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Research Paper

Analyzing Composition Emerging Trends And Environment Impact of MSW in MC Shimla, H.P., India

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ABSTRACT

The rapid growth of urbanization and industrialization has resulted in a substantial increase in daily municipal solid waste (MSW) generation. This waste contributes significantly to environmental pollution and the spread of diseases. Unmanaged waste attracts pests and decomposers, leading to unhygienic conditions and heightened health risks. The study aims to assess the quantity, trends, and composition of MSW, as well as the environmental consequences associated with its disposal in landfill sites. The data analysis of solid waste in MC Shimla from 2013 to 2023 reveals a substantial increase from 38 to 82 MTPD, attributed to rapid economic development and population growth. Correlation analysis indicates significant relationships between municipal solid waste generation and factors like District Domestic Product (DDP), per capita income, and population. This implies that as Shimla's economy and urban population expanded, there was a corresponding rise in waste generation. Notably, there was a temporary dip in waste output between 2020 and 2021 due to COVID-19. The findings underscore the necessity for effective waste management and sustainable practices to tackle Shimla's escalating waste production for environmental sustainability.The monitoring results emphasize the crucial role of proper waste management and ongoing environmental oversight for 59 landfill sites and waste-to-energy plants to comply with regulations. Water analysis reveals that cadmium, nickel, zinc, copper, fluoride, and pH levels downstream are within acceptable limits, ensuring minimal contamination. However, concerns arise over slightly elevated Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) levels. Conversely, air quality monitoring at the waste-to-energy plant indicates effective control of particulate matter (PM) emissions, staying within prescribed limits. This suggests successful implementation of air pollution control measures, mitigating potential impacts on air quality and public health.

1. Introduction

Human existence generates waste, intensified by rapid urbanization and population growth. Urban migration fuels daily production of vast amounts of municipal solid waste (MSW), especially in low-income countries. The influx of city dwellers consuming meat, cars, and electronics strains natural resources, escalating waste production and environmental pressures (Sintana E. Vergara, 2012). Waste refers to items with no purpose requiring disposal. Properly managed, waste can be a resource in manufacturing and power generation. Solid waste includes discarded materials from various sources. Municipal Solid Waste (MSW) encompasses products from daily activities. In urban settings, a slight income rise alters consumption patterns, impacting waste generation. (Medina, 1997), Municipal Solid Waste (MSW) poses a significant challenge for municipalities due to increasing quantities and complex waste types. MSW is categorized into dry waste (non-decomposable items like plastics and metals) and wet waste (organic materials with high moisture content). MSWM involves systematic handling, transportation, treatment, recycling, and proper disposal to enhance urban environments, promote economic growth, protect the environment, and optimize efficiency. The escalating volume of solid waste surpasses the agencies' capacity to improve financial and technical resources, making solid waste management a global challenge. (Ogwueleka, 2009). Annually, the world produces 2.01 billion tons of municipal solid waste, and a minimum of 33 percent of this considerable amount is handled without regard for environmental safety. On a global scale, the average

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daily waste generated per person is 0.74 kilograms, varying widely from 0.11 to 4.54 kilograms. Projections indicate that global waste will reach 3.40 billion tons by 2050, surpassing the rate of population growth during the same period, as reported by the World Bank in 2018. Furthermore, research from Iran in 2009 notes that urban areas in industrialized countries tend to produce more solid waste than their counterparts in developing countries. (WorldBank, 2018, Ogwueleka, 2009) India, a developing nation, grapples with solid waste management, generating 160,038.9 TPD. Despite a 95.4% collection efficiency (152,749.5 TPD), only 50% undergo treatment, and 18.4% end up in landfills (29,427.2 TPD). A concerning 31.7% (50,655.4 TPD) remains unaddressed. Over the past five years, solid waste processing has risen from 19% (2015-16) to 49.96% (2020-21). The government, via the 2016 Solid Waste Management Rules and initiatives like 'Swachh Bharat Mission' and 'Waste to Wealth Mission,' aims to enhance waste management. Technological interventions like automatic waste segregation and gasification are deployed. Himachal Pradesh, India's least urbanized state, boasts 59 urban agglomerations (CPCB Annual Report, 2021; Census Operations Report, 2011). In the urban areas of Himachal Pradesh, waste quantities are significantly lower compared to other metropolitan cities in India. The municipal solid waste (MSW) generated in the state is around 300-350 tons per day, which is a negligible contribution to the 100,000-120,000 tons per day produced nationwide. Specifically, Shimla City generates approximately 93.0 tons of waste daily, with a per capita waste generation rate of 350 grams per day. In 2006, the Municipal Corporation Shimla enacted Door to Door Garbage Collection Bye-laws under the Himachal Pradesh Municipal Corporation Act, 1994. The waste collection methods include door-to-door collection and community bins, totaling around 70-75 tons per day according to Municipal Corporation Shimla records. (World Bank, 2006 and HPSoER, 2007).

