore Municipal Corporation (IMC) engaged more than 800 Self-Help Groups (SHGs), comprising more than 8,000 women, to spread awareness about source segregation in the nooks and crannies of the city. Accolades like "Zero-waste tags" are awarded to those markets and colonies which excel at waste management. These tags are useful marketing tool to attract customers and charge higher rents. Dustbins were provided at subsidised rates to promote segregation. The IMC levy penalties and fines for people who litter in public spaces and do not segregate at home. Necessary resources and infrastructure like enforcement vehicles and walkie-talkies are provided to implementing officials (Niti Aayog, CSE, 2021).

2.3.1.2 Surat

City Profile

The city of Surat, is located at the GPS coordinates of 21°10′N 72°50′E. Surat, also known as the Silk City and the Diamond City, has become the hub of Gujarat's economic activity. Both small and large-scale industrial activity are concentrated there. Established in 1852, Surat's municipal corporation is one of the Nation's oldest.

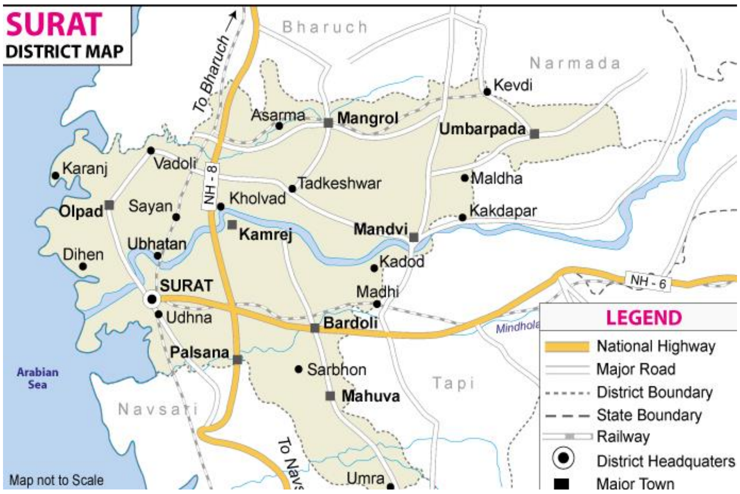

Figure 24 City map of Surat

Surat is divided into eight zones and 89 sanitary wards as part of the decentralized solid waste management system. Based on the source of generation, solid waste in Surat may be broadly categorized into eight primary categories: household garbage, biomedical waste, commercial waste, hotel waste, construction waste, textile waste, dead animal waste, and industrial waste. The composition of waste in Surat city is shown in *fig. 25*.

As per the report "Waste-Wise Cities" by NITI Aayog and the Centre for Science and Environment (CSE) (2021), the city of Surat generates a MSW of 1,838 tonnes per day (TPD), excluding C&D waste and inert. Nearly, 10,000 sanitation workers are engaged in these cleaning arrangements. The waste management vehicle fleet includes 683 vehicles. All households in the area are covered under door to door waste collection with residents actively involved in segregating and processing the waste.

According to the Swachh Survekshan ranking (Star Rating for Garbage-Free Cities) parameter, zero community bins and zero garbage-vulnerable points are strong indicators of an efficient solid waste management system. In case of the city of Surat, it has zero number of community bins as well as zero number of garbage-vulnerable points.

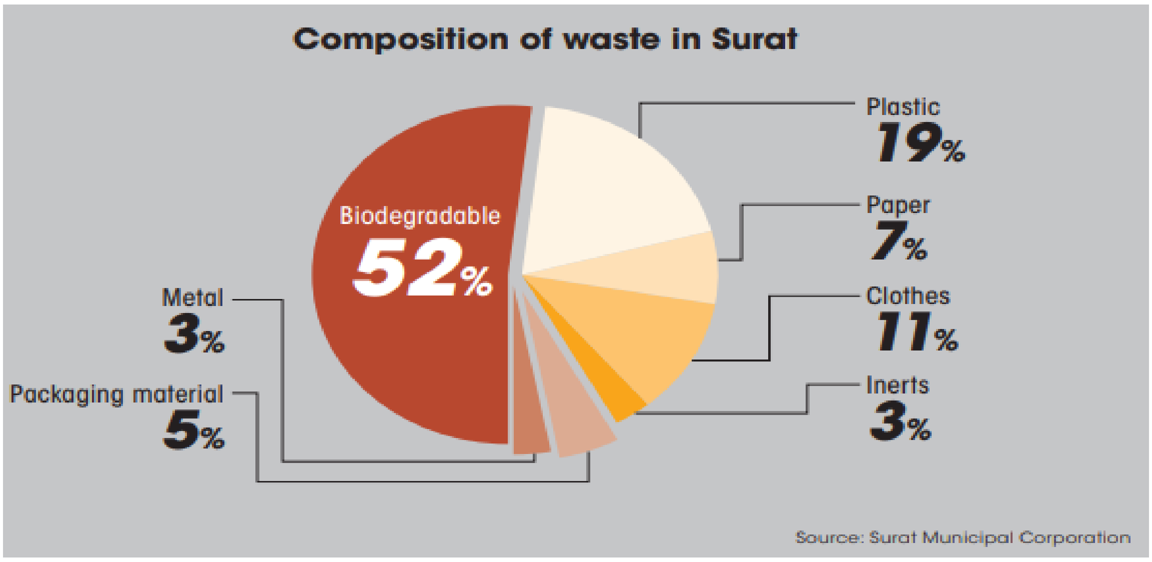

Figure 25 Composition of waste in Surat (Niti Aayog, CSE, 2021)

The Evolution

The report "Waste-Wise Cities" by NITI Aayog and the Centre for Science and Environment (CSE) (2021) states that taking a lesson from the Plague disaster in 1994, regular sweeping of streets and garbage collection was made a hallmark of Surat Municipal Corporation. Following the outbreak of the Plague disaster, the Surat Municipal Corporation swiftly implemented a centralized and subsequently decentralized process for waste collection and disposal within a span of six months. All of the city's waste is now treated efficiently in decentralised or centralised waste processing plants.

Effective Primary Collection and Transportation

As per the report "Waste-Wise Cities" by NITI Aayog and Centre for Science and Environment (CSE) (2021), the city is served by GPS- enabled vehicles having tracking systems installed in them. A private organization that operates a biological waste treatment and disposal facility on a public-private partnership model handles trash generated by hospitals and private dispensaries separately. There is a facility of separate bins for different types of waste. E-waste and plastic waste are collected separately using special vehicles. Door-to-door trucks collect non-segregated plastic waste, which is then taken to eight secondary transfer stations for further segregation in a material recovery plant.

Secondary transportation

MSW collected through the primary collection system is brought to secondary transfer stations. From there, biodegradable waste is transported to centralised composting plants in covered leak-proof containers. Non-biodegradable waste is segregated in mechanised Material Recovery Facilities (MRF) at secondary transfer stations (Atin Biswas, 2021).

Status as per Swachh Survekshan

As per the "All India Swachh Survekshan", the city of Surat has been a consistent performer in the field of MSW Management. It has shown an impressive performance by holding second rank, in consecutive last three years from 2019 to 2021. The city of Surat was among the top ten cities in India in five Swachh Survekshan since the year 2016.

Game Changer

There are a number of factors responsible for a consistent performance by the city of Surat in the Swachh Survekshan. The awareness campaigns spurred the city's citizens to transform Surat into the second-cleanest city in India. The awareness campaign among the Surat residents led to major behavioural change towards effective waste management. For this, the administration launched several initiatives to promote cleanliness and hygiene in their day-to-day lives. Surat Municipal Corporation designated eight locations for collection of plastic waste and started utilising plastic waste for construction of roads and recycled plastic waste as various plastic products such as chairs, benches and tiles (Niti Aayog, CSE, 2021).

2.3.1.3 Jaipur

City Profile

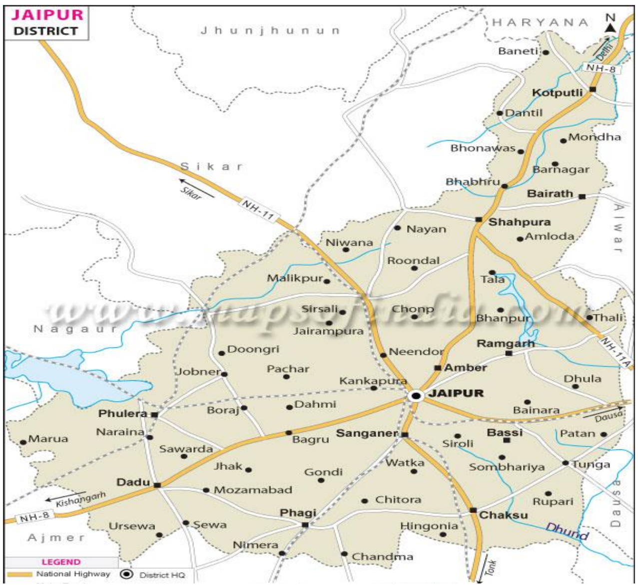

Figure 26 City map of Jaipur

The city of Jaipur is located at the GPS coordinates of 26° 55' 19.4520" N and 75° 46' 43.9860" E. This "Pink City of India" is located on the eastern Rajasthan and it is surrounded by Aravalli Hills at its three sides.

For management of MSW, the city of Jaipur is divided into eight zones. These zones are further divided into 91 municipal wards. Jaipur Municipal Corporation is responsible for MSW Management in

Jaipur city with the help of its staff and private service providers engaged contractually for secondary transportation of waste. According to the Solid Waste Management report of Jaipur Municipal Corporation (2019-20), out of 1477 TPD of Municipal Solid Waste generated 834.1 TPD is wet waste and 642.8 TPD is dry waste. C&D waste generation is around 300 TPD (Agarwal, 2020).

Primary Collection and Transportation

MSW is collected door-to-door through auto tippers by Jaipur Municipal Cooperation and sent to transfer stations at Lal Doongri and Jhalana. Waste collection and transportation from door-to-door using Geographical Positioning System-enabled vehicles were started in May 2017 with the assistance of approximately 1776 drivers and helpers (UGC).

Secondary Transportation

Jaipur Municipal Corporation (JMC) has provided 5145 green and blue dustbins for the collection of solid waste. In the JMC area, there are a number of secondary transfer stations where the collected primary garbage is transported in large vehicles for secondary processing and disposal. Jaipur Municipal Corporation has given the work of making compost from wet waste to a private firm. Jaipur Municipal Corporation has also completed the MRF centre establishment at the Mathuradaspura Landfill site and work is in progress at Sevapura (Rajasthan State Pollution Control Board, 2021).

Processing and Disposal of MSW in Jaipur Municipal Corporation

The waste which has been transported through secondary transport vehicles mainly goes to four locations in Jaipur. These are at Mathuradaspura dumpsite, Langariawas RDF Plant, Sevapura dumpsite and Sevapura composting plant. Other than these, there is one upcoming waste to energy plant with a capacity of 700 MT and one sanitary landfill site is also under process at Langariawas (UGC).

Status as per Swachh Survekshan

As per the "All India Swachh Survekshan", the city of Jaipur has not been a consistent performer in the field of Municipal Solid Waste Management. It has shown a zig zag pattern in the Swachh Survekshan since the year 2016 with all India rankings of 29th, 215th, 40th, 44th, 28th and 32nd in the years 2016, 2017, 2018, 2019, 2020 and 2021, respectively.

Game Spoilers

This non-uniform performance of the city of Jaipur can be attributed to a lot of factors. Some of the principal reasons are given below.

According to the study on "Solid waste management identifying land suitability for landfill sites - A case study of Jaipur city" (UGC), the lack of awareness among citizens and the absence of Information, Education, and Communication (IEC) initiatives in Jaipur city are identified as main causes for the collection of garbage in mixed forms. The bio-medical waste is also not segregated at the source; as a result, the rag pickers and dealing workers face extreme medical hazards and risk of infection while segregating the bio-medical waste at the secondary stage of collection. In the JMC area, there is a lack of adherence to the proper practices of waste segregation and disposal in the designated coloured bins. In absence of proper segregation, almost 80 per cent of the unsegregated waste is dumped in the open dumpsites at Sevapura and Mathuradaspura. This degrades the quality of soil and groundwater, and also poses a risk to human health and the environment.

As per the study on “Solid waste management identifying land suitability for landfill sites- A case study of Jaipur city”, the dumping site of Mathuradaspura does not fulfil the criteria of residential, soil, and wind direction and the Sevapura dumping site does not fulfil the surface water, groundwater level and soil criteria for landfill site identification. Furthermore, they are affecting the environment as well as public health; therefore, there is an urgent need for the relocation of these existing sites.

