Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 21 | No. 5 (Suppl) | pp. 2073-2087 | 2022

Original Research Paper | https://doi.org/10.46488/NEPT.2022.v21i05.005 | Open Access Journal

Seasonal Characterization and Possible Solutions for Municipal Solid Waste Management in the City of Patna, Bihar, India

F. A. Siddiqui*, R. Singh* and Prashant*†
*Department of Environmental Science, Central University of South Bihar, Gaya-824236, India
†Corresponding author: Prashant; drprashant@cub.ac.in

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 18-04-2022
Revised: 31-05-2022
Accepted: 22-06-2022

Key Words:
Municipal solid waste
Characterization
Moisture content
Calorific value

ABSTRACT

The present study aims to characterize the municipal solid waste (MSW) generated in the municipality of Patna, the second-largest city in Eastern India. MSW is heterogeneous and the composition varies with seasons and within the different parts of the city. MSW samples were characterized for the three different seasons Winter (November), Summer (May), and Monsoon (August) to select feasible waste treatment methods. The physical characterization indicates that the major fractions of the MSW were biodegradable (48.83%) and inert (18.26%), which shows variations in different seasons of about ~5%. On a seasonal basis, the chemical characterization of MSW revealed that the moisture content varies between 43.21% to 51.78%, and volatile matter between 20.18% to 29.45%. ash content between 20.20% to 26.23% and fixed carbon between 4.11% to 5.91%. The C/N was found to be between 15.81 to 28.84 and the calorific value lies between 1212 to 2627 kcal.kg^{-1} during different seasons. The characterization of MSW highlights the virtue of waste segregation at the source and developing an efficient MSW system, including the potential for recycling, composting, anaerobic digestion, and production of refuse-derived fuels (RDFs). The outcomes of the present study will be helpful for Patna Municipal Corporation (PMC) in the planning for implementing suitable waste treatment technologies for integrated solid waste management systems (ISWM).

INTRODUCTION

Globally, the population is increasing, resulting in the consumption of more and more resources. The industrial revolution promised that human resourcefulness could solve many problems. As the take-make-waste model of industrialization and resource consumption pattern disregarded environmental concerns, hence heaps of waste were added to the environment. Waste is an unnecessary evil and a byproduct of consumption and the outcome of most processes (Chen et al. 2020). The poorly managed waste is causing diseases, harming animals, choking sewers, polluting rivers and oceans, emitting Green House Gases (GHGs), local air pollution, and loss of revenues on tourism fronts (Kaza et al. 2018). It is said that a city, which is unable to manage its waste wisely is rarely able to manage its other services like health, education, or transportation (Hoornweg & Bhada-Tata 2012). In the fast-growing world, the poor handling and mismanagement of MSW in an unscientific manner has become an environmental threat and serious concern for local and central agencies in most developing nations (Parihar et al. 2017).

The waste management issues evolve as the countries and their cities in due course of time, educe from low-income to middle- and high-income economies (Kaza et al. 2018). Indian cities are experiencing continuous growth in population and urban expansion (Census 2011, Dinda et al. 2021). In the past decade, India has witnessed a growth of 31.8% in urban sprawl (Singhal et al. 2021). The total MSW generated by India is about 150847.1 tons per day (TPD). Out of the total waste generated, 96.8 % of waste is collected, and only 47% of the collected waste is treated (CPCB 2019-20). According to the latest report of the Central Pollution Control Board (CPCB), the rate of waste collection has increased but the amount of waste being treated is still on the lower side. The primary reason behind such a low rate of treatment is the unavailability of segregated waste and the lack of data on the physical composition and chemical characteristics of MSW at the city level, which eventually helps in setting up treatment facilities. Thus, the open dumping and burning of the MSW is the most preferable practice in India (Singhal & Goel 2021). Unscientific and improper municipal solid waste management (MSWM) coupled with inefficient and outdated practices, and techniques pose a serious threat to environmental and human health. So, there is an urgent need for proper quantification, upscaling segregation, and processing and treatment of waste following the concept of the circular economy.

Indian cities require a systematic way forward to channel the waste management system to cope with the ever-increasing volume of waste. The take-make-use-waste model does not support the treatment, processing, and recycling of the MSW; rather an ISWM approach shall be adopted as a sustainable waste management option. The ISWM is a comprehensive program encompassing waste prevention, recycling, processing, and safe disposal. It strives to make a balance between environmental effectiveness (waste prevention and reduction methods), social acceptability (behavioral aspects and citizen's awareness), and economic affordability (cost-effective processing and disposal methods) (Marshall & Farahbakhsh 2013). Furthermore, the Indian legislation named Solid Waste Management Rules 2016 (SWMR 2016) is in line with the concept of ISWM. Acknowledging the problem of waste shall be the very first step of the waste management program. The choice of treatment/ processing and disposal option depends on the quantity and characteristics of the MSW. Additionally, the information about characteristics of waste stream based upon seasonal variations aids in making an ISWM robust. In developing nations, it has been reported that the major fraction of MSW is organic waste (Srivastava et al. 2014). On average, Indian cities produce 41% of organic waste (Sharholy et al. 2008, Kumar et al. 2017). Studies on characterization based upon location, viz. household level, community bins, and dumpsite/landfill in developing countries, including India have been conducted (Azam et al. 2020, Rawat & Davey 2018, Sujauddin et al. 2008, Kumar & Goel 2009, Mboowa et al. 2017), but very few studies are available on the seasonal characterization of MSW. Some studies show that seasonal variation affects the MSW composition and characteristics (Sliusar et al. 2020, Singhal et al. 2021, Cheela et al. 2021, Ibikunle et al. 2020, Abylkhani et al. 2019, Sethi et al. 2013, Dasgupta et al. 2013, Gómez et al. 2009). There is a dearth of studies on seasonal variation of MSW characteristics at the city level. A study on the seasonal variation of MSW composition and characteristics may help in scheduling the capacities of the treatment and processing facility (Composting/ vermicomposting, ethanol production, biomethanation, and waste to energy i.e. WtE plants).

The present study was conducted in the capital city, Patna, one of the four upcoming smart cities in Bihar. There is a paucity of data on the seasonal characterization of MSW at Patna. This paper presents a detailed characterization of MSW on a seasonal basis to assess suitable waste processing techniques. The outcome of the present study will assist the policymakers of MSWM in making a way forward toward ISWM with a holistic approach.

MATERIALS AND METHODS

Study Area and its Sanitation Setup

Patna, the capital of Bihar is one of the oldest and second-largest cities in eastern India with a population of 1,683,200 (Census 2011). The city is situated between 25.5941° North and 85.1376° East geographical coordinates on the southern bank of the river Ganges. Being an entirely landlocked area, it enjoys a humid subtropical climate with quite hot summers (temperature 37-45 degrees Celsius) from

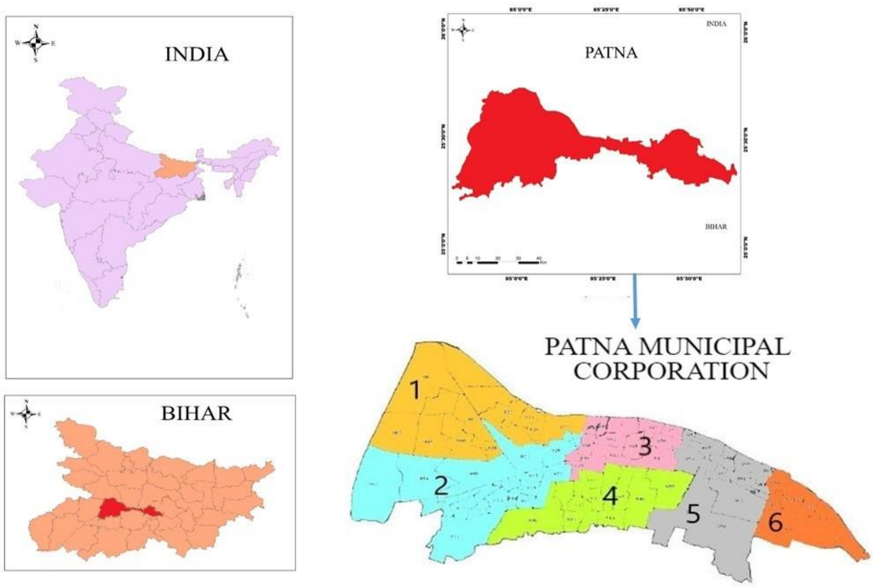

Fig. 1: Study area map with six divisions of PMC. Source: Created with software "ArcGIS 10.4.1 for Desktop".