Effective solid waste disposal management is crucial to minimize environmental harm and health risks. This process involves planning, administration, finance, engineering, and legal functions, typically governed by local, national, and international authorities. Various methods are employed for treating solid waste, including thermal treatments like incineration, pyrolysis, and gasification, as well as open burning, which contributes to air pollution.Dumps and landfills are common disposal methods, categorized as sanitary landfills, controlled dumps, and bioreactors. Sanitary landfills, designed to isolate waste from the environment, promote decomposition into inert materials. Controlled dumps are planned landfills without cell structures, while bioreactor landfills utilize microorganisms to reduce waste volume.

Biological waste treatment includes composting, decomposing organic waste with oxygen, and anaerobic digestion, decomposing waste without oxygen. Open dumping and improper incineration pose pollution and health risks, leading to the development of sanitary landfills. Hazardous and nonhazardous waste is often categorized separately, with landfills designed to minimize health and environmental risks. Modern refuse incinerators recover heat energy and adhere to stringent air quality standards. Overall, effective waste management is essential for environmental sustainability and public health. In developed countries, modern solid-waste management prioritizes recycling and waste reduction at the source over incineration and landfill disposal.

Despite the economic advantages of landfill disposal, there is a growing emphasis on sustainable practices to minimize the environmental impact of solid waste. This shift reflects a move towards more eco-friendly solutions in managing waste in these nations. (Thompson and Zandi, 1975; Rushbrook, 1983; Carra and Cossu, 1990). Therefore, landfills will continue to be the most attractive disposal route for solid waste. Indeed, depending on location, up to 95% of solid waste generated worldwide is currently disposed of in 5 landfills (Bingemer and Crutzen, 1987; Cossu, 1989; Nozhevnikova*et al*., 1993; Gendebien*et al*., 1992). Poor waste management, encompassing inadequate collection and disposal systems, results in pervasive environmental pollution. It induces air pollution, water, and soil contamination, with open landfills exacerbating these issues. Contaminated drinking water from such landfills poses health risks, fostering the spread of diseases. Solid waste is a significant contributor to environmental pollution, attracting pests and leading to unhygienic conditions that elevate health problems. Improper solid waste management has far-reaching consequences, causing health issues and environmental degradation. Landfills generate gas and leachate, contributing to greenhouse gas emissions and groundwater contamination. Methane, a potent greenhouse gas, is a byproduct of landfill waste, predicted to surge by 70% by 2050. Microbial decomposition in landfills releases leachate containing pollutants, posing risks such as air pollution, climate change, fires, and groundwater contamination. Effective waste management is crucial to mitigate these adverse environmental and health impacts..(Mutasem El-Fadel*et.al* 1995) Dumps and landfills pose a significant threat to water supplies and ecosystems. When water percolates through waste in these areas, it picks up various harmful substances, including metals, minerals, organic chemicals, bacteria, viruses, and toxic materials. The resulting leachate contaminates both groundwater and surface water, posing risks to supply wells. Furthermore, as land is used for landfills, it becomes inhospitable to many plants and wildlife, disrupting ecosystems.