Hence, there is a need to promote public awareness compaigns to make the citizens aware of the proper waste segregation at the initial stage. Also, the waste collection mechanism needs an overhaul to prevent unnecessary dumping of waste at various locations in the city. The Government may pursue public-private partnership model to improve the collection and transportation part of waste management.

2.4 Problem Analysis and Solution through Causal Loop Diagram

Indore has been named as the cleanest city of India in every Swachh Survekshan survey since 2017. As per the report "Waste –Wise Cities Best practices in municipal solid waste" the management is successful in Indore because Indore focused on achieving 100 per cent segregation at source before it proceeded to the other aspects of waste management. Without segregation, all subsequent steps in the waste management chain fall apart. Waste dumping in the landfills has been discontinued due to proper segregation and processing of waste. Illegal collection and dumping activities have been reduced almost to nil (Niti Aayog, CSE, 2021).

The success of Indore's waste management derives from its success in achieving 100 per cent segregation of waste at source into six categories. It has to be noted that Indore has been successful because the municipal authorities have showed the willingness to earn the trust of citizens and make them active participants in cleaning up of their city. Community engagement is necessary to replicate this model.

2.4.1 Define a Problem

2.4.1.1 Waste Segregation at Source

There are ample evidences from operations of recycling, composting and waste-to energy projects that their viability critically hinges on availability of segregated waste. Waste can alternatively be segregated at the point of generation (source segregation), or at the point of treatment (secondary segregation). The former offers distinct advantages over the latter (Niti Aayog, 2021). Since, the source segregation and collection have their distinct advantages in Municipal solid waste management, the approach of source segregation and collection requires a broader outreach (Niti Aayog, 2021).

Advantages of Waste Segregation at source

- Reduced need for secondary segregation.
- Least likely to be contaminated with other waste types, and therefore more likely to be recycled.
- Reduction in the quantum of waste to be treated or recycled, thereby reducing cost.
- Waste treatment often involves transportation to the treatment facility, segregation at source reduces the volume of different waste types and leads to a concomitant reduction in transportation footprint.

- Supports decentralized treatment options for efficient waste management like community composting units and dry waste collection centres.
- Minimizes waste which translates into reduced greenhouse-gas emissions from waste dumps and landfills.
- Source segregation reduces the attractiveness of the existing in-human, unhealthy and hazardous practice of rag pickers rummaging through waste piles to salvage saleable waste items.

2.4.2 Challenges in Solid Waste Management (SWM)

Some of the key challenges for the SWM system include lack of waste segregation and doorstep collection, use of inappropriate technologies for treatment, and indiscriminate disposal of waste. The key challenges in the context of SWM in India are briefly listed below (Singh, 2020).

1. There is no system of periodic data collection on waste generation. Consequently, the estimations and projections of solid waste vary wildly from one agency to the other.

2. The SWM Rules 2016 mandate the segregation of waste. However, ULBs have failed to establish systems and technologies required for segregation, collection and processing of different categories of waste. Moreover, there is a lack of public awareness regarding the process of segregation.

3. Waste collection efficiency is low in India, due to non-uniformity in the collection system. Waste collection efficiency is 100 per cent only in those areas where private contractors and non-governmental organisations are actively involved.

> Comptroller and Auditor General's Performance Audit Report No. 2 of 2019 for the State of Goa highlights the gaps in SWM infrastructure like environmentally unsound transportation, manual handling of waste without protective gear, unscientific leachate management and absence of fencing and fire-fighting equipment at waste processing and disposal sites. Only nine out of 14 ULBs were observed to have waste processing facilities, almost all of which are under-utilised to the extent of 103.40 Tonnes Per Day (TPD), clearly indicating poor collection and segregation outcomes.

4. Most cities and towns in India dispose of their waste by depositing it in low-lying areas outside the city, without taking adequate precautions. As per the report "Solid Waste

Management in Urban India: Imperatives for Improvement," the availability of land for landfills has become scarce. Since Urban Local Bodies (ULBs) do not have the resources to acquire new land, finding new land becomes a major challenge.

5. Comprehensive studies covering all cities and towns in the country to characterize the waste generated and disposed in landfills have not been conducted. Thus, it is difficult for policymakers to provide suitable solutions for the waste produced in a particular region.

6. Local authorities lack adequate funding and infrastructure. Thus, they are unable to adopt innovative and appropriate technologies for waste treatment and disposal.

7. Waste to Energy (WtE) is a widely used technology in India, but it faces several problems, including unsegregated waste and seasonal variation in waste composition. Various research documents show that most WtE plants cannot function effectively due to operational and design issues.

8. The COVID19 pandemic has introduced a new set of challenges in the SWM system in India: maintaining social distances at the treatment plants and amongst the collection staff, and a shortage of safety gears for conservancy staff. These problems undermine the safety of SWM employees, waste treatment requirements, and other procedures.

9. There is a lack of proper planning and indigenisation of sophisticated waste process facilities, as well as the provision of regular training to waste collectors. (Singh, 2020, p. paper No 283)

2.4.3 Identifying Problem Behaviour and Causal Analysis

A literature review has been done to understand behavioural problems related to the segregation of waste. Based on the literature review a Causal Loop Diagram is derived to understand the problem, various systems of the problem, and interlinkages of these systems.

Figure .27 below illustrates loops addressing variables and subsystems. Their combination and interconnectedness portray the complexity of the problem having possible environmental and social consequences.

2.4.3.1 Analysis of the Causal Loop Diagram

1. **The yellow colour balancing loop (B in yellow circle)** is a **small key to the whole problem** of waste segregation at the source. The motivation for segregation is pivotal

for generating segregation habits because a negative perception of waste segregation can adversely influence the motivation towards waste segregation at the source.

2. **The pink colour loop** represents the problem of segregation identified within the periphery of the community and governance system. **The pink colour balancing loop (B in pink circle)** shows how **public awareness** of waste segregation at the household level, positively influences the **advocacy for waste segregation at the source**. The advocacy by varied society actors facilitates prioritisation of the action by ULBs, which further helps to solve insufficient budgetary allocation for the problem solution. The **low budgetary allocation** leads to **inefficient enforcement** of waste segregation policies which **hinders accountability** of citizens and workers, causing the waste to get remixed even if an attempt to segregate is made. When citizens witness the failed segregation efforts in the form of remixed waste, it reinforces a negative perception among them about the practice of waste segregation at the source. Indeed, negative perceptions of waste segregation can hinder the development of habits for waste segregation at the source, as they disrupt motivation. This hindrance in habit creation directly impacts source waste segregation, affecting herd behaviour for source segregation and further hindering public awareness.

3. **The red colour balancing loop (B in red circle)**, which **diverged from the pink loop** from **insufficient budgetary allocation**, depicts how low budget allocation hinders data collection for appropriate policy formation of waste segregation at the source. The lack of clear policy formation regarding waste segregation can create complexity and compliance issues, ultimately affecting the essential motivation required to segregate waste at the source.

4. **The olive colour loop** that separates from the effective waste segregation policy shows that **effective policy** may bring viable business models in the sector of solid waste management. Businesses' entry into the domain may help to improve the salvage value of the waste, **thus steering motivation to segregate waste through monetary incentives**. For example, the current compost operational potential is only 13.11 lakh Tonnes Per Annum while the potential stands at 54 lakh Tonnes Per Annum. (Niti Aayog, 2021) Private players may tap this potential and produce evidence for the citizens for 'waste to resource.' Furthermore, new entrants may bring in creative solutions that reduce the cognitive burden for motivation to segregate waste, such as the bins built right now, which are counterintuitive with the hassle of operating these bins on a more frequent basis.

5. The **minor balancing pink color loop** diverging from "**Effective waste segregation policy**" illustrates how a suitable approach may result in proper enforcement, creating an **effective penalization mechanism**, and motivation for segregation at the source. It is to be noted here that a reduction in enforcement will reduce penalization, which will not be an effective solution in the long run for a problem.
6. **The blue colour balancing loop (B in blue circle)** represents the **issues around information and perception** for segregation activity. This perception that activity is time-consuming reduces citizens' participation in segregation, leading to group thinking towards a negative perception of segregating the waste at the source.
7. **The orange colour balancing loop (B in orange circle)** represents **gaps in information diffusion**, an aspect widely practiced today. The lack of information about waste segregation poses a significant challenge. This certainly has an impact on public awareness about segregation, which prevents Urban Local Bodies (ULBs) from prioritizing the issue, thereby hindering innovative collaboration to address gaps.
8. The **Green colour loop in Figure-28** illustrates the **proposed solutions** mapped on problem behaviour analysis.

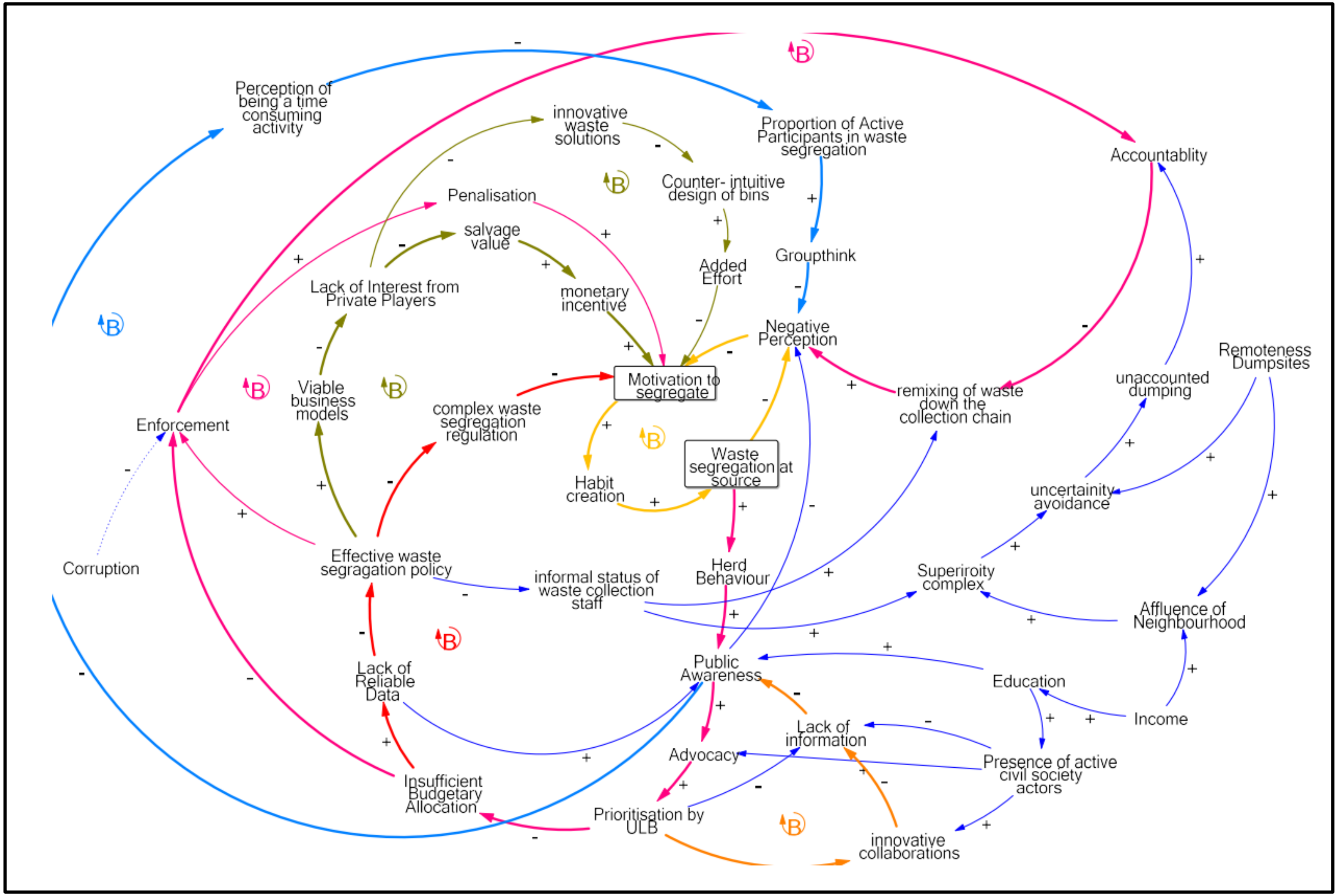

Figure 27 Causal Loop diagram for problem analysis of source waste segregation

2.4.3.2 Solution Analysis

Possible Solutions: Type of Instruments

For suggesting possible solutions (Green loop in *Fig. 28*) to the problem of segregation of waste at source, the typology as suggested by Arie Freiberg (Freiberg, 2010) in his toolkit is referred. Classifying the probable solutions under Carrot & Command-and-Control typology is also attempted. The various solutions to the problem have been classified under the following regulations (instruments).