March to June. The city receives an average rainfall of 1143 mm, from June to September and mild to chilly winters from November to February when the temperature falls up to 5 degrees Celsius.

Patna was also listed in the third round of the "100 Smart Cities Mission", an initiative of the Government of India (GoI) dated 23 June 2017 (MoUD 2017). Under *Swachha sarvekshann* (Cleanliness Survey), an annual survey of cleanliness, hygiene, and sanitation in cities and towns across India, Patna bagged 47th rank, the last among all the participating cities in 2020, and 44th out of 48 cities in 2021 (Faryal 2020, Tripathi 2021).

Solid waste management (SWM) in the city is under the Patna Municipal Corporation (PMC), one of the oldest civic bodies, established on 15th August 1952, in accordance with The PMC Act, 1951. The total area under PMC is around 109 km^2, divided into 6 divisions and 75 municipal wards (Fig. 1). Out of the total area of PMC, 47.55% comprises residential premises, which contributes to 49.56 km2. An effective SWM system is a labor-intensive service and relies upon adequate staffing (Gupta & Gupta 2015). The SWM hierarchy of PMC in the context of its supervisory and field officials is outlined in Fig. 2. As per the estimate, the city generates around 1105 TPD of MSW (BUIDCO 2020).

PMC initiated a door-to-door collection of MSW in 2018, and now this facility is being provided in all the wards of Patna. The primary collection (door-to-door) is done by PMC workers in open and closed tippers, electric tricycles, and hand carts. After primary collection, the waste is either transferred directly to the dumpsite or the transfer stations. Presently there is no treatment and processing facility for the collected waste. PMC is focusing solely on the collection and disposal of MSW in open dumpsites. The existing dumpsite (Bairiya) is an unlined dumping area of about 78 acres located on the northern side of NH 83. The present MSWM is depicted in Fig. 3. The civic body has started sensitizing the people about source segregation and cleanliness by engaging the citizens under the campaign named "one dream Patna clean" and "*Roko-Toko* (Stop and Nag)" to bring behavioral change and create a positive attitude among citizens towards SWM (Megha 2022). SWMR 2016 has made it mandatory to segregate the waste at the source of generation.

Sample Collection, Segregation and Preparation

The sampling of MSW generated in the city from all six divisions was done in accordance with ASTM D5231-92 (2016). As per this method, vehicles reaching the dumpsite from identified divisions were chosen randomly during each day of the one-week sampling period.

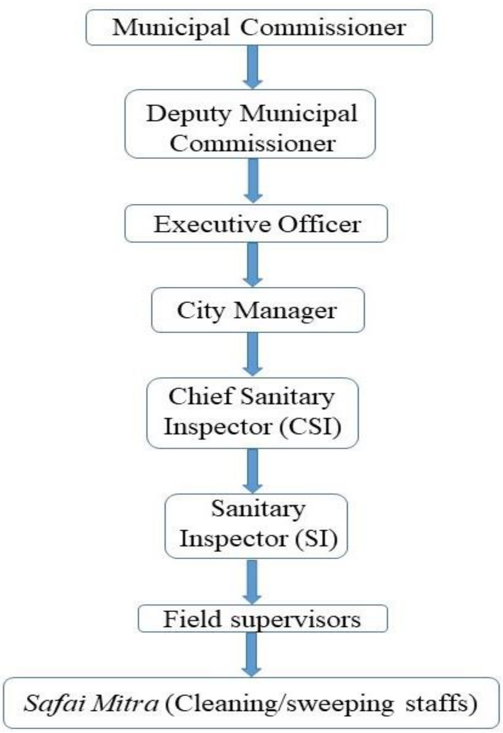

Fig. 2: Schematic representation of hierarchy of officials in PMC.

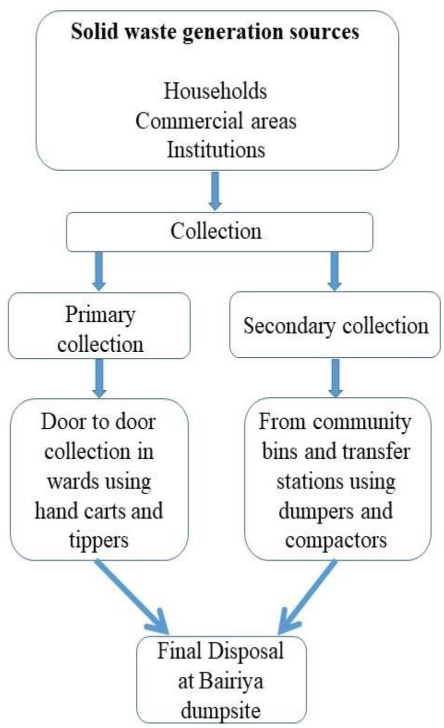

Fig. 3: Schematic representation of solid waste management in Patna.

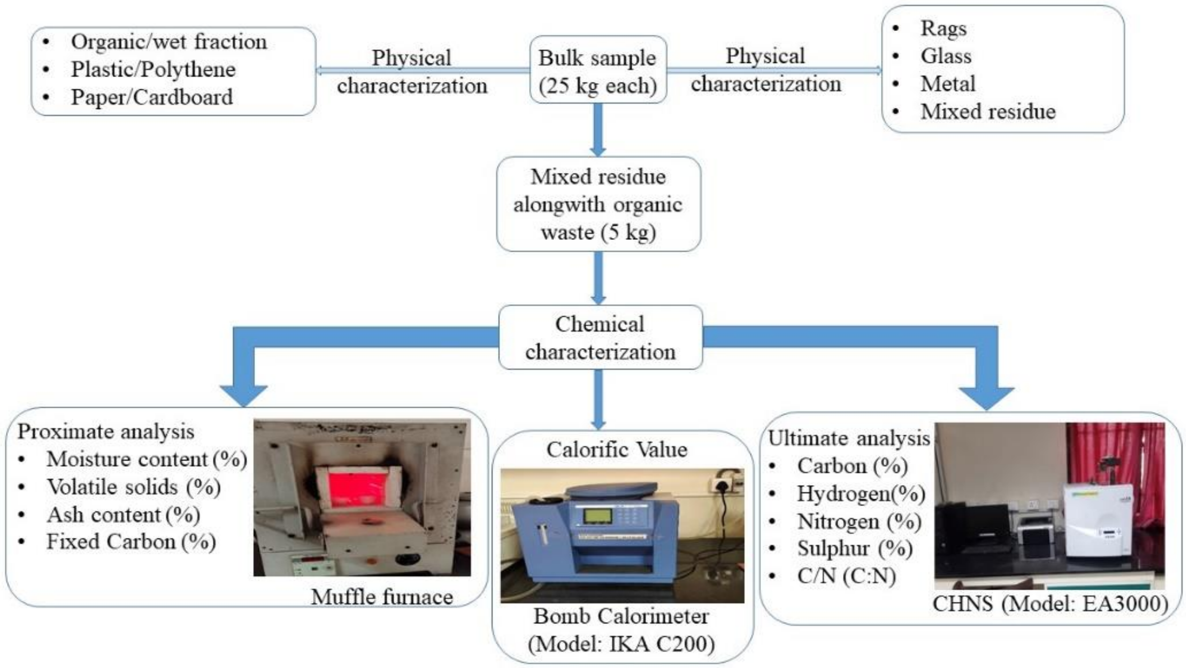

Fig. 4: Schematic diagram showing sample fractions and parameters analyzed and instruments used (Muffle furnace, Bomb calorimeter, and CHNS analyzer).

To acquire knowledge about the seasonal characteristics of MSW, the sampling was carried out for the three different seasons (Winter, Summer, and Monsoon) November, May, and August. The tippers/trucks reaching the dumpsite from the identified division were emptied by directing them to place their waste on a plastic sheet to prevent the co-mingling of underneath soil/waste. Around 100 kg of sample was collected from the waste placed on a plastic sheet for each identified division. The 100 kg of waste was collected from each division for a period of one-week sampling during each of the three seasons.

The Coning and Quartering method was implemented to obtain a representative waste sample. In this method, 100 kg of waste sample was mixed thoroughly to obtain a homogenous sample and later divided into four quarters. Further, two opposite quarters were removed and the remaining were mixed again. In this way, a representative sample of about 25 kg was obtained for each division for one week for the mentioned seasons. 5 kg of samples extracted from each representative sample were further analyzed for physical and chemical characteristics of MSW. A schematic representation of sample collection, segregation, and analysis has been presented in Fig. 4.