Living near landfills becomes undesirable due to the difficulty in finding suitable dumping grounds, and the expansion of landfills encroaches on available space. The decomposition of waste in these areas produces unpleasant odors, including sulfur compounds and volatile organic compounds, which can be strong and pervasive. These odors not only cause discomfort and nuisance to nearby communities but also contribute to air pollution, affecting the overall quality of life in the surrounding areas. The environmental impact of dumps and landfills extends beyond their physical footprint, highlighting the need for responsible waste management practices to mitigate these adverse effects. (Mutasem El-Fadel*et.al* 1995). The initiative in MC, Shimla aims to address escalating solid waste production and environmental concerns due to inadequate waste management. Objectives include assessing waste generation and composition, as well as analyzing the environmental impact during disposal in landfills and waste-to-energy plant processes.

2. Methodology

2.1Study Area

Shimla, nestled in the Central Himalayas, was discovered by the British in 1819 and has transformed from a small hill settlement into a popular tourist destination in India. Positioned between 31º 4' to 31º 10' north latitude and 77º 5' to 77º 15' east longitude, the city features rugged mountains, steep slopes, and deep valleys at an altitude of 2130 meters above sea level. Shimla experiences cold winters with temperatures ranging from 0-13ºC, including snowfall around Christmas. Summers (May – June) are mild, ranging from 20-30ºC, while the monsoon season lasts from June to September with moderate rainfall. Shimla Municipal Corporation is one of the oldest municipalities of India and dates back to 1851.The Municipal Corporation of Shimla, covering an expanded area of 35.00 sq km, faces challenges in waste management, particularly in hilly terrain. The amalgamation of New Shimla, Totu, and Dhalli areas has expanded its jurisdiction to 34 wards, addressing both urban core and fringes. Solid waste issues affect urban forests and storm water drainage, impacting the aesthetic appeal and causing scavenging problems. Human-monkey conflicts are reported, with waste management identified as a potential solution. Despite intangible challenges, Shimla's tourism industry continues to grow, emphasizing the need for effective waste management to mitigate environmental issues and enhance the city's appeal. (Chauhan &Pirta, 2010 and UNDP, 2012).

2.2 Data Collection

The data collection approach in this study is comprehensive, incorporating both primary and secondary sources. Primary data is obtained through direct engagement with relevant individuals, employing interviews, group conversations, and semi-structured questionnaires. The researcher conducted physical field visits to the Waste to Energy Plant, personally observing operations and processes. Water samples from downstream areas and hand pumps were collected for groundwater analysis. Additionally, secondary sources, including scholarly work, documentaries, journals, articles, and books, were extensively leveraged to enrich the research.The study employs statistical analysis, specifically a linear model, to quantify correlations between solid waste generation and population rise, GDP, and per capita income in MC Shimla. The forecasting of municipal solid waste generation involves mathematical calculations based on estimating future population trends. The impact of landfills on water quality and ambient air analysis from waste to energy plants is monitored for environmental impact assessment.The water sampling procedure for assessing the landfill's impact on water quality involves taking samples from downstream locations in Bhariyal at Tara Devi Totu Bye Pass Road during the monsoon season. Overall, the research employs a multifaceted methodology to comprehensively analyze and forecast municipal solid waste generation and its environmental impacts.The water sample analysis conducted at the Regional Laboratory of the State Pollution Control Board in Shimla involved the examination of various physicochemical parameters to assess water quality. Plastic Jerry cans with stoppers were used for sample collection, treated with nitric acid, and autoclaved for preservation. The analysis covered parameters such as pH, turbidity, total dissolved solids, total hardness, conductivity, alkalinity, chlorides, nitrates, fluorides, heavy metals, and biological indicators.

The testing methods for temperature involved immersing a thermometer directly into water samples, while turbidity was determined using a nephelometer. The pH was measured using an electrometric method employing a glass electrode. Total hardness was assessed through the EDTA method, where chelation reactions with metal ions were exploited. Chlorides were determined by titration with silver nitrate, and alkalinity was measured using sulfuric acid with indicators like phenolphthalein and methyl orange.Additionally, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were employed to gauge organic pollution, with BOD representing the oxygen consumed by microorganisms over five days and COD indicating the oxygen required for chemical oxidation. The presence of faecal coliforms, used as indicators of fecal contamination and potential pathogens, was assessed using the Most Probable Number (MPN) technique. Monitoring these parameters is essential for ensuring water safety and adhering to regulatory standards.