1. **Economic Regulations**: These involve the manipulation of the production, allocation, or use of material resources such as money or property, in all its forms. Forms of economic regulation include taxes, subsidies and tradable permit schemes. Each of these can be used to promote as well as restrict or even prevent certain activities. Taxes, charges and levies can be used to influence the behaviour of individuals. Tax expenditures are provisions in tax laws that encourage certain behaviour by individuals or corporations by deferring, reducing or eliminating their tax obligation. Bounties and subsidies are a government fiscal instruments whereby payments are made in exchange for a form of activity. Accordingly, possible solutions such as Deposit Refund Scheme, In-situ Composting Units, Pay As You Throw (PAYT), Community reporting, Subsidising Decentralised recycling centres and Token System are organised under the Economic Regulations in Table 2.
2. **Transactional Regulations**: Area variant of economic regulation where the form of the tool assumes great importance. Transactional regulation refers to regulation that occurs through the direct interaction between parties via a contract, grant agreement or other financial arrangement under which the parties have a right to enter into the arrangement or negotiate its terms. Transactional regulation does not require direct legislative authority and rests primarily on the general concepts of contract law. The first is the delivery of what may be termed the primary regulatory outcome, Government may deliver those products or services itself or it may arrange for their delivery by other parties through contractual or other arrangements such as grants. The second regulatory dimension, however, relates to the pursuit of regulatory outcomes that are extraneous to the primary purpose of the contract or grant but considered to be in the public interest. The possible solutions such as Formalization of informal waste collectors, Public Private Partnerships and Budget are organised under Transactional Regulations in the Table 2.
3. **Authorization Regulations**: The exclusive power that governments have to confer benefits by permitting certain forms of conduct is a major resource that can be deployed to

direct or prohibit activities. Authorisation mechanisms are essentially tokens of trust issued by governments. Thus, apart from formal terms and conditions in Formalization of informal waste collectors, it may require certain license/permissions from Government also and therefore it is included under Authorization regulation also in the Table 2.

4. **Structural Regulations**: relate to the ability to manipulate the physical environment to influence action. It refers to tools or mechanisms that are designed to produce regulatory outcomes by removing or limiting choice and structuring behaviour in such a way that regulators have no choice at all but to act in accordance with the desired regulatory pattern. From a governmental viewpoint, the state can be regarded as providing not only the legal framework but also the physical environment in which human activity takes place. The possible solutions such as Refusal to Accept and Measuring waste generated are placed under Structural regulations in Table 2.

5. **Informational Regulations**: relate to access to knowledge or beliefs (University, 2010). Information asymmetries have been identified as one of the reasons that governments may wish to regulate. Information is a resource that is used widely as a regulatory tool by governments for various purposes including persuasion or attitude change, capability development and norm formation or modification. Possible solutions such as Ranking of neighbourhood, Information Education and Communication (IEC) and Data on waste generation are kept under the Informational Regulation in Table 2.

6. **Carrot**: refers to financial means, providing incentives. – They may be positive (grants, subsidies) as well as negative [taxes, user charges] from a consumer’s perspective. Token System is placed under carrot.

7. **Command-and-Control**: relates to imposing standards backed by criminal sanctions. Powers for effective enforcement under this regulation.

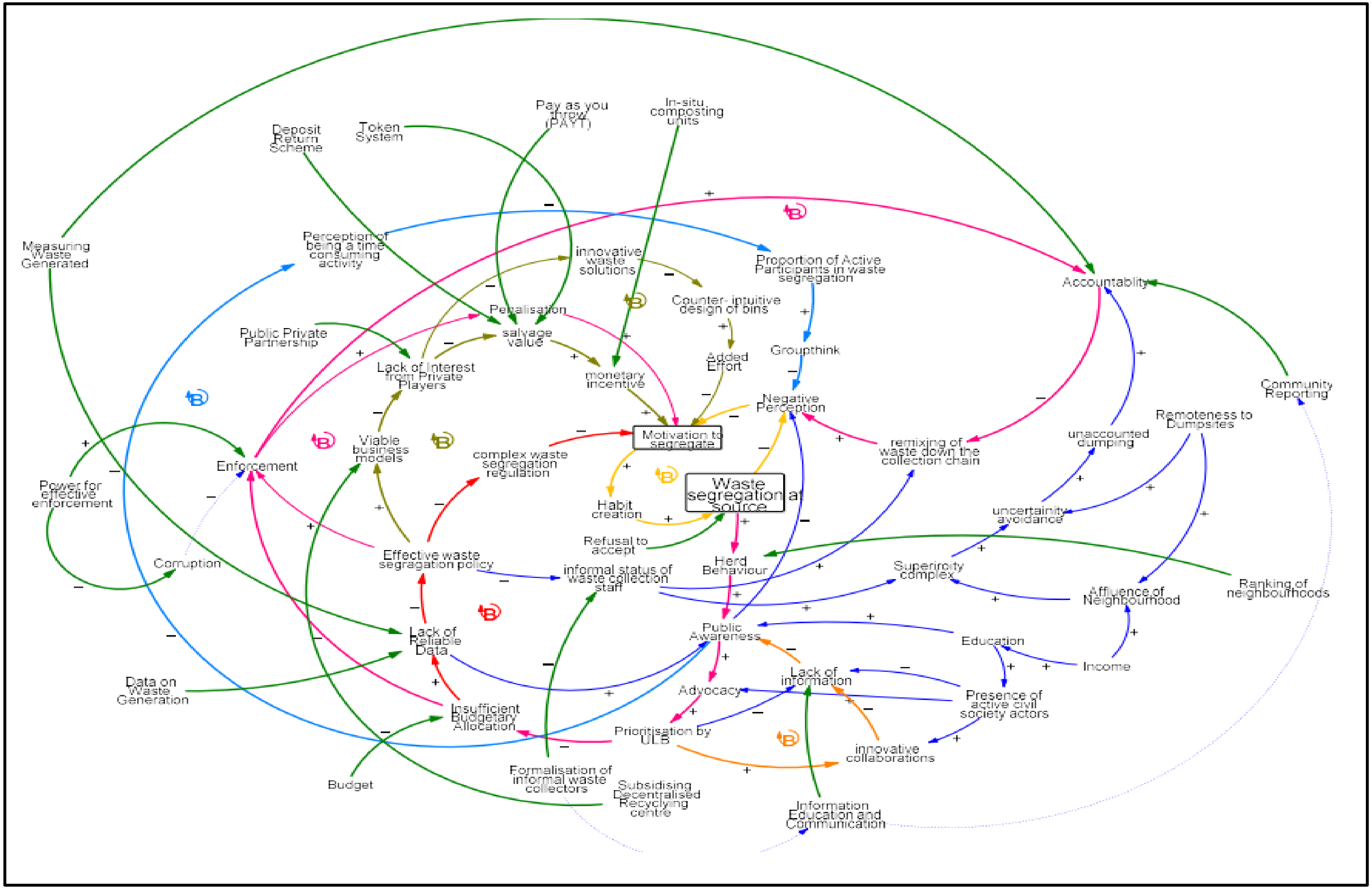

Figure 28 Causal Loop diagram for Solution analysis of source waste segregation

Table 2 Solution Analysis of Causal Loop Diagram based on various instrument types

The possible solutions (*Fig. 28*) illustrated by green colour loops are tabulated below under Economic, Transactional, Authorization, Structural, Informational, Carrot and Command-and-Control mechanisms with description:

<table>
<tr><th>Sr. No.</th><th>Solution</th><th>Instrument Type</th><th>Description</th></tr>
<tr><td rowspan="2">1.</td><td rowspan="2">Deposit Refund Scheme (DRS)</td><td>Economic Regulation- Price Regulation</td><td rowspan="2">DRS can be used to tackle the challenge of recycling by offering a financial incentive to consumers who deposit their used containers in return for money.</td></tr>
<tr><td>Carrot</td></tr>
<tr><td rowspan="2">2.</td><td rowspan="2">In-situ Composting Units</td><td>Economic Regulation-Tax Expenditure.</td><td>In-Situ Composting can be encouraged by connecting with incentives like reduction of Property tax, House tax, Water tax etc. for waste generators who are doing composting at their original places.</td></tr>
<tr><td>Economic Regulation-Price Regulation</td><td>Buy back the compost from Resident Welfare Associations.</td></tr>
<tr><td>3.</td><td>Pay As You Throw (PAYT)</td><td>Economic Regulation-Taxes</td><td>PAYT Taxes is a system in which each household is taxed as per waste generated by it.</td></tr>
<tr><td>4.</td><td>Community reporting</td><td>Economic Regulation-Bounties</td><td>Community reporting may be encouraged by rewarding citizens for useful reporting on waste generation.</td></tr>
<tr><td>5.</td><td>Subsidising Decentralised recycling centre</td><td>Economic Regulation-Bounties and subsidies</td><td>Subsidising Decentralised recycling centres may provide subsidies for opening decentralised recycling centres for waste reducing pressure on landfills.</td></tr>
<tr><td rowspan="2">6.</td><td rowspan="2">Token System</td><td>Economic Regulation-Tradable Permits.</td><td rowspan="2">Incentives (supermarket coupons, discount coupons, public transport) in the form of tokens may be used for effective waste segregation.</td></tr>
<tr><td>Carrot</td></tr>
</table>

7.	Formalisation of informal waste Collectors.	Transactional Regulation-Contract	Formalisation of informal waste collectors can be done with proper terms and conditions of employment and social security.
		Authorisation Regulation-Registration	Maintenance of proper registration of waste collectors may lead to job guarantee for the waste collectors and will help in proper segregation of waste. This will also synchronize the waste segregation with other waste treatment steps.
8.	Public Private Partnership (PPP)	Transactional Regulation-Contract	PPP model may be adopted for proper segregation and collection.
9.	Budget	Transactional Regulation-Grants	Improvement in allocation of budget for building infrastructures like tippers, R&D, and innovation funding may further improve the process of waste segregation.
10.	Refusal to Accept	Structural Regulation-Process Design	Refusal to Accept can be implemented which means refusal to accept non-segregated waste by waste collectors. This will make it mandatory for waste generators to segregate at the waste source.
11.	Measuring waste generated	Structural Regulation-Technology	Measuring waste generated is one of the solutions in which Tippers fitted with automatic weight sensors may be used to send data to centralised data centres for accurate data collection. This data may be further used to tax or levy charges proportionally based on the quantum of waste generated by a household / locality / organisation.
12.	Ranking of neighbourhoods	Informational Regulation: Performance indicators	An initiative for ranking neighbourhoods can be done in various localities based on their performance with respect to waste segregation. Stickers for ranking can be used and rewards may also be given for

			appreciation to households with the best waste segregation practices.
13.	Information Education and Communication (IEC)	Informational Regulation: Capacity, Advice, Attitude change	Information, Education, and Communication (IEC) is a multilevel tool for promoting and sustaining risk-reducing behaviour change in individuals and communities. The IEC campaign may target households, shops, as well as other stakeholders to ensure their participation in managing city waste by discharging their role effectively. The ULBs may accord required priority to IEC and ensure that IEC activities are appropriate and create awareness about the harmful effects of ineffective SWM management on health and environment. Some other ways are- Pledge, Training, debates, door to door promotion, sharing information about positive trends etc.
14.	Data on waste generation	Informational Regulation: Disclosure	Disclosure of waste collected/ segregated by concerned entities.
15.	Powers for effective enforcement	Command and Control	Powers for effective enforcement of Sanitary inspectors, who are directly involved with day-to-day operations, should undergo regular monitoring, reporting, and review based on Key process indicators (KPIs). Adequate power to Sanitary inspectors may be granted for imposing and collecting waste segregation penalties with respect to waste segregation.

2.4.4 Conclusion

It is estimated that urban India generates between 1,30,000 to 1,50,000 metric tonnes (MT) of MSW every day – some 330-550 grams per urban inhabitant a day. This adds up to roughly 50 million MT per year; at current rates, which will increase to approximately 125 million MT a year by 2031. It is estimated that some 800 million MT are disposed of in 3,159 dumpsites across the country, according to the CPCB data (Niti Aayog, CSE, 2021). A city produces varied types of waste. It can be Wet Waste, Dry Waste, Bio-Medical Waste, Hazardous Waste, Plastic Waste, E-Waste, Biodegradable Waste or Non-Biodegradable Waste. The waste characterisation determines the strategy for its management. This is why segregation of waste is the most important step at the initial level of Municipal Waste Management. The flagship programmes of the Government of India – the Swachh Bharat Mission, the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) and the Smart Cities programme have all created an enabling environment to drive this transformation.