Physical Sorting and Composition of MSW Samples

The waste samples were hand-sorted manually with the help of waste handlers and staff present at the dump site. The samples were analyzed on a wet-weight basis. Various components like paper, polythene, plastic bottles, and other materials, milk pouches, tetra packs, concrete, stone, ash, glass, metals, soft drink cans, cartons, soiled textiles, etc. were segregated manually under the categories like organic/wet waste, plastics/polythene, paper/cardboard, soiled clothes/ textiles, glass, metal and inert or construction and demolition waste and street sweepings. The physical characterization of the MSW sample was determined seasonally for all six divisions. Different components obtained after segregation were weighed separately to obtain the percentage composition in the total waste sample.

Chemical Characterization of Collected Waste Samples

Chemical characterization of collected waste samples was done to examine their potential for different waste treatment methods including composting, incineration, and refused derived fuel (RDF). Chemical characterization includes two broad analysis procedures i.e. proximate and ultimate analysis. The proximate analysis is a specific measurement used to estimate the capability of MSW as fuel (Pichtel 2020) and in evaluating the combustion properties of waste. A limitation of the proximate analysis is that it does not indicate possible pollutants emitted during combustion. It was done to obtain the percent of moisture content, volatile solids, ash content, and fixed carbon by following the procedure described by Ibikunle et al. (2021) and Pichtel (2020).

Moisture content (MC)- The organic waste sample of 5 gm was taken into crucibles and dried in the oven at 105°C for 1 h based on ASTM D1348-94. The crucible with the sample was then cooled in a desiccator and weighed. The difference found in weight is moisture content denoted in percentage.

Volatile solids (VS)- The sample used for MC determination was then covered and heated in the muffle furnace at 950°C for 7 minutes, based on ASTM D3175-11. The sample was then cooled down and weighed. The loss in weight is taken as the percentage of volatile matter.

Ash content (AC)- It was determined by heating the remaining part of the sample in the crucible after VS estimation without lid/cover at 750°C for 30 minutes. The sample was then placed into a desiccator and cooled. The loss in weight is ash content.

Fixed Carbon (FC)- This, in the waste sample, was determined by subtracting the sum of MC (%), VS (%), and AC from 100 i.e. 100-(MC+VS+AC). The calorific value was estimated using the Bomb calorimeter (Model IKA C200). Samples were dried, ground, sieved, and made into pellets (1 gm) for energy estimation in terms of Kcal/kg.

The ultimate analysis is useful during mass balance calculations for chemical or thermal processes. The organic fraction of MSW is characterized through ultimate analysis for the determination of chemical composition. The ultimate analysis also includes the nutrient ratios, such as C/N for biological conversion processes such as composting. It involves percentage determination of total elemental analysis of Carbon, Hydrogen, Nitrogen, and Sulphur in dried samples. This was done using a CHNS analyzer (Model EA 3000) according to ASTM D3176-09. The organic sample was firstly air dried, ground to powder and again dried in a hot air oven at 105°C for 24-48 hours to remove all the moisture content.

MSWM IN PATNA: AT A GLANCE

Primary Collection and Street Sweeping

The sanitary workers (*Safai mitra*) associated with waste collection collect the waste in the morning, starting from 6 am in all six divisions (75 wards), and dump it at the nearest secondary collection/transfer station. The door-to-door collection and street sweeping are conducted in closed and open tippers respectively. In narrow and congested streets, hand carts and electric tricycles are used for waste collection. Each waste-carrying vehicle except hand carts and electric tricycles is equipped with a GPS device with a defined route for waste collection. Secondary collection points or transfer stations are open spaces provided by PMC located nearby residential areas without paved surfaces. Informal waste recycling activities are very common near secondary collection points/transfer stations. Rather than the transfer of waste from smaller to larger vehicles, no other facilities such as mechanical or manual sorting, recyclable material drop-off for citizens, and screening of MSW fractions are available at transfer stations. In some areas, these points are located near a dense population which creates a nuisance for residents. Primary collection is impeded when the vehicles used in waste collection or transportation break down.

Secondary Collection and Transportation

The secondary collection within the city is carried out using compactor trucks and open trucks (*Tata 407*), which carry the waste from secondary storage points to the Bairiya dumpsite (open dumpsite) for final disposal. The loading of waste into these vehicles is done by a skid loader, also known as a *bobcat,* or manually with the help of sanitary workers. Each division is provided with vehicle stands from where vehicles are operated and parked after waste collection. There are two vehicle workshops within the PMC boundary for the servicing and maintenance of vehicles in divisions 2 and 4 only.

Final Disposal of MSW

The fate of collected MSW ends up in an open dumping area, Bairiya dumpsite, surrounded by agricultural land. The site has been used for the last 25-30 years by the PMC. Approximately 1105 tons of MSW are dumped every day by the PMC (BUIDCO 2020). There are huge heaps of waste that can be seen from far away. The MSW dumped in the dumpsite is made to be spread by the poclain machine and leftover without proper soil coverage which causes a foul smell and unhygienic conditions. During the summer season, the case of fire breakouts occurs, releasing toxic fumes and creating a suffocating situation for onsite waste handlers and the nearby population. A weighbridge has been installed at the dump site for the quantification of waste being carried by the vehicles. There is no leachate collection system or groundwater monitoring well. Thus the leachate so generated may ooze into the soil and potentially contaminate the groundwater.

There are several infrastructures developed in very close proximity to the dump site. A school within 100 m, several godowns, and informal recycling centers with residences have been established (Fig. 5). SWMR 2016 states that groundwater monitoring well within 50 m and a buffer zone of no development activity around the dumpsite shall be maintained. As the dumpsite is surrounded by agricultural land, the associated farmers have issues with leachate runoff to their agricultural land.

Fig. 5: a) Poclain machines at the dumpsite, b) waste dumping, c) A school near the dumpsite; (Images captured during field/sampling work by researchers at different time-periods during 2021-2022 using camera model- Nikon D 3300).

RESULTS AND DISCUSSION

Physical Composition of MSW

The physical characterization of MSW is the first step and plays a crucial role in selecting waste management techniques. The results of the physical characterization of MSW of six divisions of PMC are presented in Table 1 and Fig. 6. It was observed that the organic waste (49%) remained the most prominent fraction during three different seasons in all the divisions, followed by inert (18.3%), plastic (11.3%), and paper (10.3%) (Table 1).

Rags and other waste constituted approximately 7.47% and 2.9% respectively. The presence of glass (.75%) in a low fraction in the MSW stream may be because of selling glass to the recyclers by generators and waste handlers/rag pickers in exchange for instant cash. Other studies carried out in eastern India (Kharagpur and Dhanbad), north-central India (Allahabad), and Silicon Valley of India (Bengaluru) reported 0.5%, 0.7%, and .65% of glass in MSW respectively (Sharholy et al. 2007, Kumar & Goel 2009, Mboowa et al. 2017, Ramachandra et al. 2018).

The metal fraction in MSW was 0.22% (Table 1). This negligible value indicates the practice of storing the metal at the household level and selling it to ragman (*kabaddi wala*). The manual scavenging of metal pieces by rag-pickers from secondary collection points or the roadside is also a reason for the lower percentage of metals in the MSW stream coming to the dumpsite (personal observations during sampling).

Seasonal Characterization of MSW

The variations in the composition of MSW in different seasons can be referred to the geographic location, climatic conditions, food consumption behaviors, cultural, and economic status, and religious events (CPCB 2012, Denafas et al. 2014, Ghosh 2017). As per Table 1 and Fig. 6, the difference in the seasonal variations was found in MSW components such as compostable, plastic/polythene, paper/cardboard, rags, and inert materials. Food residue or compostable fractions were higher in summer being, around 51.3% as compared to winter (46%) and monsoon (49.1%) seasons. The possible cause behind more food/compostable waste generation in summer could be the availability and

Table 1: Tabular representation of the physical composition of MSW for various divisions of Patna city on seasonal basis.