3. Result & Discussion

The Municipal Corporation of Shimla (MC Shimla) plays a significant role in solid waste production, contributing 38-78 Metric Tons per day (MTPD). Over the past decade, solid waste generation in MC Shimla surged from 38MTPD in 2013 to 78MTPD in 2023, marking a 10.53% annual increase (Fig.1). Notably, a temporary decline occurred in 2020-2021 due to the COVID-19 pandemic, attributable to lockdowns, reduced economic activity, and altered consumption patterns. The correlation analysis reveals that municipal solid waste generation in Shimla is linked to economic factors, with positive correlations observed with District Domestic Product (DDP), per capita income, and population growth (Fig.3). This underscores the impact of economic and population growth on solid waste generation trends in urban areas, necessitating sustainable waste management strategies to address this upward trajectory.

The regression study conducted in MC Shimla reveals a positive correlation between solid waste generation and factors such as population growth, GDP, and per capita income. Notably, the strongest connection is identified between waste output and per capita income, indicating that per capita income has the most significant impact on the quantity of waste produced (Fig.4). The implication is that as per capita income increases in MC Shimla, there is a corresponding rise in garbage production. This relationship is attributed to factors like elevated spending capacity, shifts in consumer behavior, and heightened demand for goods and services associated with higher income levels, leading to increased waste generation. (Table.1) shows the growth trend in population and solid waste generation in coming 3 decades. Population and solid waste generation increased 34% from 2011 to 2021 and 26% from 202 to 2031 and 16% from 2031 to 2041 respectively.

Shimla town's municipal solid waste composition reveals a substantial presence of recyclable and compostable materials. The informal sector, represented by rag pickers, actively collects recyclables like paper, plastic, metals, glass, and rubber from streets, bins, and disposal sites. The data indicates that organic waste constitutes the majority, comprising 56% of total garbage, predominantly composed of food and garden waste. Following closely is paper waste at 10%, encompassing cardboard, newspapers, and office paper. Plastic waste holds a significant share at 13%, emphasizing the notable role of plastics in the waste stream. Glass and metal waste contribute 4% and 2%, respectively, with glass bottles and various metallic objects prominent in this category. An "Other" category, comprising 15%, underscores the existence of diverse waste types requiring specific waste management strategies. This breakdown sheds light on the town's waste landscape, urging tailored measures for effective waste disposal and recycling (Fig.2).

The management of municipal solid waste (MSW) in Shimla Town poses significant challenges, requiring effective solutions for the sake of environmental protection, public health, and the overall quality of life for citizens. The MSW (Management and Handling) Rule 2000 emphasizes the need for economically and environmentally friendly MSW management. The responsibility for managing MSW in Shimla Town falls on the Municipal Corporation. To address this issue at the local level, Shimla Town established the Shimla Environment Heritage & Beautification (SEHB) in 2009. SEHB operates at the ward level and is led by the corporation commissioner of Shimla Town, with its members including ward council members and the secretary of the Corporation Health Office.

Currently, Shimla Town generates approximately 82 tons of MSW per day, with collected garbage ranging from 60 to 85 metric tons per day. On a per-person basis, the town produces 350 grams of garbage daily. The collection methods include door-to-door collection and community bins, contributing to an overall collection of around 85 metric tons of rubbish. The implementation of effective MSW management is crucial to address the complexities associated with waste disposal in an urban setting.(SPCB report, 2020-21).The Door-to-Door Waste Collection Bye-laws were established in 2006 in Shimla, and the Municipal Corporation (MC) has since made efforts to implement effective waste management. The Shimla Environment Heritage Beautification (SEHB) Society plays a key role in collecting household waste through door-to-door collection in selected wards. Two colored bins, yellow for non-biodegradable and green for biodegradable waste, are provided to homes and businesses for primary storage and sorting.The success of the program is attributed to micro-planning, administrative decisions, financial sustainability, legal protections, and end-user acceptance. The SEHB Society manages its human resources efficiently, providing waste collectors with personal protective gear and organizing them into groups, including married couples in the same ward. The Shimla Municipal Corporation has imposed penalties for violating waste disposal laws, ranging from Rs. 500 to Rs. 5000.