The case studies of Indore, Surat and Jaipur also show that waste segregation at the door-to-door collection level is the most crucial level for proper management of MSW management. The cities of Indore and Surat have an extremely efficient waste segregation mechanism which have enabled it to gain top rankings in the past "Swachh Survekshan" surveys. However, the city of Jaipur faces challenges in implementing an efficient waste management mechanism to compete with other cities.

The "Causal Loop Diagrams" methodology has been used to explore the systems that are negatively influencing the segregation of waste at the source. Some of the major challenges in the effective segregation of waste are Public Awareness, Low budget allocation, steering motivation to segregate waste through monetary incentives, and effective implementation of a penalization mechanism for segregation.

Theme – 3: Pollution Caused By Road Dust: A Case Study of Delhi and Mumbai

3.1 Introduction

Dust pollution is one of the major issues in the urban environment nowadays because its contribution to air pollution is significant. Road dust is a complex mixture of heavy metals, organics, inorganic, mould spores, pollen etc. The movement of any vehicle and wind results in the suspension of dust particles in the air. The particles and associated metals, particularly fine dust, remain suspended in the air longer under certain meteorological conditions. Road dust experience forces which include gravity, particle drag, Brownian diffusion[16], electrical charge effects and particle inertia. Suspension and deposition of dust are combined effects of all the forces acting on road dust. The developing megacities of India, where people may spend a significant portion of their working lives close to the roadside, including consuming street food, have an obvious source–pathway– receptor linkages.

In the urban environment, sources of road dust can be both natural and human. The impact of these sources changes from city to city depending on the economic focus and individual sources in their scope for contamination. This may also vary from city-wide injection of fine particles and gases from power plants to very local, medium-sized dusty industries such as ceramic production or small-scale light industry such as metal working. Road dust contains a large number of contaminants and if not degraded into a less toxic form, then its concentration will increase with the passage of time. Particulate matter causes poor air quality, loss of visibility and climate change. Heavy metals attached to particulate matter in ambient air cause serious health effects and environmental pollution.

Various man-made sources have contributed to the occurrence of heavy metals in roadside soil and street dust. These sources include vehicular emissions from traffic, tyre-road wearing, brake lining residues, weathering of asphalt pavement and street surfaces, abrasion of vehicles and engine parts and flaked or polished paint particles. Other industrial dust emissions are released from gas-fired power plants, thermal processes of coal combustion, metallurgical factories, chemicals, steel, cement, glass and ceramic industries (National Library of Medicine, 2019). Sources of particulate matter include the incomplete combustion of fuel, coal mining and mining-related processes, trash burning, construction, transportation and burning of

[16] Brownian diffusion is the characteristic random wiggling motion of small airborne particles in still air, resulting from constant bombardment by surrounding gas molecules (De-LingLiu, 2010)

agricultural produce. Transportation and vehicle traffic emitting particulate matter are considered to be the primary sources of these pollutants in urban areas. There are three main sources of exposure to dust. The first is ingestion, the second is inhalation and the third is dermal absorption. Ingestion happens as a result of hand-to-mouth contact, inhalation occurs through the nose, and dermal contact occurs as a result of skin absorption.

Particles can be so small that they pass through the nasal passage, travel to the deepest parts of the lungs and cause serious damage to respiratory system. To compound the problem, toxic and cancer-causing chemicals can attach themselves to particulate matter and can produce much more profound effects when inhaled. The tiniest of particles can even pass through the lungs into the bloodstream. The children, old age persons and people with respiratory or heart disease are more prone to this situation. Apart of this, healthy people can also be affected especially the outdoor exercisers.

Environmental damage caused due to particulate matter are:

- Poor air quality, loss of visibility, climate change, and also radiative forces.
- Contribution to acid rain effects.
- Depletion of nutrients in the soil.
- Change of nutrient balance in coastal waters and large river basins.
- Make lakes and streams acidic.
- Changing the nutrient balance in coastal waters and large river basins.

Keeping in view of the above concerns, this particular study was conducted to analyse the concentration of heavy metals like copper, zinc, lead, chromium etc. present in urban road dust in two cities of India i.e., Delhi and Mumbai with the help of pollution indices like contamination factor, ecological risk assessment, degree of contamination and also assessed the associated health effects due to presence of heavy metals in road dust.

3.2 Research Objectives

The broad objectives of carrying out this particular research are as follows:

- To analyze the status of pollution caused due to the presence of heavy metals in the road dust with the help of pollution indices such as contamination factor, degree of contamination, pollution load index, and ecological risk index for Delhi and Mumbai.
- To outline the possible health impact that can occur to the people due to the presence of heavy metals and the emission of particulate matters from the road dust.

3.3 Research Methodology

The present study is to analyse the status of pollution caused due to the presence of heavy metals like copper, zinc, lead and chromium etc. in road dust in Delhi and Mumbai and also assess their associated human health. The tools used for the assessment are pollution indices and health risk assessment models. Pollution indices (Joanna Beata Kowalska, 2018) are widely considered a useful tool for the comprehensive evaluation of the degree of contamination. The pollution indices which are used for the evaluation of contamination in this research are contamination factor, pollution load index, ecological risk index, and degree of contamination. The extent and risk of exposure to heavy metals for human health were calculated using the United States Environmental Protection Agency (USEPA) Human Health Assessment Method (United States Environment Protection Agency, n.d.).

For this study, the values of average concentration present in road dust for two cities in India i.e. Delhi (Sayantee Roy, 2019) and Mumbai (Amit Gawade, 2016) are collected from the existing literature. The description of pollution indices and health risk assessment model are given below:

3.3.1 Assessment of heavy metal contamination

Different pollution indices such as Contamination Factor (CF) (Shilpi Mondal, 2021), contamination degree (C_d), modified degree of contamination (mCd), risk index (RI) and pollution load index (PLI) are for comparative study of different samples. The indices are described below:

3.3.1.1 Contamination Factor (CF)

This index is used to calculate the contribution of heavy metals in road dust in comparison to the background value of that metal in an area. As per Håkanson classification (1980) (Joanna Beata Kowalska, 2018), the Contamination factor is used for calculation of the contamination status of air quality and dust .The formula used for its calculation is given below:

$$CF = Cs / Cb \qquad \textbf{Equation 1}$$

Where, Cb denotes the reference concentration of heavy metal signifying the Indian natural soil background and Cs is the concentration of heavy metals found in the samples. The metal concentration of unpolluted soil was considered as background value due to the unavailability of information for the background concentrations of metals in road dust, and Cs is the average concentration of heavy metals found in the samples. According to Håkanson (1980): Cf < 1 indicates low contamination; Cf 1-3, moderate contamination; Cf 3-6, considerable contamination; and 6 ≤ Cf indicates very high contamination.

Hakanson Method - It is a potential ecological risk index tool developed by Hakanson in 1980. Although it is developed to assess water quality, it has been a widely accepted tool even today and may be utilized to assess air and soil quality as per reference range suggested by Hakanson for different pollution indices.
(Source- https://www.sciencedirect.com/science/article/abs/pii/0043135480901438)

3.3.1.2 Pollution Load Index (PLI)

This index is used to calculate the combined effect of heavy metals present at the sites. It is also used to evaluate air and dust quality at the sites. The formula which is used for its calculation is given in the form of an equation below:

$$PLI=(CF_1 \times CF_2 \times CF_3 \times \ldots \ldots CF_n)^{1/n} \qquad \textbf{Equation 2}$$

Where, CF is the contamination factor for single heavy metal and value of PLI<1 signifies no pollution, PLI=1 indicates only baseline levels of contaminations, and PLI>1 reveals deterioration of site air quality (M I Sujaul, 2019) .

3.3.1.3 Degree of Contamination (Cd)

The total degree of contamination at a given location was calculated by adding the contamination factors of all heavy metals. The value of the degree of contamination is calculated by the following formula:

$$Cd = \sum_{i=1}^{i=n} CF \qquad \textbf{Equation 3}$$

According to the Håkanson classification; Cd < 6 shows a low degree of contamination; Cd 6-12 is a moderate degree of contamination; Cd 12- 24 is a considerable degree of contamination; and Cd ≥ 24 is a high degree of contamination indicating serious anthropogenic pollution.

$$mCd = \frac{\sum_{i=1}^{i=n} CF}{n}$$ **Equation 4**

In Equation 3, n = number of analyzed heavy metals, i= i^{th} heavy metals, and CF = contamination factor .For the classification and description of the modified degree of contamination (mCd) in the sample, the subsequent classifications are proposed :mCd < 1.5 indicates nil to a very low degree of contamination, 1.5≤ mCd <2 indicates a low degree of contamination, 2 ≤ mCd <4 indicates a moderate degree of contamination, 4 ≤ mCd< 8 indicates a high degree of contamination, 8 ≤ mCd <16 indicates a very high degree of contamination, 16 ≤ mCd <32 indicates an extremely high degree of contamination, and mCd ≥ 32 indicates an ultra-high degree of contamination.

3.3.1.4 Potential ecological risk index (RI)

The potential ecological risk index (RI) is used to calculate the ecological risk of the presence of heavy metals in road dust. Road dust contains heavy metals that stick to plant surfaces and clog stomata, preventing photosynthesis and reducing plant development. The RI was proposed by Håkanson (1980). The RI and potential ecological risk coefficient (E) are calculated by Equations 5 to 7 below:

$$CF = Cs / Cb$$ **Equation 5**

$$E = Ti \times CF$$ **Equation 6**

$$RI = \sum Ei$$ **Equation 7**

Where CF is the contamination factor; and T is the toxic response factor (i.e. Cadmium (Cd) =30, Lead (Pb) =Copper (Cu) =5; Chromium (Cr) =2; and Zinc (Zn) =1). According to Håkanson, Ei<40 indicates low ecological risk, 40 ≤Ei<80 indicates moderate ecological risk, 80 ≤Ei <160 indicates considerable ecological risk, 160 ≤ Ei <320 indicates high ecological risk, and 320 ≤Ei indicates serious ecological risk. An RI <150 indicates a low potential ecological risk, 150 ≥RI < 300 indicates a moderate potential ecological risk, 300 ≥RI < 600 indicates a considerable ecological risk, and 600 ≥RI indicates a very high ecological risk.

3.3.2 Human health risk assessment

Particulate matter (PM) is a common proxy indicator for air pollution (World Heath Organization, n.d.). It affects more people than any other pollutant. The major components of PM are sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. While particles with a diameter of 10 microns or less, (≤ PM10) can penetrate and lodge deep inside the lungs, the even more health-damaging particles are those with a diameter of 2.5 microns or less, (≤ PM2.5). PM 2.5 can penetrate the lung barrier and enter the blood system. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer.

There are mainly two types of risks associated with dust pollution as mentioned below:

3.3.2.1 Non-carcinogenic risk

Non-carcinogenic risk means the potential for adverse systemic or toxic effects caused by exposure to non-carcinogenic chemicals of concern, expressed as the hazard quotient.

Heavy metals present in road dust can reach the human body via three main exposure pathways. The average daily dose (ADD) of heavy metals via three different pathways was calculated by the following equations (8-10):

$$ADD_{ing} = \frac{C \times R_{ing} \times CF \times EF \times ED}{BW \times AT}$$ **Equation 8**

$$ADD_{inh} = \frac{C \times R_{inh} \times EF \times ED}{PEF \times BW \times AT}$$ **Equation 9**

$$ADD_{dermal} = \frac{C \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT}$$ **Equation 10**

Where ADD_{ing} is the average daily dose due to ingestion, ADD_{inh} is the average daily dose due to inhalation and ADD_{dermal} is the average daily dose due to absorption from skin. C is the average concentration of heavy metal, R_{ing} is the ingestion rate in (mg/day). ED is the exposure duration (years) which is 6 for children and 24 for adults, EF is the exposure frequency, BW is the average body weight (kg), AT is the averaging time (days) for non-carcinogens; R_{inh} is the inhalation rate (m3 day^{-1}); PEF is particle emission; SL represents the skin adherence factor (mg cm^{-2} day^{-1}); ABS is dermal absorption factor (dimensionless and SA signifies the exposed skin area (cm^2).

ADD estimation for ingestion, inhalation and dermal exposure pathways, the non-carcinogenic risk by the heavy metals in PM and road dust was quantified by the hazard quotient (HQ). The HQ is calculated by Equations (11) and the carcinogenic risks (CR) posed by heavy metals in PM and road dust via inhalation were calculated by Equation (12):

$$HQ = \frac{ADD_i}{RfD}$$ **Equation 11**

$$HI = \sum HQ$$ **Equation 12**

Where ADD_i is the average daily dose for the exposure of heavy metals via ingestion, inhalation, and dermal pathways. The RfD (mg $kg^{-1}day^{-1}$) is the reference dose. According to USEPA (1989, 2001), no risk of adverse health effects occurs for HQ < 1, and there will be a probability of adverse health effects for HQ > 1. The HI is the summation of multiple exposure pathways of HQ. There is concern about the potential for non-carcinogenic effects if the exposure level of a heavy metal exceeds the limit HI >1. However, if HI≤1, then the non-carcinogenic risk posed is insignificant.