MSW Fractions		Div. 1	Div. 2	Div. 3	Div. 4	Div. 5	Div. 6	Average
Compostable/ organic	Winter	44.4	44.2	44.23	46	57	40.18	46.00
	Summer	51	51.5	48	52.3	59.5	46	51.38
	Monsoon	48.2	50.5	46.88	48.77	55.6	44.6	49.09
	Average	47.87	48.73	46.37	49.02	57.37	43.59	48.83
Plastic/Polythene	Winter	12.15	9.5	13.88	9.5	6.88	8.32	10.04
	Summer	16	14.8	17.7	14.6	10	7.15	13.38
	Monsoon	13	11.3	14	11.65	8.2	5.26	10.57
	Average	13.72	11.87	15.19	11.92	8.36	6.91	11.33
Paper/Cardboard	Winter	9	13.2	9.5	14.4	10	13.2	11.55
	Summer	8.3	8.6	7.8	7.28	6.2	9.66	7.97
	Monsoon	7.36	11	12	11.86	13.4	12.55	11.36
	Average	8.22	10.93	9.77	11.18	9.87	11.80	10.30
Rags	Winter	11.5	9.2	12.32	8.48	5.6	6.16	8.88
	Summer	7.6	3.6	8.5	7.2	5	5.25	6.19
	Monsoon	9.5	6.48	8	6.3	6.37	7.39	7.34
	Average	9.53	6.43	9.61	7.33	5.66	6.27	7.47
Glass	Winter	1.26	0	0.6	0.4	1.3	0	0.59
	Summer	0	1.5	0	1.3	1	2.3	1.02
	Monsoon	0	0	2.2	0	1	0.6	0.63
	Average	0.42	0.50	0.93	0.57	1.10	0.97	0.75
Metal	Winter	0.8	0.2	0.1	0	0.8	0	0.32
	Summer	0	0.2	0.1	0	0	1.6	0.32
	Monsoon	0	0.13	0	0	0	0.1	0.04
	Average	0.27	0.18	0.07	0.00	0.27	0.57	0.22
Inert	Winter	19.55	22.2	18.37	20.02	15.8	29.6	20.92
	Summer	13.33	16.4	14.4	16	13.3	26	16.57
	Monsoon	14.84	17.45	15.23	18.67	11	26.5	17.28
	Average	15.91	18.68	16.00	18.23	13.37	27.37	18.26
Others*	Winter	1.34	1.5	1	1.2	2.62	2.54	1.70
	Summer	4	3.4	3.5	1.32	5	2.04	3.21
	Monsoon	7.1	3.14	1.69	2.75	4.43	3	3.69
	Average	4.15	2.68	2.06	1.76	4.02	2.53	2.87

All the values are in percentage; *Includes waste like dry leaves, thermocol and coconut shells.

consumption of various fruits and peeled vegetables and their wastage due to rotting caused by high temperatures. A seasonal characterization study conducted in Guwahati city revealed that the MSW contained approximately 49% (Singhal et al. 2021) of compostable or food waste in the summer season, which is similar to the results found in the present study. Plastic or polythene wastes were found to be high during summer (13.38%) as compared to winter and monsoon seasons (10% and 10.57% respectively), which is likely due to the consumption of different types of drinks contained in plastic-made bottles (Sethi et al. 2013). Plastic ice cream cups were also found in high amounts. A study conducted by Cheela et al. (2021) in Vishakhapatnam has shown similar findings (9.39-9.86%), with no significant changes in plastic waste fractions in winter and pre and post-monsoon seasons. The paper/cardboard and soiled cloth/textile wastes were higher in the winter season being 11.5 and 8.8% respectively. During the winter season, several

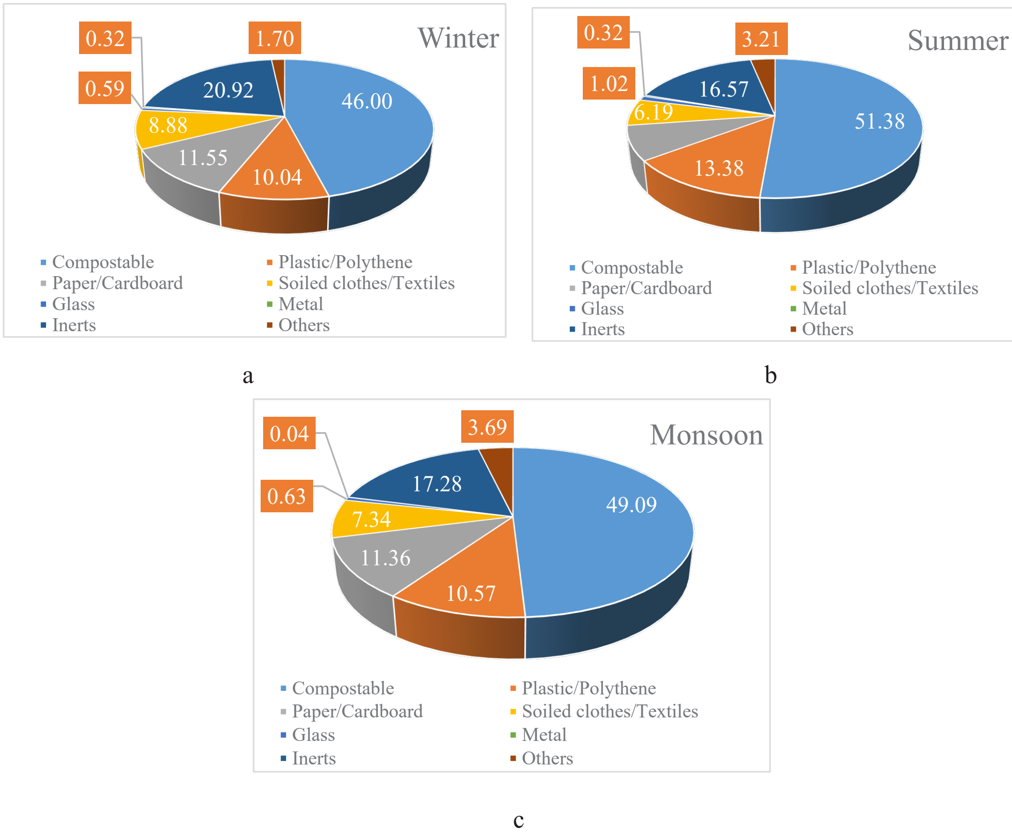

Fig. 6: Pie diagrams representing average variation in seasonal composition of MSW.

festivals are celebrated in this region of India such as *Diwali* followed by a festival named "*Chhath*" an ancient and most holy festival historically native to the Indian subcontinent, more specifically, the Indian state of Bihar. In the lead-up to these festivals, celebrants prepare for a month-long by cleaning, renovating, and decorating their homes and workplaces (Kumar 2008) which could be a strong reason for the generation of paper and rags during the winter season. Inert waste is the second most abundantly present component in the MSW stream. The inert waste contains sand, stones, concrete, ash, grits, and construction and demolition waste. The highest amount of inert waste was witnessed in the winter season (21%). The possible reason for this is the practice of burning wood, coal, etc. to get protection against cold. Local public administration also provides this facility along the roadside and at various nooks of the city for people which adds up during street sweeping to the inert material in the MSW stream. The other reasons for highly inert materials are unpaved roads, street sweeping, construction activities under smart area development projects, and dredging and cleaning of a storm drain (Miezah et al. 2015, Khan et al. 2016, Kumar et al. 2017). Several other waste components such as dry leaves, thermocol, and coconut shells were mostly found in higher quantities in the summer and monsoon seasons (3.21% and 3.69%).

Spatial Variation in MSW Composition

The mean values of different waste components based on the divisions in the study area are presented in table 3. Compostable waste fraction (CWF) is the major component of the MSW in each division. CWF fraction of 57.3% was significantly present in division 5, as this division has several vegetable markets and is attributed to the low-income group. The low-income group generates more CWF (Rana et al. 2018) as solid fuels such as coal, wood, briquette, and dung cakes are used for cooking purposes (Khan et al. 2016). The highest amount of plastic and rags wastes were found to be 15.3% and 9.61% respectively from division 3, which is dominated by commercial establishments, institutions, and offices. The major activities contributing to plastic waste generation are the use of plastics as packaging materials, bottling drinks, and carrying bags (Miezah et al. 2015). On the other hand, some area of division 3 is situated along the bank of the river Ganges which has several cremations ground that adds up to the rag fractions. The lowest CWF and highest inert fraction were found in division 6. It may be

Table 2: Division-wise population of PMC.