Shimla has stringent regulations against plastic usage due to the Himachal Pradesh Non-Bio-degradable Garbage (Control) Act of 1995 and the 2011 Notification on Plastic Waste (Management and Handling) rules. The municipality also enforces laws related to hazardous and biomedical waste. While door-to-door collection serves most residents, 15% rely on community bins. The SEHB Society covers all 34 wards, but the percentage of the population serviced varies. A labor scarcity has led some regions to have private waste collection systems alongside SEHB personnel. Commercial establishments, like hotels and offices, manage their waste independently. The secondary collection system involves community bins, and the municipality is replacing traditional methods with wire mesh structures to prevent scavenger access. Shimla, considered a dumper-free city, relies on 15 dumper containers with a 4.5 Cum capacity. The frequency of clearing these bins varies, and concrete bins and dumper containers are strategically located for easy access. In certain wards, burning and open dumping of waste were prevalent, but the introduction of municipal bins has addressed the issue in some areas. Overall, Shimla's waste management system involves both door-to-door collection and secondary collection methods to ensure proper disposal and minimize environmental impact.

Step II(Transportation) :The Shimla Municipal Corporation (SMC) manages waste transportation from secondary collection points to the Bhariyal treatment facility and landfill. With 64 vans of varying capacities, 25 purchased under JNNURM, and 34 under the smart city initiative, SMC employs hydraulic and non-hydraulic pickups, dumper placers, auto-tippers, and back-loaders. Bhariyal, a PPP with Elephant Energy Pvt. Ltd., processes waste from 34 wards. SMC aims to enhance door-to-door waste pickup, eliminate conventional storage, and address monkey intrusion. Currently, only 11–12% of generated waste reaches the processing facility, necessitating improved infrastructure, increased workforce, and daily removal for success. SMC, aided by GIZ, devised a ward-level routing plan for efficient waste collection and loading. Manual loading at the primary level will transition to drop systems in remote areas for direct pickup.

The Waste-to-Energy Plant in Shimla, established through a 20-year agreement between the Municipal Corporation of Shimla (MC Shimla) and Elephant Energy Pvt. Ltd., is a key initiative for solid waste disposal and renewable energy production. Located at an altitude of approximately 5000 feet above Mean Sea Level, the plant aims to address waste management challenges by converting municipal solid waste into energy.

Operational details of the plant involve the processing of 100 tons of waste daily, with 50 tons transformed into Refuse Derived Fuel (RDF) through shredding and sorting processes. The RDF serves as the primary fuel for combustion within the plant, generating heat utilized in subsequent processes to produce electricity. The facility employs a gasification process, subjecting solid waste to high temperatures and controlled oxygen levels, converting it into synthesis gas (Syngas). This Syngas, composed mainly of carbon monoxide and hydrogen, is used for heat production and electricity generation.

The plant comprises five 300 kW engines responsible for converting RDF into electricity. Gasification, a crucial aspect, involves the conversion of carbonaceous raw material into Syngas, which has versatile applications. The complete process includes vehicle weighing, waste dumping, manual sorting, JCB extraction, sorting conveyor belt, ballistic separation, magnetic separation, shredding, drum drying, and RDF production. The RDF production process is intricate, involving multiple stages such as manual sorting, ballistic separation, magnetic separation, shredding, drum drying, and eventual RDF production. The RDF, with a high calorific value, can be used as a fuel source for electricity generation. Additionally, MC Shimla sends approximately 25-30 MTPD RDF to a Cement Plant as an alternative energy source. The gasification process results in Syngas with a temperature of approximately 900°C, which undergoes air pollution control through devices like primary cyclone filters, primary venturi scrubbers, secondary cyclone filters, secondary venturi scrubbers, and a catalytic converter before being released through the exhaust stack. This meticulous process not only addresses waste management but also contributes to sustainable energy production in Shimla. A thorough analysis by the H.P. State Pollution Control Board at the Waste to Energy Plant, Bhariyal Landfill Site in Shimla examined water quality downstream. The findings provide crucial insights into groundwater quality and safety, addressing environmental impacts associated with solid waste and landfill sites.