3.3.2.2 Carcinogenic risk (CR)

Carcinogenic risk denotes the probability of an individual developing any type of cancer over a lifetime due to carcinogenic exposures (United States Environment Protection Agency, 1996). The carcinogenic risks posed by heavy metals in PM and road dust via inhalation were calculated by following Equation:

$$CR = ADD_{inh} \times SF_{inh} \qquad \textbf{Equation 13}$$

Where, CR= Carcinogenic risk, ADD_{inh}= Average daily dose due to inhalation, SF_{inh}= Carcinogenic Slope factor. The CR value in the range of 10^{-6} to 10^{-4} is considered a tolerable limit of cancer risk (USEPA 1996). In this study, the carcinogenic risks were estimated for Nickel(Ni), Chromium (Cr), and Cadmium (Cd), as the carcinogenic slope factors of other heavy metals were not available.

USEPA (2002) is a framework of Risk Assessment of metals developed by United States Environment Protection Agency (USEPA). It addresses all special attributes and behaviours of metals and metal compounds along with assessing their human health and ecological risks. This framework describes the basic principles for assessing risks posed by metals and foster consistency in conducting their assessment.

Although, this framework was primarily intended to be agency risk assessors, but now it is widely accepted framework across the globe among stakeholders and the public for principles and recommendations for metals risk assessment.

3.4 Results and Discussion

The status of heavy metals present in the road dust is evaluated with the help of pollution indices. Data on the concentration of heavy metals present in the road dust have been collected from the existing literature available for Delhi (Roy, Ecological and human health risk assessment of heavy metal contamination in road dust in the National Capital Territory (NCT) of Delhi, India, 2019) and Mumbai (Amit Gawade, 2016) and thereafter computing the other pollution indices as described in Appendix-A. The assessment of carcinogenic and non-carcinogenic risks due to the presence of heavy metals in the road dust has been done with the help of the health risk assessment model developed by USEPA (2002) (EPA, 2007).

3.4.1 Findings for Delhi

The Iron (Fe) retained the highest mean concentration among heavy metals followed by Zinc (Zn), Lead (Pb), and Copper (Cu). The mean concentrations of Lead (Pb), Zinc (Zn), and Copper (Cu) in road dust of the National Capital Territory (NCT) were higher than their background concentration reported for the natural soil of India and comparably higher than their world's average shale values. The mean concentration of Nickel (Ni) and Chromium (Cr) was below the background levels of both Indian soil and the world's average shale concentration. The increase in Lead (Pb) concentration in Delhi could be attributed to the corrosion of car surfaces and the wide use of gasoline and road paints. The high concentration of Zinc (Zn) was presumably caused by motor vehicle emissions, braking system wear and tear, and galvanization. The high-temperature wearing of tyres leads to the large emission of Zinc (Zn) in road dust. The elevated concentration of Iron (Fe) could be linked to heavy traffic due to congestion and construction and demolition works.

Since background concentrations of Manganese (Mn) and Iron (Fe) are not available for Indian unpolluted soil, the world's average shale values were considered for comparisons in this paper. The other pollution indices of Delhi are described below:

3.4.1.1 Contamination factor

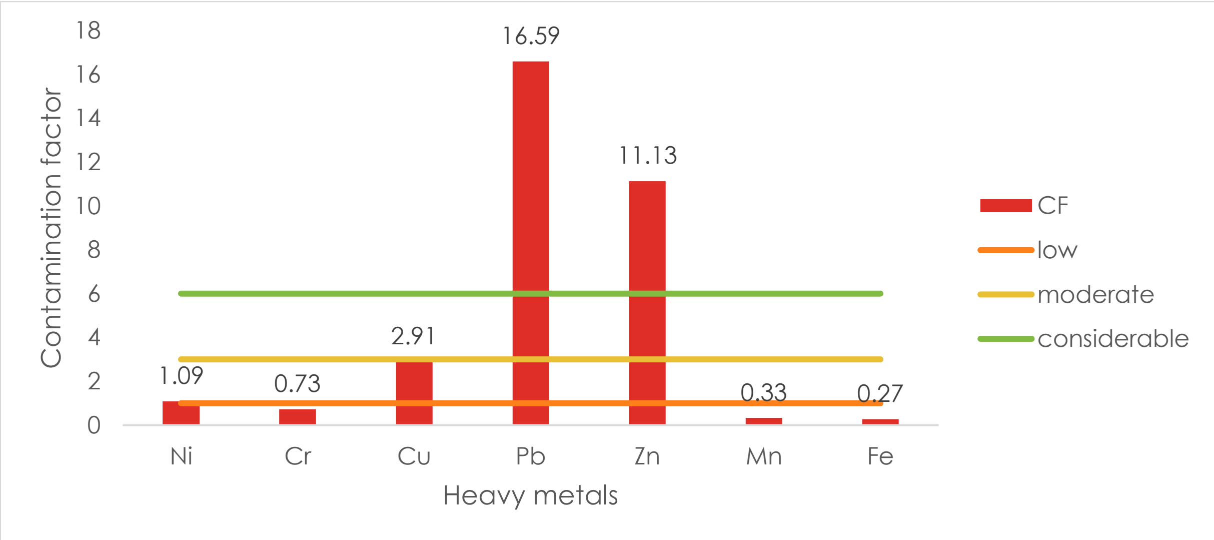

Figure 29: Contamination factor of different metals

It is concluded from the graph that the contamination factor of lead is on higher side in comparison to other heavy metals because of the low background mean concentration. The contamination factor of iron is the lowest though its concentration was highest in comparison to other metals in road dust. This is because of the reason that the average world shale value (background value) of iron is higher in comparison to its mean concentration in road dust. The contamination factor of heavy metals in road dust of Delhi varies from low to very high. The contamination factor of lead and zinc is very high ($CF \geq 6$) while the contamination factor of manganese and iron is low ($CF<1$). The contamination factor of nickel is moderate.

3.4.1.2 Total degree of contamination

The overall degree of contamination is computed to be greater than 24, which indicates that the degree of contamination is high and can lead to serious anthropogenic pollution. The modified degree of contamination is calculated as 4.72, which comes in a range between 4 and 8 and represents a high degree of contamination.

3.4.1.3 Pollution load Index (PLI)

The pollution load index due to all heavy metals present in road dust is computed to be greater than 1, which represents a deteriorating site quality. The high PLI could be attributable to the cumulative concentrations of heavy metals indicating an alarming condition.

3.4.1.4 Potential Ecological Risk Index

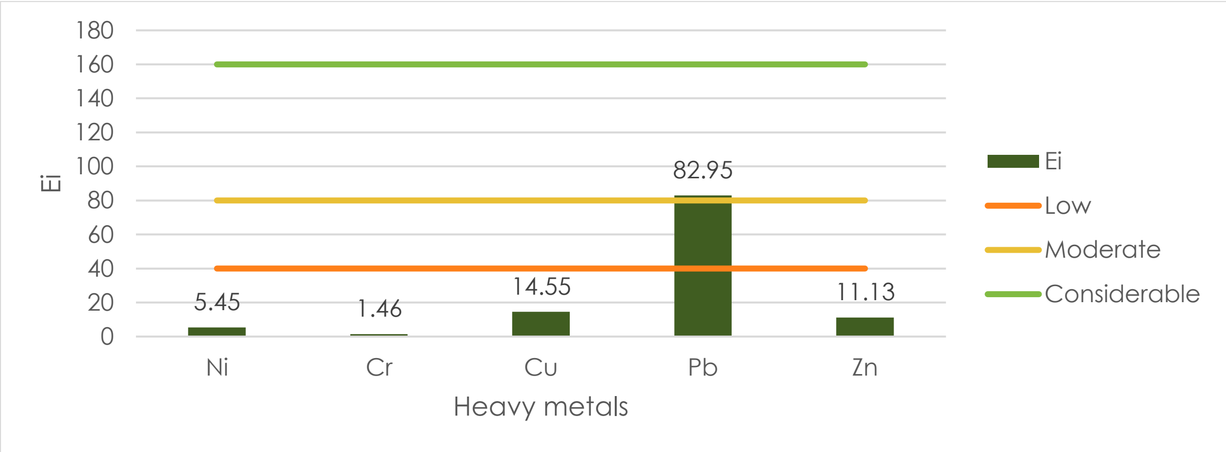

Figure 30: Potential ecological risk coefficient of different metals in Delhi (Ei)

Considering the influence of individual heavy metals on the toxicity condition, Lead (Pb) could be the major contributor to the ecological risk of road dust. Moreover, the risks due to Zinc (Zn), Cooper (Cu), Nickel (Ni), Chromium (Cr), and Manganese (Mn) were low in all areas of Delhi. Despite Lead (Pb) and Zinc (Zn) recording comparable concentrations, a considerable ecological risk was observed for Lead (Pb) due to its relatively high toxic response value. The Copper (Cu) metal depicts a toxic response value similar to that of Lead (Pb), but the risk due to Copper (Cu) was very low because of its low concentration in road dust. On average, the maximum ecological risk of about 83 per cent was obtained from Lead (Pb) for the entire study area of NCT. Other metals, Zinc (11 per cent) and Copper (15 per cent) showed a moderate contribution to the deterioration of the environmental quality.

3.4.1.5 Human health risk assessment model

The human health risks from exposure to heavy metals in road dust were categorized into non-carcinogenic health risks and carcinogenic health risks. A separate evaluation was done for adults and children as detailed below:

Non-carcinogenic risk

Non-carcinogenic risk is defined as the probability of occurrence of any given probable amount of harmful health impacts over a determined time period that is not known to cause cancer. Based on the computed hazard quotients (HQ) and hazard indices (HI), the mean HQ of metals for the three different exposure pathways (i.e., ingestion, inhalation, and dermal contact) were calculated. The trends of exposure risk are given below:

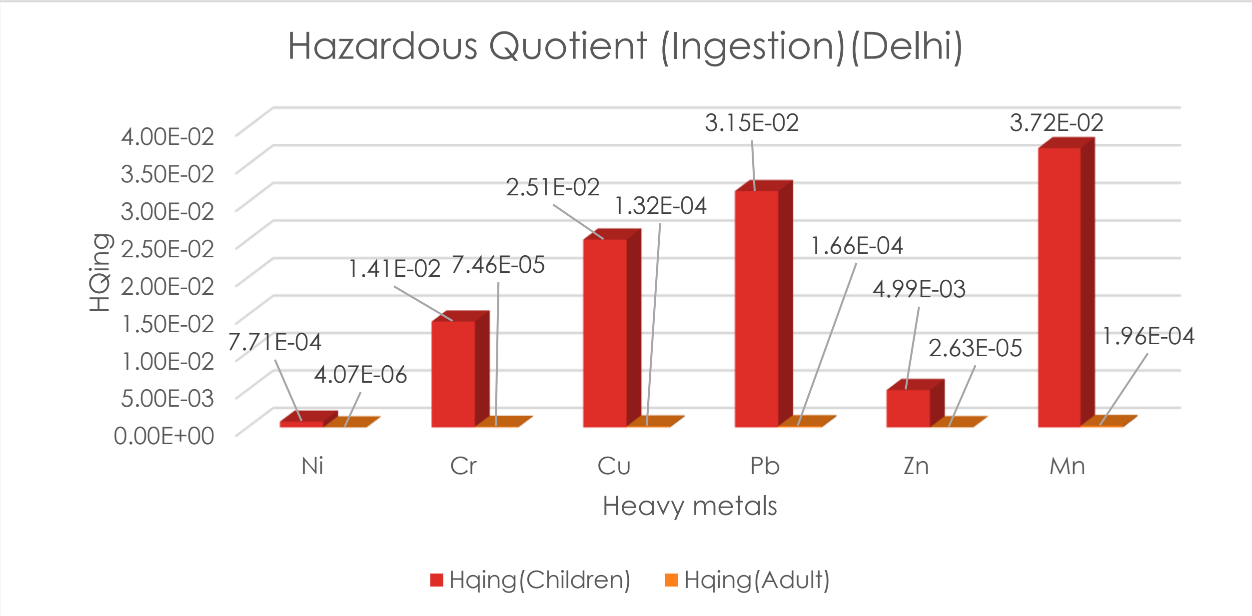

Figure 31: Comparison of probable Ingestion risk in Adults and Children in Delhi

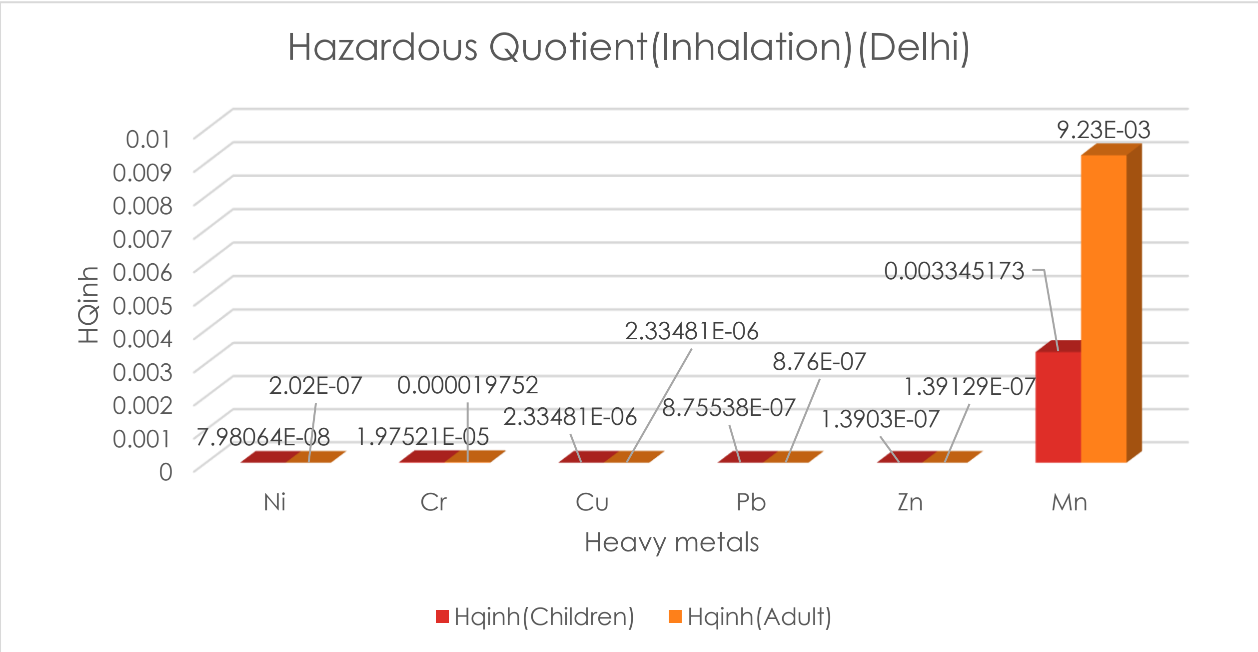

Figure 32: Comparison of probable Inhalation risk in Adults and Children in Delhi

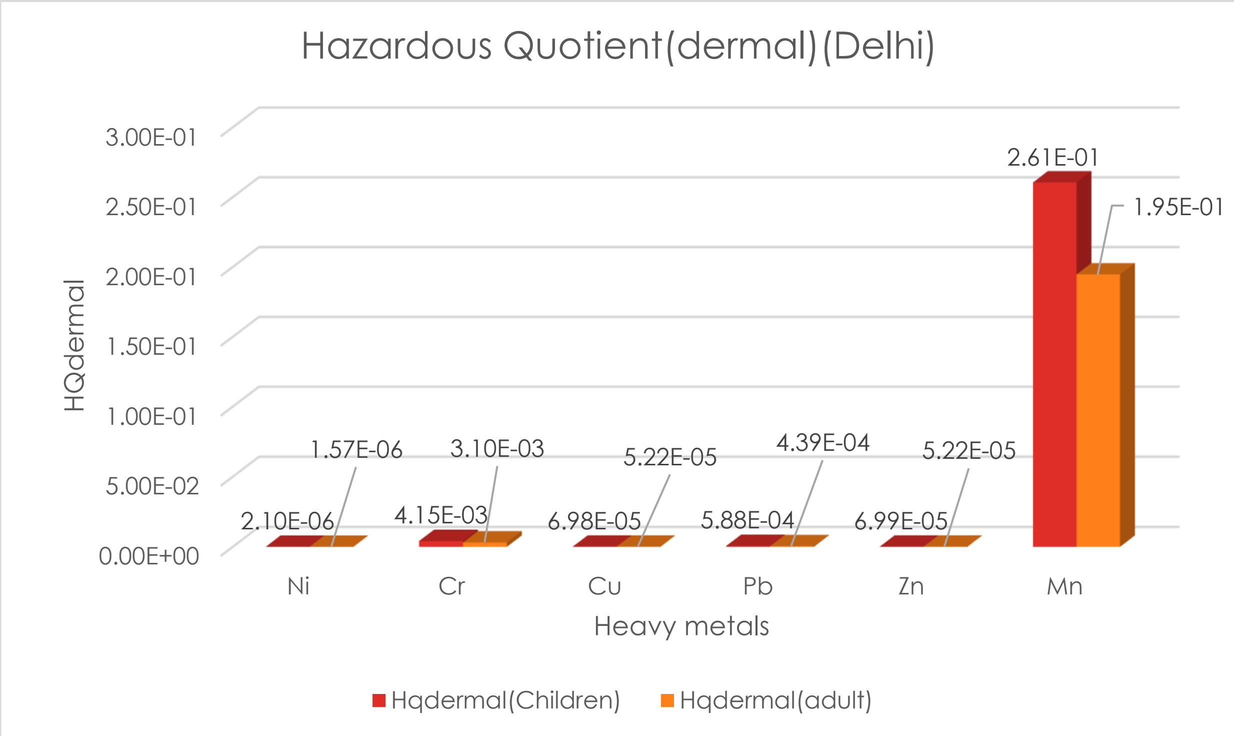

Figure 33: Comparison of probable Dermal risk in Adults and Children in Delhi

The human health risk from road dust exposure was evaluated using Hazard Quotients (HQs) and Hazard indices (HIs) derived using the US EPA framework (USEPA 2002), where HQ = 1 is the limit above which for a single variable and a single exposure route, a non-carcinogenic risk is likely to give adverse health effects (E. Liu et al. 2014). This framework considers the ingestion, inhalation and dermal exposure routes, modelling daily exposure doses for each route (CDI), where CDI accounts for the concentration in the road dust, the rate of ingestion or inhalation or skin absorption, exposure frequency and duration, body-weight, average time of exposure and specifically for inhalation a particle emission factor, whist for dermal exposure skin area, skin adherence and dermal absorption factor. This CDI is normalized to a reference dose (RfD) to give an exposure route hazard quotient (HQ), where the reference dose is the maximum value likely to not produce adverse effects over a lifetime. The cumulative sum of the HQs for each route is the Hazard Index (HI). Separate calculations are made for children and adults, where children are taken to be aged up to 6 years. The calculations are based solely on non-carcinogenic effects.

Based on the values given above, it is evident that the Hazardous Quotient due to ingestion is highest followed by dermal and inhalation which means HQ_{ing}>HQ_{dermal}>HQ_{inh}. The hazardous quotient due to ingestion and dermal is more for children in comparison to adults while the hazardous quotient due to inhalation is more for adults in comparison to children. The hazardous quotient of ingestion value for all inhalation, ingestion and dermal contact is less than 1 which signifies that the non-carcinogenic risk is within the admissible limit due to all heavy metals but the risk may increase if adequate steps are not taken in this area. According to USEPA (1989, 2001), no risk of adverse health effects occurs for HQ < 1, and there will be a probability of adverse health effects for HQ > 1. Road dust consists of a large amount of contaminants and if they are not degraded into less toxic form then their concentration will increase as time passes.

Hazardous index (HI) is the sum of hazardous quotient due to ingestion (HQ_{ing}), inhalation (HQ_{inh}) and dermal contact (HQ_{dermal}). The hazardous index is more for children in comparison to adults. The value of the hazardous index for Delhi has been computed as less than 1 which signifies that the overall risk due to ingestion, inhalation and dermal contact is within an admissible limit. The HI is the summation of multiple exposure pathways of HQ. There is concern about the potential for non-carcinogenic effects if the exposure level of a heavy metal exceeds the limit HI >1. However, if HI≤1, then the non-carcinogenic risk posed is insignificant.

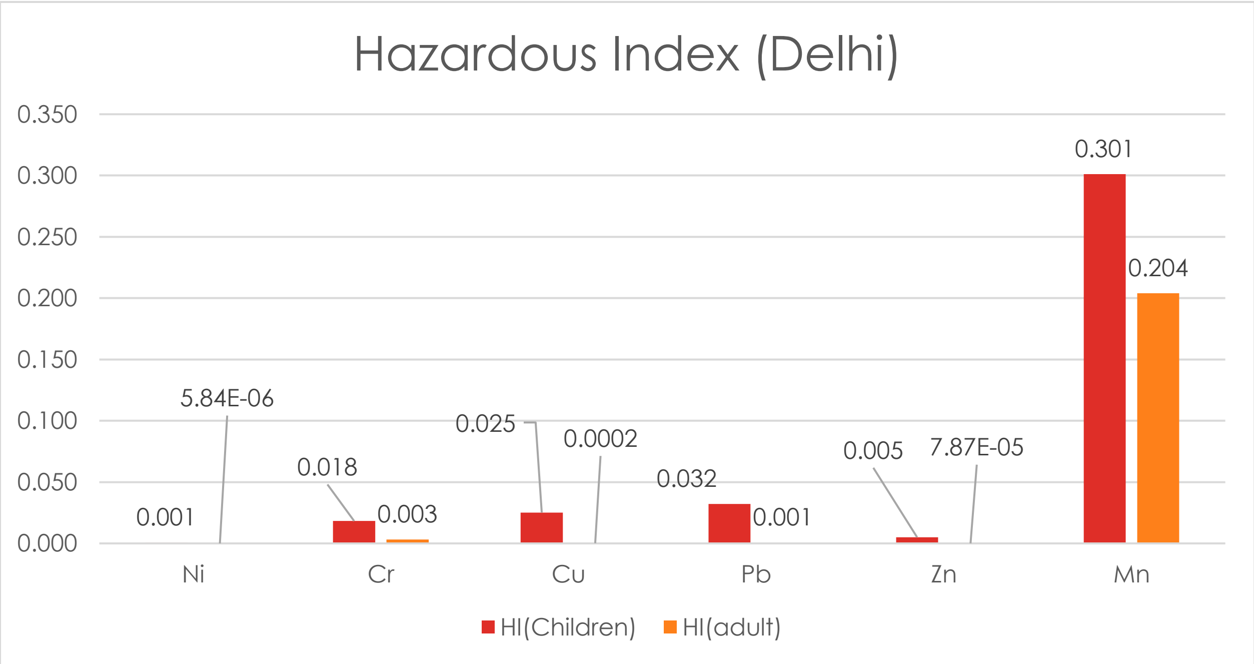

Figure 34: Hazardous Index of Delhi

Carcinogenic risk

Carcinogenic risk denotes the probability of an individual to develop any type of cancer over a lifetime due to carcinogenic exposures. The carcinogenic risk only due to inhalation of chromium and nickel has been considered for computation due to unavailability of the values of carcinogenic slope factors for other heavy metals. The value of carcinogenic risk has been computed as less than 10^{-6}, which means there is no risk but the risk may increase if serious steps will not be taken in this domain. The CR value in the range of 10^{-6} to 10^{-4} is considered a tolerable limit of cancer risk (USEPA 1996).