Div. 1	Div. 2	Div. 3	Div. 4	Div. 5	Div. 6
367053	313821	254090	282332	293356	173570

Source: PMC 2011; https://www.censusindia.co.in/towns/patna-population-patna-bihar-801373

Fig. 7: Transportation of sand in open tractor trolleys. (Image captured during field/sampling work by researchers at different time-periods during 2021-2022 using camera model- Nikon D 3300).

because of the considerably higher population in this division rear cattle and utilize the generated CWF as cattle feed. Hence linked to a comparatively lesser generation of CWF with the least population among all the divisions (Table 2). Inert waste was found in the highest quantity in divisions 2 and 6 due to infrastructure development (construction work) and sand mining along the banks of the river Ganges. The transportation of sand in open tractor trolleys causes spill-off on the roads as shown in Fig. 7 (taken during the field survey).

Chemical Characterization of MSW

The chemical characterization provides an insight into the percentage of elements present in the MSW, which further aids in deciding the appropriate treatment technology that needs to be incorporated (Rana et al. 2018). The results of the proximate and ultimate analysis are presented in Table 4 and Table 5 respectively.

The MC of MSW ranged between 43% to 52% across the seasons. The data on MC helps develop suitable methods for the treatment of MSW (Cheela et al. 2021). The earlier study for Indian cities with a population between 1-2 million reported the MC between 25% - 65% (Kumar et al. 2009). In a study conducted in the Tricity region of Northern India (Chandigarh, Mohali, and Panchkula) the MC was reported

Table 3: Characterization of MSW on a divisional basis.

MSW Fractions	Div. 1	Div. 2	Div. 3	Div. 4	Div. 5	Div. 6
Compostable	47.87	48.23	46.20	49.02	57.37	43.59
Plastic/ Polythene	13.72	12.20	15.31	12.25	8.77	6.91
Paper/ Cardboard	8.22	10.93	9.79	11.91	9.87	11.80
Soiled clothes/ Textiles	9.53	6.43	9.61	6.03	4.99	6.27
Glass	0.42	0.54	1.13	0.13	1.10	0.97
Metal	0.27	0.18	0.07	0.00	0.27	0.57
Inert	15.91	18.82	16.07	18.56	13.03	27.37
Others	4.05	2.67	1.82	2.08	4.61	2.53

All the values are in percentage (%).

to be between 40% - 50% (Rana et al. 2018). The MC thus found in the Tricity region is quite similar to the present study. The high MC was observed in the Monsoon season, while the lowest was in the summer season. The high MC was due to rainfall. During the field visits, it was observed that most of the waste-carrying vehicles are not designed to meet the requirements of the existing situation and are incapable of achieving the design value. Additionally, due to uncovered transport of the MSW in the vehicle during rains, disposing of the MSW on wetland margins and urban sewer drains leads to high MC (43%-51%). The volatile solids (VS) were observed between 20%-29%. Based on the results of MC and VS, composting and biomethanation can be suggested as the MSW treatment option. Ash content was between 20% - 26%. The possible reason for the high ash content (26%) in the winter season could be the presence of inert material in this season. The ash content in the mixed waste sample from a dumpsite in Chennai was found to be 21% (Peter et al. 2019).

While looking into the elemental composition, Carbon (C) ranges between (16%-20%), Hydrogen (H) (1.6%-5%), Oxygen (O) (13%-17%), and Nitrogen (N) and Sulphur (S) together comprised of 1%. The Highest C content was found in division 5. It may be due to the presence of large vegetable markets and a holy place of Sikhs, *Gurudwara Patna Saheb*, where a large dining hall (*Langar Seva*) utilizing tons of vegetables and other natural foods is run throughout the year which leads to the generation of vegetable and food wastes. An optimum range of C/N ratio was observed in divisions 1 and 4, due to the segregation of waste at the secondary dumping/collection point for composting by PMC.

Thus, there exists a possibility of a decentralized approach to implementing composting and vermicomposting facilities in these divisions. However, the average C/N ratio

Table 4: Tabular description of proximate analysis of MSW.

		Div. 1	Div. 2	Div. 3	Div. 4	Div. 5	Div. 6	Average
Moisture	Winter	49	51.3	47	50.55	51.5	39.26	48.10
	Summer	47.5	45.6	43.3	48.25	42.6	32	43.21
	Monsoon	55.6	53	53.6	53.6	53.4	41.5	51.78
	Average	50.70	49.97	47.97	50.80	49.17	37.59	47.70
Volatile matter	Winter	17.7	20	22	20.6	20.15	20.64	20.18
	Summer	25.3	28	31	30.2	34.6	27.6	29.45
	Monsoon	16.3	28.6	24.8	22.45	22	29.8	23.99
	Average	19.77	25.53	25.93	24.42	25.58	26.01	24.54
Ash content	Winter	27.3	26	26.2	24.6	21.3	32	26.23
	Summer	20.65	20.4	20	17.3	17.5	33.6	21.58
	Monsoon	25.29	15.2	17.2	20.18	20.8	22.5	20.20
	Average	24.41	20.53	21.13	20.69	19.87	29.37	22.67
Fixed carbon	Winter	6	2.7	5.7	4.12	7.1	8.4	5.67
	Summer	6.5	6	5.6	4.95	5.6	6.8	5.91
	Monsoon	2.81	3.2	4.5	3.78	3.8	6.55	4.11
	Average	5.10	3.97	5.27	4.28	5.50	7.25	5.23

All the values are in percentage (%).

of the mixed MSW was low (23%) to be used directly for composting. It may increase and the optimum range of 30:1 can be achieved after segregation. The calorific value (CV) of the MSW from all the divisions during the studied seasons was in the range of 823-3839 kcal.kg^{-1} (Table 6). On average the estimated CV was 1700 Kcal/Kg. The CV, only during the summer season was in the range prescribed under SWMR 2016 (>1500Kcal/kg) for incineration or RDF generation. The CV was below the prescribed limit during the monsoon and winter seasons which may render the incineration and

Table 5: Tabular description of the ultimate analysis of MSW.

Elements	Div. 1	Div. 2	Div. 3	Div. 4	Div. 5	Div. 6	Average
Carbon	16.15	15.5	18.34	13.65	21.43	19.8	17.48
Hydrogen	3.9	4.55	3.74	4.68	2	1.6	3.41
Nitrogen	0.56	0.93	1.16	0.47	1.07	0.72	0.82
Sulfur	0.013	0.031	ND	ND	0.65	0.045	0.18
Oxygen	13.6	14.26	13.2	14	17.43	13.01	14.25
C/N	28.839	16.66	15.81	29.04	20.02	27.5	22.98

All the values are in percentage (%) except the C/N ratio.

Table 6: Seasonal variations in calorific value of MSW (in kcal/kg).

Divisions	Winter	Summer	Monsoon
Div. 1	1435	2540	1345
Div. 2	1223	2704	1035
Div. 3	1142	2887	1166
Div. 4	1546	3839	1673
Div. 5	1302	2458	1232
Div. 6	912	1336	823
Average	1260	2627.33	1212.33

WtE generation process. A WtE plant of 400 MW of green power is under the planning stage at the dumpsite (CPCB 2019-20). In this context, the government alongwith the civic body may have to adopt the latest and the most advanced technology for the thermal treatment of MSW which may require additional fuel (Wilson et al. 2012) and provisions for adequate fund allotment in the budget for waste management (CPHEEO 2016).

Existing MSW Processing Techniques in Patna

Composting

After the implementation of SWMR 2016 and the Swachha Bharat Mission, the PMC initiated the installation of composting plants in various areas within the boundary of the PMC. In the first phase of installation 15 such plants have been installed with an input load of 2000 kg and 500 kg capacity per day of biodegradable waste. The civic body has set a target to install 22 more composting plants in the city (Faryal 2021). Till now, no to very less potential buyers have been identified and the compost so produced is being stored. Composting in open windrows is preferred because of the ambient temperature of the city. In comparison with available MSW treatment technologies, from installation, and maintenance to operation, composting requires the lowest capital investment.

Waste Recycling

The PMC itself directly is not indulged in the recycling facility. The recycling activity is generally carried out by small or large-scale recyclers. Recyclable junk such as plastics, paper, cardboard, metals, and glasses are either sold directly by households or by waste handlers. Most of the recycling businesses flourish in the near vicinity of the waste dumping areas, as the waste pickers found abundant recyclable material there which they use to pick, sort, and sell for their livelihood.