The water quality assessment downstream of a landfill site reveals crucial information about various parameters that impact environmental and public health. Alkalinity, measured at 380 mg/L, signifies the water's ability to resist pH changes, acting as a natural buffer against potential acidic inputs. This is crucial for maintaining stable pH conditions, minimizing acidification effects, and ensuring overall water quality. Cadmium concentration within permissible limits is a positive finding, indicating effective control over this heavy metal's impact on groundwater. Cadmium, released from industrial processes and waste sites, poses significant health and environmental risks. Keeping cadmium within limits prevents harm to aquatic life, potential bioaccumulation, and ensures safe water and food consumption for humans. Iron levels at 2.884 mg/L, below the permissible limit of 3.0 mg/L, suggest satisfactory water quality. Monitoring is necessary to maintain these levels and prevent taste, discoloration, and health concerns associated with excessive iron concentration. Nickel concentration at 0.210 mg/L, well below the permissible limit of 3.0 mg/L, reflects effective waste management, minimizing potential nickel pollution and ensuring water safety.Zinc concentration at 0.020 mg/L, significantly below the permissible limit of 5.0 mg/L, indicates successful waste management practices, preventing excessive zinc contamination and safeguarding water quality. Copper levels at 0.016 mg/L, below the permissible limit of 3.0 mg/L, assure water safety, as excess copper can lead to water quality issues and health risks. Total Suspended Solids (TSS) at 95.5 mg/L, slightly below the 100 mg/L limit, suggests acceptable water quality. TSS, originating from soil erosion and landfill leaching, can affect water clarity, but the current concentration poses no immediate concern. Low fluoride concentration at 0.14 mg/L, well below the 2.0 mg/L limit, ensures safe water consumption, avoiding dental fluorosis and health issues.

Chemical Oxygen Demand (COD) at 276 mg/L, exceeding the 250 mg/L limit, indicates high organic and inorganic pollutant influx, posing risks to aquatic life, human health, and water usability. Adherence to COD limits is crucial for environmental health and regulatory compliance. pH at 8.07 falls within the acceptable range (5.5–9.0), ensuring safe water for various purposes. Biochemical Oxygen Demand (BOD) at 10.0 mg/L, below the 30 mg/L limit, signifies low organic matter, ensuring safe water quality. Low Nitrate-Nitrogen (NO3-N) at 2.91 mg/L, well below the 10 mg/L limit, ensures safe water consumption. Fecal coliforms at 21.0 MPN/100ml raise concerns about water contamination, emphasizing the need for immediate attention, remedial actions, and effective waste management. Moving to ambient air quality around the waste-to-energy plant, Particulate Matters (PM) at 43.30 Mg/Nm3 within limits indicates effective control measures. Compliance with PM limits is crucial for air quality and human health (Table. 2, 3).

Table 1. Increasing trend of Population growth and solid waste management In SMC area.

Head/Year	2011	2021	2031	2041
Resident Population	1,69,758	2,56,883	3,49,361	4,18,296
Floating Population	76,000	1,00,000	1,25,000	1,50,000
Solid waste Generation(MT)	86.01	124.91	166.03	198.90

(Source- Projections: City sanitation plan for shimla)

Table 2. Sampling results of analysis of water samples downstream of landfill.

Sr. No	Parameters	Results	Units	Permissible limit	Remarks
1.	T-Alkalinity	380.0	Mg/L	NA	NA
2.	Sodium	72.5	Mg/L	NA	NA
3.	TDS	2014.0	Mg/L	NA	NA
4.	Potassium	37.2	Mg/L	NA	NA
5.	Cadmium	0.0	Mg/L	2.0	Within Permissible Limit.
6.	Iron	2.884	Mg/L	3.0	Within Permissible Limit.
7.	Nickel	0.210	Mg/L	3.0	Within Permissible Limit.
8.	Zinc	0.020	Mg/L	5.0	Within Permissible Limit.
9.	Manganese	0.266	Mg/L	NA	NA
10.	Lead	0.0	Mg/L	NA	NA
11.	Copper	0.016	Mg/L	3.0	Within Permissible Limit.