3.4.2 Findings for Mumbai

The concentration of Zinc is computed to be 938.80 mg/kg, which is the highest in Mumbai as compared to other heavy metal concentrations. The high concentration of Zinc (Zn) was possibly due to motor vehicle emission, wear and tear of the braking system and use of galvanized steel. Lead is the second-highest heavy metal in the sampling site i.e. 152.91mg/kg and the high concentration of lead is due to release of vehicle exhaust and fuel combustion in vehicles, mostly leaded petrol used in cars. The third highest heavy metal concentration was found in copper i.e. 136.54 mg/kg. & it is due to corrosion of metallic parts & spillage of lubricants in vehicles. The mean heavy metal concentration of Iron is found to be 119.53 mg/kg & it gives less concentration as compared to other heavy metal concentrations. The presence of Fe indicates that it was emitted by wear and tear of brake pads and vehicle engine parts and is also a component of the earth's crust. The heavy metal concentration in the roadside dust of Mumbai are Zinc>Lead>Copper >Iron>Nickel>Cadmium. The other pollution indices computed for Mumbai are described below:

3.4.2.1 Contamination factor

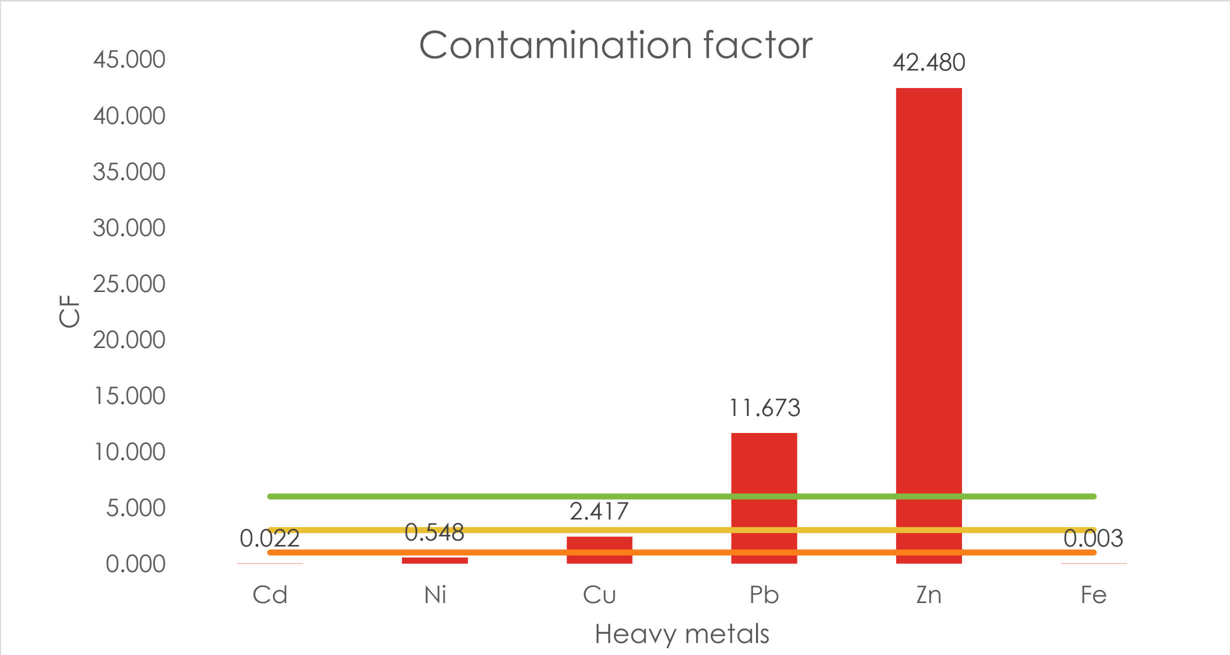

Figure 35: Contamination factor (CF) of different metals in Mumbai

It is revealed from the graph that the contamination factor of zinc is on higher side in comparison to other heavy metals followed by lead, copper, nickel and iron. The contamination factor of zinc and lead is very high because of their high concentration in road dust while the contamination factor of nickel and iron is low due to their low concentration in road dust (<1). The contamination factor of heavy metals in road dust varies from low to very high.

3.4.2.2 Total degree of contamination

The total degree of contamination at a given location is calculated by adding the contamination factors of all heavy metals. The overall degree of the "Degree of Contamination" is greater than 24, which denotes that the degree of contamination is high indicating serious anthropogenic pollution. The modified degree of contamination is the average contamination factor of all heavy metals and its value is greater than 8, which represents a very high degree of contamination.

3.4.2.3 Pollution Load Index

The pollution load index due to all heavy metals present in road dust is less than 1, which represents pollution due to road dust is within prescribed limits.

3.4.2.4 Potential Ecological Risk Index

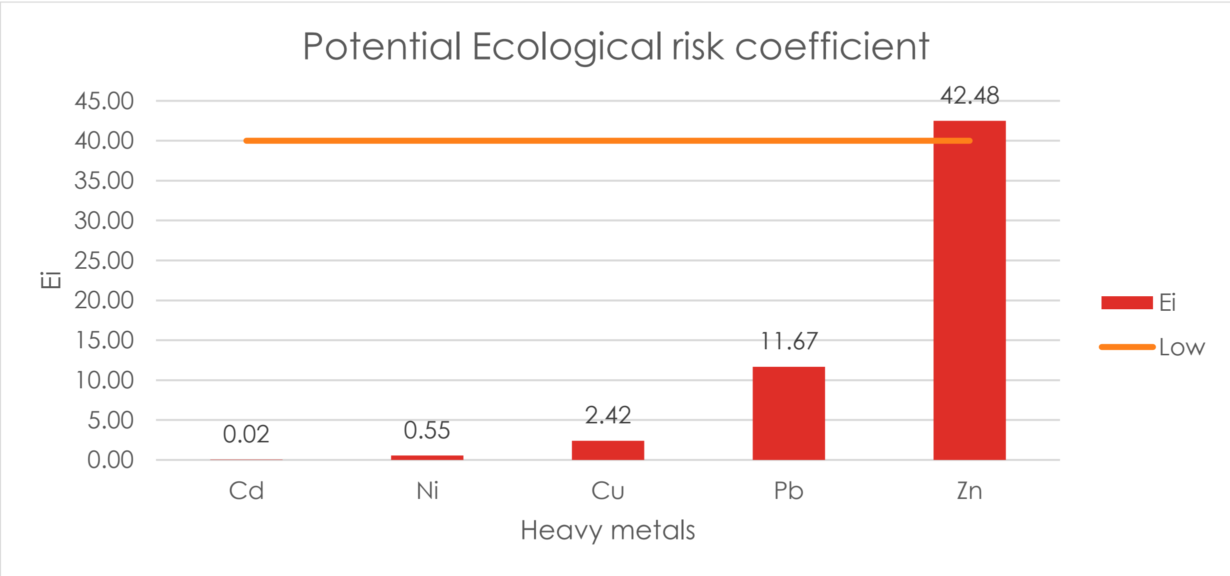

Figure 36: Potential ecological risk coefficient (Ei) of Mumbai

The potential ecological risk coefficient of lead is on higher side in comparison to other heavy metals because concentration and toxicity of lead were high in comparison to other metals. The potential ecological risk coefficient of nickel is low because of low concentration of nickel in road dust. The overall ecological risk index due to all heavy metals present in road dust is low because its value is less than 150.

3.4.2.5 Human health risk assessment model

The human health risks from exposure to heavy metals in road dust were categorized into non-carcinogenic health risks and carcinogenic health risks. A separate evaluation was done for adults and children for Mumbai as per details below:

Non-carcinogenic risk

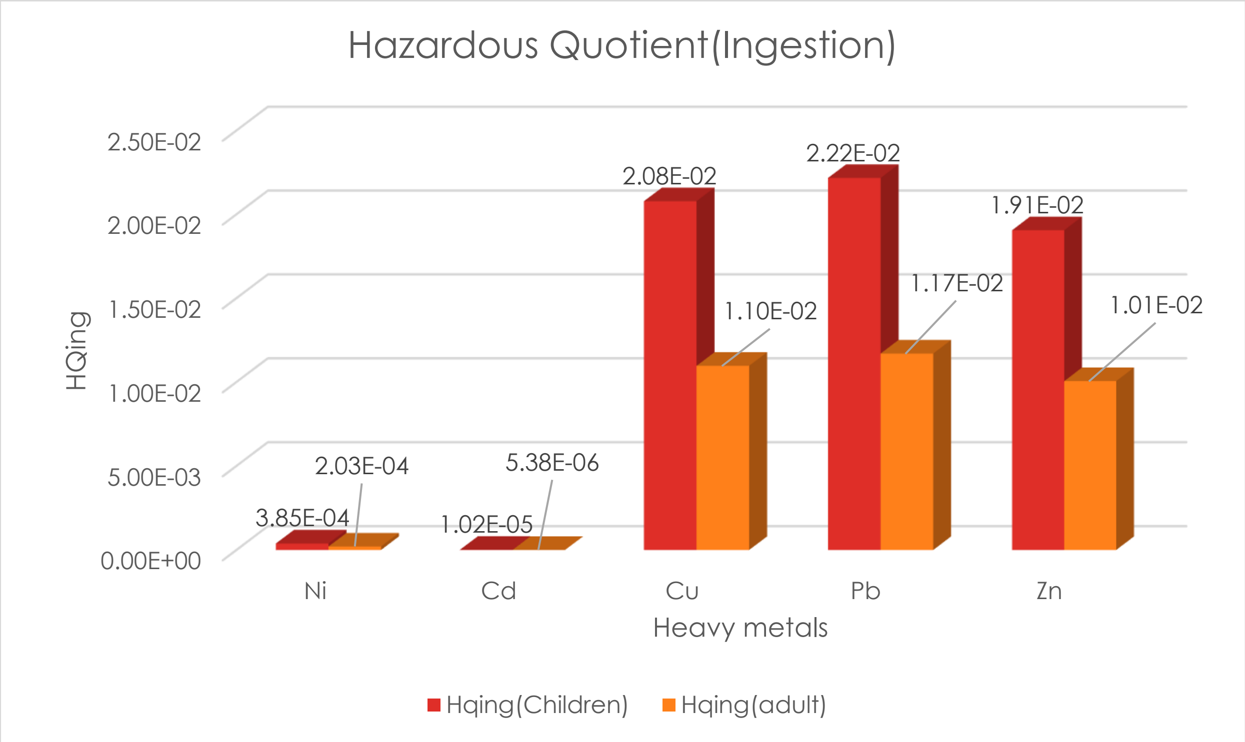

Figure 37: Hazardous Quotient (Ingestion) of Mumbai

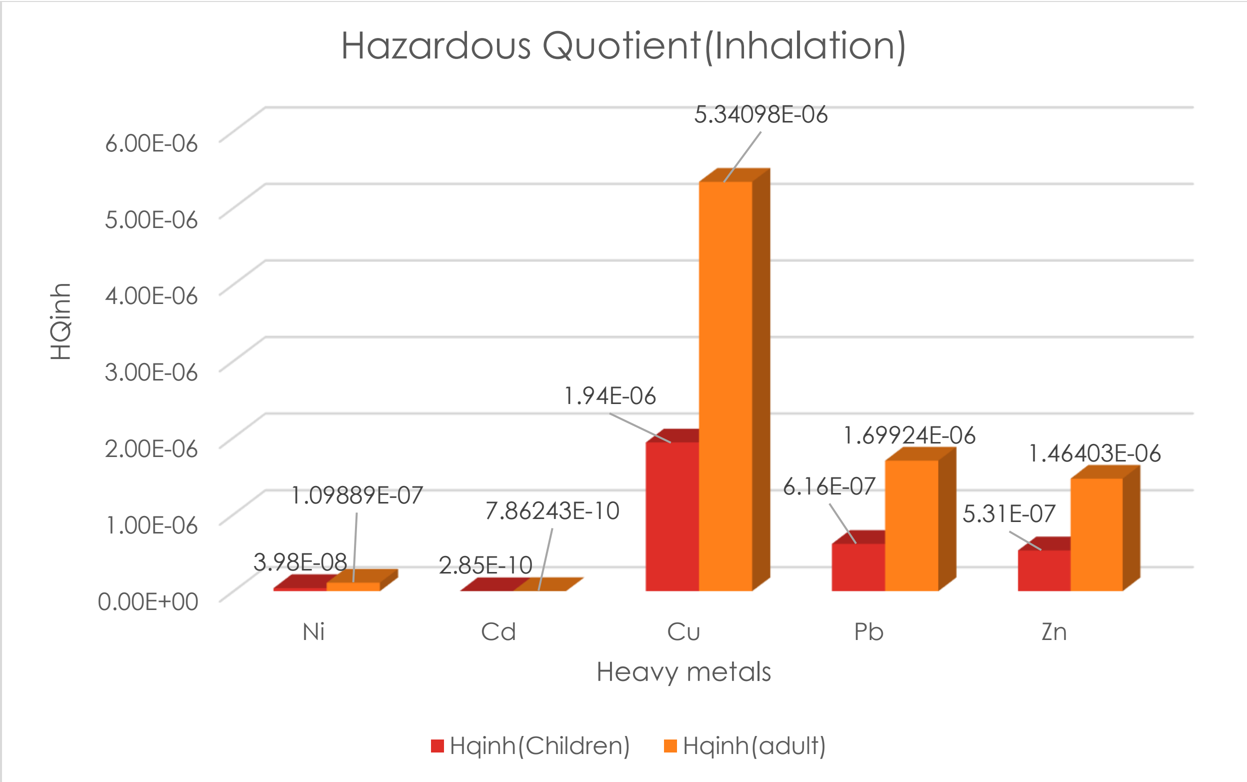

Figure 38: Hazardous Quotient (Inhalation) of Mumbai

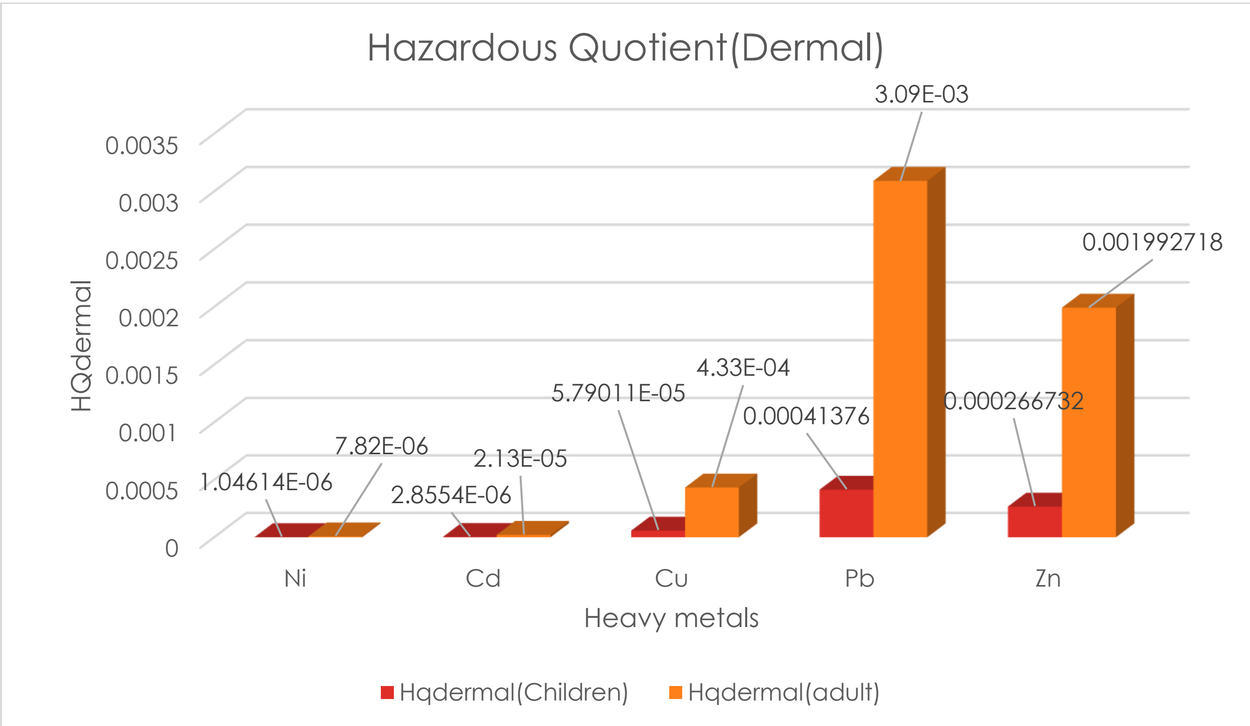

Figure 39: Hazardous Quotient (Dermal) of Mumbai

Based on the values given above in the graph, it is evident that the Hazardous Quotient due to ingestion is highest followed by dermal and inhalation $HQ_{ing}>HQ_{dermal}>HQ_{inh}$. The hazardous quotient due to ingestion and dermal is more for children in comparison to adults while the hazardous quotient due to inhalation is more for adults in comparison to children. The hazardous quotient of ingestion value for all inhalation, ingestion and dermal contact are less than value of 1, which signifies that the non-carcinogenic risk is within permissible limit due to all heavy metals but risk may increase if we will not pay more attention to this area. Road dust consists of a large amount of contaminants and if it is not degraded into less toxic form then its concentration will increase as time passes.

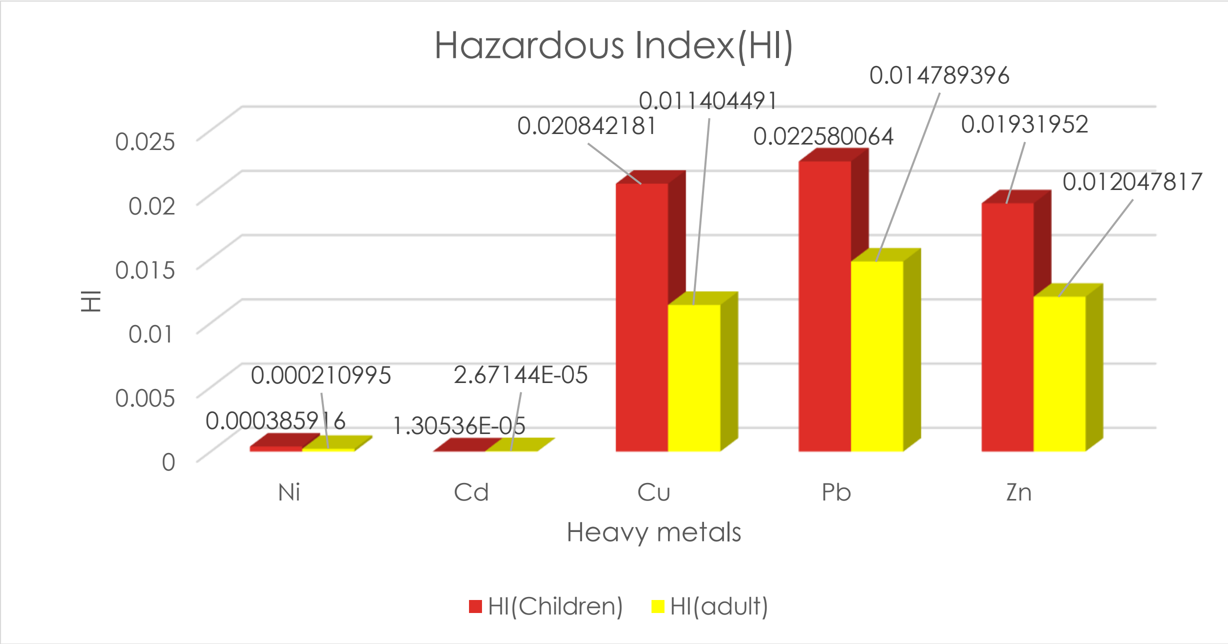

Figure 40: Hazardous Index (HI) of Mumbai

The Hazardous index (HI) is the sum of the hazardous quotient due to ingestion (HQ_{ing}), inhalation (HQ_{inh}) and dermal contact (HQ_{dermal}). The hazardous index is more for children in comparison to adults. The value of the hazardous index for Mumbai is less than 1 which signifies that the overall risk due to ingestion, inhalation, and dermal contact is insignificant.

Carcinogenic risk

Carcinogenic risk denotes the probability of an individual developing any type of cancer over a lifetime due to carcinogenic exposures. The carcinogenic risk only due to inhalation of nickel and cadmium is considered because of the unavailability of values of carcinogenic slope factors of other heavy metals. The value of carcinogenic risk has been calculated to be less than 10^{-6} indicating there is no risk; but the risk may increase if serious steps are not taken in this domain.

The CR value in the range of 10^{-6} to 10^{-4} is considered a tolerable limit of cancer risk (USEPA 1996).

3.5 Findings

Based on the outcomes of this study, the following are some of the important findings:

Parameters	Findings
Contamination factor (CF)	The Contamination factor of lead is on the higher side in Delhi The Contamination factor of Zinc is on the higher side in Mumbai.
Degree of contamination (Cd)	High for both Delhi and Mumbai.
Pollution load Index (PLI)	PLI>1 for Delhi shows deteriorating site quality in Delhi. PLI<1 for Mumbai represents dust pollution within prescribed norms.
Potential Ecological Risk Coefficient (Ei)	Potential Ecological Risk coefficient is towards the higher side for lead in both Delhi and Mumbai.
Hazardous Quotient (HQ)	HQ_{ing}> HQ_{dermal} >HQ_{inh} for both Delhi and Mumbai. HQ_{ing}, HQ_{dermal} and HQ_{inh} is less than 1, which represents that the non-carcinogenic risk of all heavy metals via ingestion, inhalation, and dermal contact is within prescribed limit for both Delhi and Mumbai. HQ_{ing} and HQ_{demal} for both the cities are more for children in comparison to adults which represents the probability of non-carcinogenic risk due to ingestion and dermal is more in children than adults. HQ_{inh} for both the cities is more for adults in comparison to children which represents the probability of non-carcinogenic risk due to inhalation is more in adults than children.
Hazardous Index (HI)	The Hazardous index is less than 1, it means that the probability of getting non-carcinogenic risk is insignificant for both adults and children.
Carcinogenic risk (CR)	Risk is insignificant for both Delhi and Mumbai.

3.6. Conclusion

The present study elaborated on the heavy metal pollution created by road dust and also evaluated the potential health impacts due to the presence of heavy metals in road dust in Delhi and Mumbai.

In Delhi, the overall average concentration of iron is on higher side. However, the concentration of Iron was lower than its world's average shale value. The concentrations of Lead, Zinc, and Copper in the road dust exceeded the background values of Indian soil as well as the average world's shale values, possibly due to vehicular emission, tyre /brake wear and vehicle engine abrasion. The contamination factor varies from low to very high. The degree of contamination due to the presence of all heavy metals is high indicating serious anthropogenic pollution. The PLI is greater than value 1 indicating deteriorating site quality. An assessment of health risks showed that ingestion was the main route for the exposure of the local population to road dust; while the least risk was found through inhalation. There was no substantial non-carcinogenic risk of road dust heavy metals. The mean value of HI was higher for children compared to that for adults, indicating that the children were at greater risk of heavy metals than the adults. The carcinogenic risk due to the inhalation of chromium and nickel is insignificant for both children and adults.

In Mumbai, the overall average concentration of Zinc, lead and copper is on higher side in comparison to other heavy metals possibly due to motor vehicle emission, wear and tear of the braking system and use of galvanized steel. The heavy metal concentration in the roadside dust of Navi Mumbai are Zinc>Lead>Copper>Iron>Nickel>Cadmium. The concentrations of Zinc in the road dust exceeded the background values of Indian soil. The contamination factor of Mumbai varies from low to very high. The degree of contamination due to the presence of all heavy metals is high indicating serious anthropogenic pollution. The PLI value is less than 1 indicates pollution with in prescribed limit. An assessment of health risks showed that ingestion was the main route for the exposure of the local population to road dust, while the least risk was found through inhalation. There was no substantial non-carcinogenic risk of heavy metals. The mean value of HI was high for children compared to that for adults, indicating that the children were at greater risk of the health hazards of heavy metals than the adults. The carcinogenic risk due to the inhalation of nickel and cadmium is insignificant.

3.7 Recommendations

Based on the conclusions drawn in this paper, it can be concluded that the concentration of heavy metals has increased significantly in the road dust of NCT of Delhi and Navi Mumbai.

The presence of heavy metals like Lead, Zinc etc. has contributed a significant part to dust pollution. The PLI evaluated an overall deterioration of environment in Delhi due to the presence of heavy metals in road dust. Therefore, continuous monitoring of heavy metals in road dust should be conducted at regular intervals. Consequently, the formulation and development of policies conforming to such problems and environmental regulations are required to be initiated and strictly followed. Based on the outcomes, it is evident that as of now, there is less probability of non-carcinogenic and carcinogenic risk yet precautions must be taken to control and reduce the input of heavy metals in the road dust. The following steps can be taken to control the pollution caused due to dust:

Sl. No.	Important steps which may be taken to control pollution due to road dust
1.	Use of proper dust palliatives or water sprinkling system to control the road dust.
2.	Improving the conditions of roads by maintaining pot holes for free flow of traffic to reduce the emission of road dust.
3.	Controlling the number of vehicles and solving the problem of traffic congestions. Previously, an Odd-Even scheme was applied by the Delhi Government for a short trial period which is needed to be continued to control the number of vehicle congestion on the road.
4.	Creation of green buffers along the traffic corridors.
5.	Reducing the speed of vehicles. Studies show that the emission of PM_{10} or dust increases significantly when the vehicle speed is high. Reducing speed from 40 miles per hour (mph) to 20 mph reduces dust emissions by 65 per cent. Speed limit signs and enforcement of strict laws can reduce the trend of driving above the usual speed (The great state of Alaksa, n.d.).
6.	Introducing mechanical sweepers on the basis of feasibility study in cities.
7.	Sewage treatment plant-treated water sprinkling system with PVC (Polyvinyl Chloride) pipeline along the roads and at intersecting road junctions. Further, spraying of water twice a day before peak traffic hours.

8.	With the help of windbreaks, the speed of wind can be controlled. Good windbreaks will not create excessive turbulence or wind eddies. Windbreak materials may include picket and board fences (with gaps between pickets) berms, snow fences, and rows or hedges of plants.
9.	Undertake building green cover and plantation. Undertake greening of open areas, community places, schools and housing societies.
10.	Stringent implementation of C&D Rules, 2016, of the Government of India.
11.	More research work is needed in the area of the assessment of carcinogenic health risks due to heavy metals present in road dust networks because of the unavailability of carcinogenic slopes for many heavy metals.

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