In most developing nations, waste is perceived as a valuable resource for the informal sector. The scavenging activities by the informal sector where there is no established municipal structure in operation provide employment, reduce littering, increase the lifespan of the landfill, pollution is abated and ultimately, the flow of waste is reduced (Damghani et al. 2008, Monirozzaman et al. 2011, Ezeah et al. 2013). In India, there are around 2 million waste-pickers (Swaminathan 2018, Chaturvedi 2010) though some figures say that almost 40 percent of waste-pickers are less than 18 years of age (Swaminathan 2018). In the informal sector, activities are usually carried out by persons or family groups. Fig. 8 represents and describes the role of various sectors from bottom to top i.e. from waste picking (segregation) to processing and its use as raw material in manufacturing industries.

Suggestions and Possible Solutions for Enhanced SWM in Patna

The science of waste management is dependent upon the physical composition and chemical characteristics of the MSW. Presently, the established waste management system in Patna city follows a linear fashion which neither includes proper source segregation nor the pre-treatment of MSW (Fig. 9). There seems to be an urgent need to redesign the current MSWM system which should include appropriate waste treatment technology in compliance with

(Source: Modified Wilson et al. 2006)

Fig. 8: Hierarchy of informal sector recycling

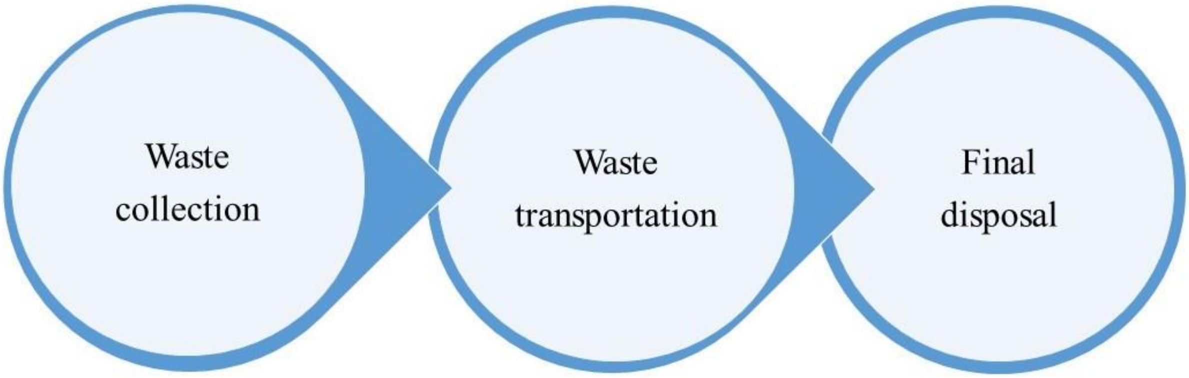

Fig. 9: Linear fashion of present waste management at Patna.

SWMR 2016. Based on the findings of the study following recommendations have been put forward.

Source Segregation and Collection of MSW

The segregation of waste at the source or household level is the first and crucial step for the successful implementation of available waste treatment technologies. The findings indicate that a large fraction of the MSW is organic and inert. Thus ensuring the segregation of MSW at the source of generation, scheduling of collection of recyclables at the household level and segregation facility at transfer stations to prevent the co-mingling during secondary collection and transportation is a dire need.

- The principal step in source segregation is educating, sensitizing, and creating awareness in the population at a massive level.
- Secondly, providing and implementing basic amenities such as two or three-bin systems for separate collection of waste is recommended.
- Additionally, Urban local bodies (ULBs) need to facilitate the infrastructure development and train the field staff for separate collection of waste to prevent the comingling of organic waste with inert fractions.
- The sources of inerts in the MSW stream are street sweepings, construction activities, sand, and grits from unpaved roads. A separate waste collection system must be implemented to ensure separate collection.
- The inert fraction so collected may be used for daily covers at landfills or dumpsites.
- The capacity of containers needs to be designed by the civic body based on the population density and waste generation rate.

Recycling and Recovery

Although recycling ranks third in the waste management hierarchy, it can be given priority as the recyclable fractions (22%) in MSW streams are present in noticeable amounts. However, recycling or recovery activities can be achieved at a higher potential only when the practice of source segregation is implemented strictly. The plastic recovery rate in India is estimated to be around 40% which is far better and much higher than in developed nations having only a recycling rate of 10-15% (Srivastava et al. 2005, Srivastava & Jain 2007, Sethi et al. 2013, Srivastava et al. 2014, Rana et al. 2018)

- SWMR 2016 suggests that the degradable (organic fraction) and non-biodegradable (recyclables/dry waste) shall be stored separately at the household level in separate bins and collected separately by ULBs. Thus, proper segregation of MSW can increase the potential for scientific treatment and disposal.
- Informal waste segregation by waste pickers was observed in several parts of the city and at the dump site. The PMC should focus on formalizing informal waste sectors by registering them under a state policy of SWM strategy with stakeholders including the representative of informal waste handlers.
- The segregation of recyclable materials and organic fractions of MSW by formalizing the waste recycling chain can provide a source of revenue generation that may be used for infrastructure development as well as a better-quality end product in the form of compost.

Anaerobic Digestion or Biomethanation

Anaerobic digestion (AD) is a process through which bacteria break down organic matter such as animal manure, wastewater bio-solids, and food wastes in the absence of oxygen that produces biogas and liquid slurry (Demirbas 2016). The composition of biodegradable waste (46%-51%) and MC (43%-51%) of MSW of the city along with humid weather, provide suitable conditions for AD. The C/N ratio

(23) and VS (25%) are somewhat low, and incompatible to favour the AD process. However, with proper waste segregation at the household level, the MSW can be used for AD. There is a difference in the composition of MSW within the different divisions of the city. Thus implementing a decentralized system for waste treatment by AD may reduce the transportation cost of the waste for final disposal to the dumpsite and hence burden on the landfill. The biogas thus produced may take the route to electricity generation or can be converted into biofuel.

Composting

Alternative to AD, several studies have recommended that composting (aerobic digestion) can play an important role in managing the biodegradable waste fraction of MSW (Giusti 2009, Rawat et al. 2013, Pathania et al. 2014, Mengistu et al. 2017). Except for a few fractions, almost all the compostable waste is dumped directly into the dumpsite in an unscientific manner.

- In this regard, composting could be seen as a suitable 'baseline' waste treatment method to be applicable in Patna city.
- The results of physical and chemical characterization of the MSW in the study area revealed that almost half the fraction of the total MSW generated is organic with high moisture content in the range of 43%-51% which makes composting an attractive and preferable waste treatment option.
- The average C/N ratio estimated in the study area was found to be 23 which is lower than the optimum C/N ratio for composting (30:1). Still, with proper waste segregation, the optimum range can be achieved.
- The leachate production in the dumpsite is mainly due to biodegradable waste. In this context, a decentralized composting mechanism can reduce the burden on dumpsites and thus, leachate production.

Refuse Derived Fuel

As mentioned in part II section 3 (ii) of the SWMR 2016, RDF is the combustible fraction of MSW that is converted into pellets by drying, shredding, dehydrating, and compacting. At present throughout the world, approximately 84% of the electricity is generated by burning fossil fuels, which is a non-renewable natural resource (Kumar & Samadder 2017). In this regard, RDFs seem to be an alternative and sustainable option to be co-processed with coal in large coal-based industries such as cement kilns and thermal power plants. However, there are several limitations to the co-processing and use of RDFs in industries because of irregular supply, lack of established practice, and retrofitting of the existing mechanism to make the present machinery use RDF as fuel. As per Central Public Health and Environmental Engineering Organisation (CPHEEO 2016), these shortcomings can be overcome by producing crude RDFs and transporting them to industries from multiple locations. Furthermore, based on specific requirements the crude RDFs can be refined by the industries themselves. There is a total of 129 RDF/palletization plants operational in India. Madhya Pradesh has 83, the maximum number of RDFs plants installed and operational till now (CPCB 2019-20).

The average CV of the MSW in the study area is also appropriate for the generation of good-quality RDFs. The PMC has started sorting legacy waste by installing trommel machines with sieving sizes of 8mm, 20-30 mm, and 40 mm at the dumpsite with a plan to segregate the fresh MSW shortly. The legacy waste thus segregated produces compost, fine earth, and crude RDFs. The crude RDFs is sold and transferred to the cement industry situated in the Aurangabad district of Bihar. The compost so produced is being purchased by the local farmers for their agricultural purposes.