12.	TSS	95.5	Mg/l	100	Within Permissible Limit.
13.	Fluoride	0.14	Mg/L	2.0	Within Permissible Limit.
14.	Boron	0.11	Mg/L	NA	NA
15.	COD	276	Mg/L	250	Not Within Permissible Limit.
16.	Total Phosphate	0.026	Mg/L	NA	NA
17.	Total Hardness	451.0	Mg/L	NA	NA
18.	Ca++	133.87	Mg/L	NA	NA
19.	pH	8.07	Mg/L	5.5-9.0	Within Permissible Limit.
20.	Conductivity	4057.0	Micro Siemens	NA	NA
21.	Faecal coliform	21.0	MPN/100ml	NA	NA
22.	BOD	10.0	Mg/L	30	Within Permissible Limit.
23.	Turbidity	14.0	NTU	NA	NA
24.	Nitrate-N	2.91	Mg/L	10	Within Permissible Limit.

Table 3.H.P. State pollution control board report by state board analyst (Stack/Ambient Air Monitoring Report.)

Sr. No.	Parameter	Results	Units	Remarks
1.	Particulate Matters (stack)	43.30	Mg/Nm3	Within Limit

(Source- H.P. state pollution control board)

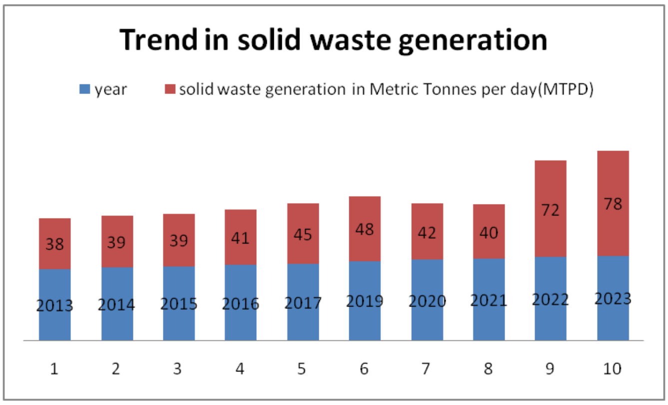

Fig. 1. Graph showing production of solid waste from 2013-2023.

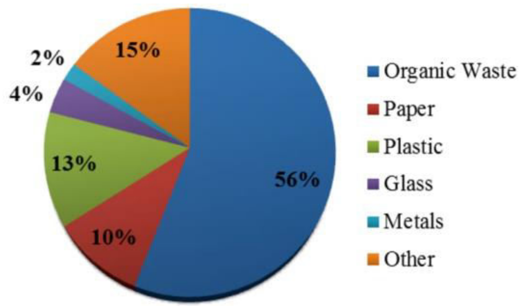

Fig. 2. Pie chart showing composition of solid waste in MC, Shimla.

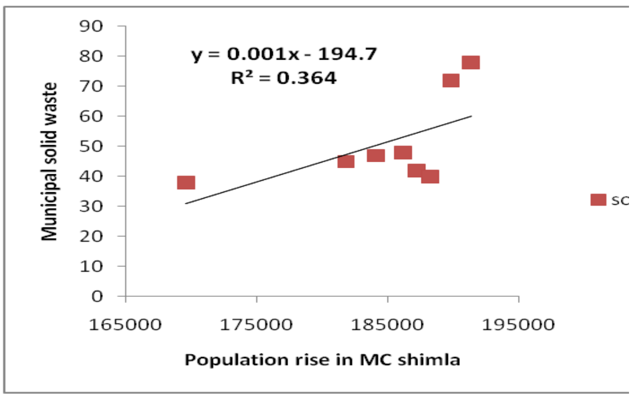

Fig. 3. Relationship between municipal solid waste generation and population from 2011-2023