CONCLUSION

The study is based on the seasonal characterization of MSW, which provides baseline data to outline the effective waste management strategy and best available MSW processing technologies for the city of Patna. In addition, the lacking and issues alongwith possible solutions in the functional elements of waste management have been discussed. The compositional analysis of MSW of the city of Patna shows the approximate average composition of biodegradable matter, plastic/polythene, paper/cardboard, rags, glass, metals, inert, and others to be 49%, 11.33%, 10.3%, 7.5%, 0.75%, 0.22%, 18.26%, and 3% respectively. The results of physical characterization revealed that the major fractions of the MSW stream were biodegradable (49%) and inert waste (18%). A difference of ~5% in the biodegradable, ~3% in the plastic/polythene, and ~3.6% in the paper/cardboard fractions of the MSW was observed during the winter and summer seasons. Inert fraction must be considered, as its presence in a high amount generally hinders the treatment process. The inert fraction which includes sand, street sweepings, and C&D waste, must be prevented from mixing up with the MSW and collected separately. Chemical characterization including MC, VM, AC, C, H, N, and S has also shown variations during three different seasons. The MC was highest in monsoon (~52%) while lowest in the summer season. The VM was found to be high during summers (~29%) while AC was high in the winter season (~26%). While looking into the energy content (CV) of the MSW, the average CV was determined as 1700 $kcal.Kg^{-1}$ which was noticeably highest in summer (2627 kcal.kg^{-1}) and lowest in monsoon season (1212 kcal.kg^{-1}).

The characterization of MSW in the study area unveils the fact that the ULB has several options for treatment technology. Composting alongwith vermicomposting facilities is simple, low budget, and easy to maintain technology is an urgent need to treat compostable waste. The city of Patna has content of recyclables such as plastics and papers which have a high potential for producing RDFs or to be used again by installing a formal chain supply of recycling facilities. Still, the practice of source segregation is the key step for strengthening the broader concept of waste to wealth. Currently, in the city of Patna, the MSW is present in mixed form, which makes the treatment quite difficult and costly. So, the city has to gear up to improve the SWM practices and increase the ranking in the Cleanliness survey (*Swachha Survekshann)* for holistic development including the concept of ISWM.

ACKNOWLEDGEMENTS

The authors are thankful to the University Grants Commission (UGC) for providing funding support as a Research Fellowship (NET-JRF/SRF) to the first author, Faiz Ahmad Siddiqui for completing this work as a part of his Ph.D. research. Furthermore, the authors are grateful to the municipal commissioner, Shri Keshav Ranjan Prasad for granting permission to collect samples at the landfill site. The cooperation and help extended by the onsite workers at the dumpsite are also acknowledged.

REFERENCES

Abylkhani, B., Aiymbetov, B., Yagofarova, A., Tokmurzin, D., Venetis, C., Poulopoulos, S., Sarbassov, Y. and Inglezakis, V.J. 2019. Seasonal characterization of municipal solid waste from Astana city, Kazakhstan: Composition and thermal properties of the combustible fraction. Waste Manag. Res., 37(12): 1271-1281.

ASTM Method D1348-94. 2008. Standard Method for Moisture in Cellulose. West Conshohocken: ASTM International.

ASTM Method D3175-11 2013. America Society for Testing and Materials, for Volatile Matters. West Conshohocken: ASTM International, 504-509.

ASTM. 2016. Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste. D5231–92. West Conshohocken, PA, USA: American Society for Testing and Materials.

Azam, M., Jahromy, S.S., Raza, W., Raza, N., Lee, S.S., Kim, K.H. and Winter, F. 2020. Status, characterization, and potential utilization of municipal solid waste as a renewable energy source: Lahore case study in Pakistan. Environ, Int., 134: 105291.

BUIDCO 2020. Tender notice for Patna and Gaya municipal corporations, Bihar Urban Infrastructure Development Corporation Limited, 1: 1-82. http://www.buidco.in/Application/TenderDoc/556_07-Nov-2020_Bid%20Document%20Patna%20n%20Gaya%20Part%201.pdf

Census 2011. Census of India 2011. Government of India. Provisional Population Totals. https://censusindia.gov.in/2011-prov results/paper2/data_files/india2/1.%20data%20highlight.pdf

Census 2011. Census of India 2011. Government of India. Provisional Population Totals. https://web.archive.org/web/20120507135928/http:/www.censusindia.gov.in/2011-prov-results/paper2/data_files/India2/+_2_PR_Cities_1Lakh_and_Above.pdf

Central Pollution Control Board (CPCB) 2020. Annual Report 2019-20 on Implementation of Solid Waste Management Rules, 2016. CPCB, New Delhi, pp 1-143.

Chaturvedi, B. 2010. Mainstreaming waste pickers and the informal recycling sector in municipal solid waste. Handling and Management Rules 2000. A discussion paper, WEIGO, Women in Informal Employment: Globalizing and Organizing, UK.

Cheela, V.R.S., Goel, S., John, M. and Dubey, B. 2021. Characterization of municipal solid waste based on seasonal variations, source, and socio-economic aspects. Waste Disp. Sustain. Energy, 3(4): 275-288.

Chen, D.M.C., Bodirsky, B.L., Krueger, T., Mishra, A. and Popp, A. 2020. The world's growing municipal solid waste: Trends and impacts. Environ. Res. Lett., 15(7): 074021.

CPCB 2012. Consolidated Annual Review Report on implementation of municipal solid wastes (management and handling) Rules, 2000, Central Pollution Control Board, New Delhi.

CPHEEO 2016. Municipal Solid Waste Management Manual (MSWMM) (Part I and II), 2016. Central Public Health and Environmental Engineering Organization (CPHEEO). Swachh Bharat Mission. 1(1).

Damghani, A.M., Savarypour, G., Zand, E. and Deihimfard, R. 2008. Municipal solid waste management in Tehran: Current practices, opportunities, and challenges. Waste Manag., 28(5): 929-934.

Das, S. and Bhattacharyya, B.K. 2013. Municipal solid waste characteristics and management in Kolkata, India. In The 19th International Conference on Industrial Engineering and Engineering Management (pp. 1409-1399). Springer, Berlin, Heidelberg.

Dasgupta, B., Yadav, V.L. and Mondal, M.K. 2013. Seasonal characterization and present status of municipal solid waste (MSW) management in Varanasi, India. Adv. Environ. Res., 2(1): 51-60.

Demirbas, A., Taylan, O. and Kaya, D. 2016. Biogas production from municipal sewage sludge (MSS). Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 38: 3027-3033.

Denafas, G., Ruzgas, T., Martuzevičus, D., Shmarin, S., Hoffmann, M., Mykhaylenko, V., Ogorodnik, S., Romanov, M., Neguliaeva, E., Chusov, A. and Turkadze, T. 2014. Seasonal variation of municipal solid waste generation and composition in four East European cities. Resour. Conserv. Recycl., 89: 22-30.

Dinda, S., Chatterjee, N.D. and Ghosh, S. 2021. An integrated simulation approach to the assessment of urban growth pattern and loss in urban green space in Kolkata, India: A GIS-based analysis. Ecol. Indic., 121: 107178.

Ezeah, C., Fazakerley, J.A. and Roberts, C.L. 2013. Emerging trends in informal sector recycling in developing and transition countries. Waste Manag., 33(11): 2509-2519.

Faryal, Rumi 2020. Patna last among 47 cities in Swachh Survekshann, The Times of India (ToI), August 21, 2020. Available at: https://timesofindia.indiatimes.com/city/patna/patna-last-among-47-cities-in-swachh-survekshan/articleshow/77660860.cms.

Faryal Rumi 2021. Patna to get 22 more waste composting plants: Civic body, The Times of India (ToI), March 12, 2021. Available at: https://timesofindia.indiatimes.com/city/patna/civic-body-patna-to-get-22-more-waste-composting-plants/articleshow/81454115.cms

Ghosh, S.K. 2017. Centre for regional development, Country Chapter. United Nations, NY.

Giusti, L. 2009. A review of waste management practices and their impact on human health. Waste Manag., 29: 2227-2239.

Gómez, G., Meneses, M., Ballinas, L. and Castells, F. 2009. Seasonal characterization of municipal solid waste (MSW) in the city of Chihuahua, Mexico. Waste Manag., 29(7): 2018-2024.

Gupta, N. and Gupta, R. 2015. Solid waste management and sustainable cities in India: the case of Chandigarh. Environ. Urban., 27(2): 573-588.

Hoornweg, D. and Bhada-Tata, P. 2012. What a waste: a global review of solid waste management. World Bank Publications, Washington DC.

Ibikunle, R.A., Titiladunayo, I.F., Dahunsi, S.O., Akeju, E.A. and Osueke, C.O. 2021. Characterization and projection of dry season municipal solid waste for energy production in Ilorin metropolis, Nigeria. Waste Manag. Res., 39(8): 1048-1057.

Ibikunle, R.A., Titiladunayo, I.F., Lukman, A.F., Dahunsi, S.O. and Akeju, E.A. 2020. Municipal solid waste sampling, quantification and seasonal characterization for power evaluation: Energy potential and statistical modeling. Fuel, 277: 118-122.

Kaza, S., Yao, L., Bhada-Tata, P. and Van Woerden, F. 2018. What a waste 2.0: a global snapshot of solid waste management to 2050. World Bank Publications, Washington DC.

Khan, D., Kumar, A. and Samadder, S.R. 2016. Impact of socioeconomic status on municipal solid waste generation rate. Waste Manag., 49: 15-25.

Kolekar, K.A., Hazra, T. and Chakrabarty, S.N. 2016. A review on prediction of municipal solid waste generation models. Procedia Environ. Sci., 35: pp. 238-244.

Kumar, A. and Samadder, S.R. 2017. A review of technological options of waste to energy for effective management of municipal solid waste. Waste Manag., 69: 407-422.

Kumar, K.N. and Goel, S. 2009. Characterization of municipal solid waste (MSW) and a proposed management plan for Kharagpur, West Bengal, India. Resour., Conserv. Recycl., 53(3): 166-174.

Kumar, P. 2008. Meri Khoj Ek Bharat Ki. ISBN -1240-4357-1-978 9. Archived from the original on 10 January 2022

Kumar, S., Bhattacharyya, J.K., Vaidya, A.N., Chakrabarti, T., Devotta, S. and Akolkar, A.B. 2009. Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: An insight. Waste Manag., 29(2): pp.883-895.

Kumar, S., Smith, S.R., Fowler, G., Velis, C., Kumar, S.J., Arya, S., Rena, Kumar, R. and Cheeseman, C. 2017. Challenges and opportunities associated with waste management in India. Royal Soc. Open Sci., 4(3): 160764.

Marshall, R.E. and Farahbakhsh, K. 2013. Systems approach integrated solid waste management in developing countries. Waste Manag., 33(4): 988-1003.

Mboowa, D., Qureshi, S., Bhattacharjee, C., Tonny, K. and Dutta, S. 2017. Qualitative determination of energy potential and methane generation from municipal solid waste (MSW) in Dhanbad (India). Energy, 123: 386-391.

Megha 2022. Swachh survey: PMC to boost public participation in cleanliness efforts, Hindustan Times (HT), February 14, 2022. https://www.hindustantimes.com/cities/patna-news/swachh-survey-pmc-to-boost-public-participation-in-cleanliness-efforts-101644808448169.html

Mengistu, T., Gebrekidan, H., Kibret, K., Woldetsadik, K., Shimelis, B. and Yadav, H. 2018. Comparative effectiveness of different composting methods on the stabilization, maturation, and sanitization of municipal organic solid wastes and dried fecal sludge mixtures. Environ. Syst. Res., 6(1): 1-16.

Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B. and Mensah, M.Y. 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Manag., 46: 15-27.

Moniruzzaman, S.M., Bari, Q.H. and Fukuhara, T. 2011. Recycling practices of solid waste in Khulna city, Bangladesh. J. Solid Waste Technol. Manag., 37(1): 1-15.

Parihar, R.S., Ahmed, S., Baredar, P. and Sharma, A. 2017. Characterization and management of municipal solid waste in Bhopal, Madhya Pradesh, India. Waste Resour. Manag., 170: 95-106. Thomas Telford Ltd.

Pathania, R., Bhardwaj, S.K. and Verma, S. 2014. Analysis of urban solid waste generation in Solan town and its bio-recycling through composting. Agric. Sustain. Develop., 2(2): 149-152.

Peter, A.E., Nagendra, S.M.S. and Nambi, M.I. 2019. Environmental burden by an open dumpsite in urban India. Waste Manag., 85: 151-163.

Pichtel, J. 2014. Waste management practices: municipal, hazardous, and industrial. CRC Press, Boca Raton.

PMC 2011. Patna Population, Religion, Caste, Working Data Patna, Bihar - Census 2011. https://www.censusindia.co.in/towns/patna-population-patna-bihar-801373

Ramachandra, T.V., Bharath, H.A., Kulkarni, G. and Han, S.S. 2018. Municipal solid waste: Generation, composition and GHG emissions in Bangalore, India. Renew. Sustain. Energy Rev., 82: 1122-1136.

Rana, R., Ganguly, R. and Gupta, A.K. 2018. Physico-chemical characterization of municipal solid waste from Tricity region of Northern India: A case study. J. Mater. Cycl. Waste Manag., 20: 678-689.

Rawat, M., Ramanathan, A.L. and Kuriakose, T. 2013. Characterization of municipal solid waste compost (MSWC) from selected Indian cities-a case study for its sustainable utilization. Scientific Research, 4: 163-171.

Rawat, S. and Daverey, A. 2018. Characterization of household solid waste and current status of municipal waste management in Rishikesh, Uttrakhand. Environ. Eng. Res., 23(3): 323-329.

Sethi, S., Kothiyal, N.C., Nema, A.K. and Kaushik, M.K. 2013. Characterization of municipal solid waste in Jalandhar city, Punjab, India. J. Hazard. Toxic Radioact. Waste, 17(2): 97-106.

Sharholy, M., Ahmad, K., Mahmood, G. and Trivedi, R.C. 2008. Municipal solid waste management in Indian cities–A review. Waste Manag., 28(2): 459-467.

Sharholy, M., Ahmad, K., Vaishya, R.C. and Gupta, R.D. 2007. Municipal solid waste characteristics and management in Allahabad, India. Waste Manag., 27(4): 490-496.

Singhal, A. and Goel, S. 2021. Spatio-Temporal Analysis of Open Waste Dumping Sites Using Google Earth: A Case Study of Kharagpur City, India. Springer, Cham, pp. 137-151.

Singhal, A., Gupta, A.K., Dubey, B. and Ghangrekar, M.M. 2021. Seasonal characterization of municipal solid waste for selecting feasible waste treatment technology for Guwahati city, India. J. Air Waste Manag. Assoc., 72(2): 147-160.

Sliusar, N., Polygalov, S., Ilinykh, G.I., Korotaev, V., Vaisman, Y. and Stanisavljevic, N. 2020. Seasonal changes in the composition and thermal properties of municipal solid waste: A Case study of the city of Perm, Russia. Environ. Res. Eng. Manag., 76(2): 54-64.

Srivastava, A. and Jain, V.K. 2007. A study to characterize the suspended particulate matter in an indoor environment in Delhi, India. Build. Environ., 42(5): 2046-2052.

Srivastava, P.K., Kulshreshtha, K., Mohanty, C.S., Pushpangadan, P. and Singh, A. 2005. Stakeholder-based SWOT analysis for successful municipal solid waste management in Lucknow, India. Waste Manag., 25(5): 531-537.

Srivastava, R., Krishna, V. and Sonkar, I. 2014. Characterization and management of municipal solid waste: a case study of Varanasi city, India. Int. J. Curr. Res. Acad. Rev., 2(8): 10-16.

Sujauddin, M., Huda, S.M.S. and Hoque, A.R. 2008. Household solid waste characteristics and management in Chittagong, Bangladesh. Waste Manag., 28(9): 1688-1695.

Swaminathan, M. 2018. How can India's waste problem see a systemic change? Econ. Polit. Week., 53: 16.

Tripathi, P. 2021. Bihar is last among 13 states in Swachh Survekshann; Patna at 44th position out of 48 cities, The Times of India (ToI), November 20, 2021. Available at: https://timesofindia.indiatimes.com/city/patna/bihar-last-among-13-states-in-swachh-survekshan-patna-at-44th-position-out-of-48-cities/articleshow/87821036.cms

Wilson, D.C., Rodic, L., Scheinberg, A., Velis, C.A. and Alabaster, G. 2012. Comparative analysis of solid waste management in 20 cities. Waste Manag. Res., 30: 237-254.