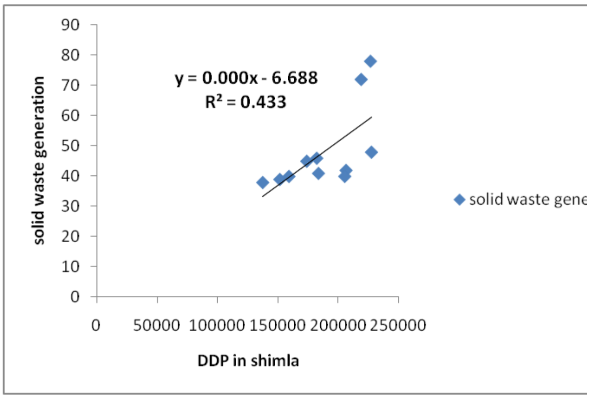

Fig. 4. Relation between municipal solid waste and DDP from 2011 to 2023**.**

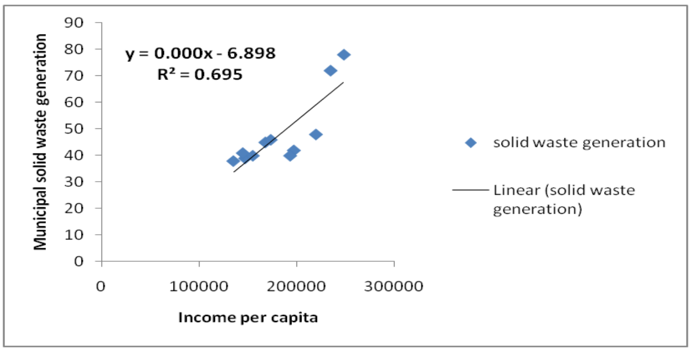

Fig. 5. Relationship between Municipal solid waste generation and per capita income increase.

In conclusion, while some parameters reflect positive outcomes, elevated COD levels and fecal coliform presence underscore the importance of robust waste management practices and continuous monitoring to safeguard water and air quality, environmental health, and regulatory compliance. The absence of methane emissions monitoring and gas recovery in the landfill site highlights areas for improvement in waste management practices to mitigate environmental impact. The current waste management practices in Shimla lead to wasted energy resources and missed opportunities for sustainable practices. A significant issue is the lack of waste segregation before sending it to the waste-to-energy plant, resulting in inefficiencies in waste processing. The high moisture content in the waste further hampers the plant's efficiency. Proper solid waste management, including household-level waste segregation, is crucial to prevent environmental impact and health hazards. Composting organic waste is emphasized as the best method for disposal. To address these challenges, several solutions are recommended, such as regular monitoring of methane emissions, establishing ambient air quality monitoring systems, installing a gas recovery system in landfills, conducting heavy metal analysis to prevent contamination, implementing effective waste segregation practices, and considering biological reactors for wet waste to optimize waste-to-energy conversion.

4. Conclusion

The data analysis conducted on solid waste generation in MC Shimla spanning from 2013 to 2023 reveals a substantial increase from 38MTPD to 82MTPD. This surge is attributed to the combined impacts of rapid economic development and population growth in the city. Correlation analysis establishes significant relationships between municipal solid waste generation and key factors like District Domestic Product (DDP), per capita income, and population, indicating that as Shimla's economy and urban population have expanded, so has the waste output. Notably, a temporary decrease occurred in 2020-2021 due to the COVID-19 epidemic. The findings underscore the urgency of effective waste management strategies to ensure environmental sustainability in Shimla. Despite challenges, the Municipal Corporation of Shimla and the Shimla Environment Heritage Conservation and Beautification Society (SEHB) are actively involved in managing municipal solid waste. The door-to-door waste collection system and community bins cover a substantial portion of the population, while a waste-to-energy plant in Bhariyal processes the collected waste, utilizing Refuse Derived Fuel (RDF) for electricity generation. The remaining waste is disposed of in a sanitary landfill. Shimla's solid waste management practices involve collection, transportation, processing, and disposal, emphasizing sustainability and resource recovery. Ongoing efforts focus on optimizing processes, enhancing efficiency, and improving infrastructure. Environmental monitoring ensures that 59 landfill sites and waste-to-energy plants comply with regulations. Water samples indicate compliance with permissible limits for most parameters, though there are slight concerns about Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS). Air quality monitoring at the waste-to-energy plant demonstrates effective control of particulate matter (PM) emissions, assuring minimal impact on air quality and public health. In summary, the comprehensive waste management approach in Shimla addresses challenges, emphasizing environmental compliance and public well-being.

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Conflict of Interest
The authors declare no conflict of interest regarding financial, commercial, legal, or professional relationships with organizations or persons that could influence this research.

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