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Research Article

Composition and characteristics of excavated materials from a legacy waste dumpsite: Potential of landfill biomining

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ABSTRACT

Landfill biomining (LFBM) has been proposed as a viable method for the reclamation of legacy waste dumpsites as well as the subsequent recovery of valuable resources and land value spaces. Despite these advantages, the potential of LFBM faces a significant challenge due to the composition, characteristics and end-use of the excavated materials. This paper assesses the composition of the excavated waste obtained during the LFBM operation of the four legacy waste heaps at the Boragaon dumpsite in North-East India and determines the physicochemical characteristics crucial for the material and energy recovery from the key reclaimed fractions. The compositional analysis revealed that the proportion of combustible and non-combustible fractions decreases from the youngest heap HP4 to the oldest heap HP1 due to variations in the consumption habits of the local community and the inadequate recycling of recyclable materials. However, the proportion of fine fraction (FF) shows an increasing trend from HP4 to HP1, suggesting enhanced biodegradation of easily degradable waste over the years. The proximate and energy content analysis suggest that refuse-derived fuel (RDF) preparation is the most suitable valorization option for the combustible fractions since surface defilements are too high for good quality material recovery. The elevated amount of organic matter and leachable heavy metals indicate that unrestricted reuse of FF as earth-fill material can cause long-term settlements and groundwater contamination, respectively. Even though every dumpsite is different in characteristics, the findings of this case study can assist in developing new strategies for recycling excavated waste.

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INTRODUCTION

Open dumping of municipal solid waste (MSW) has been practised as a prevalent waste disposal method in most developing countries. It thrives because of the lack of appropriate technology, financial and human resources, coupled with the insufficient political will to improve the existing waste disposal practices. More than 90% of the MSW is disposed at non-engineered landfills or open dumpsites in India and other developing countries [1]. As a result, the existing dumpsites in urban India are overloaded with the heap of an extensive amount of legacy waste. These legacy waste dumpsites often lack of the necessary facilities and control measures to safely manage the gaseous and liquid by-products of waste decomposition [2]. It not only leads to human exposure to toxic chemicals via all three medium matrixes (i.e., air, water, and soil) but also causes significant pollution of these medium matrixes [3]. Moreover, natural anaerobic

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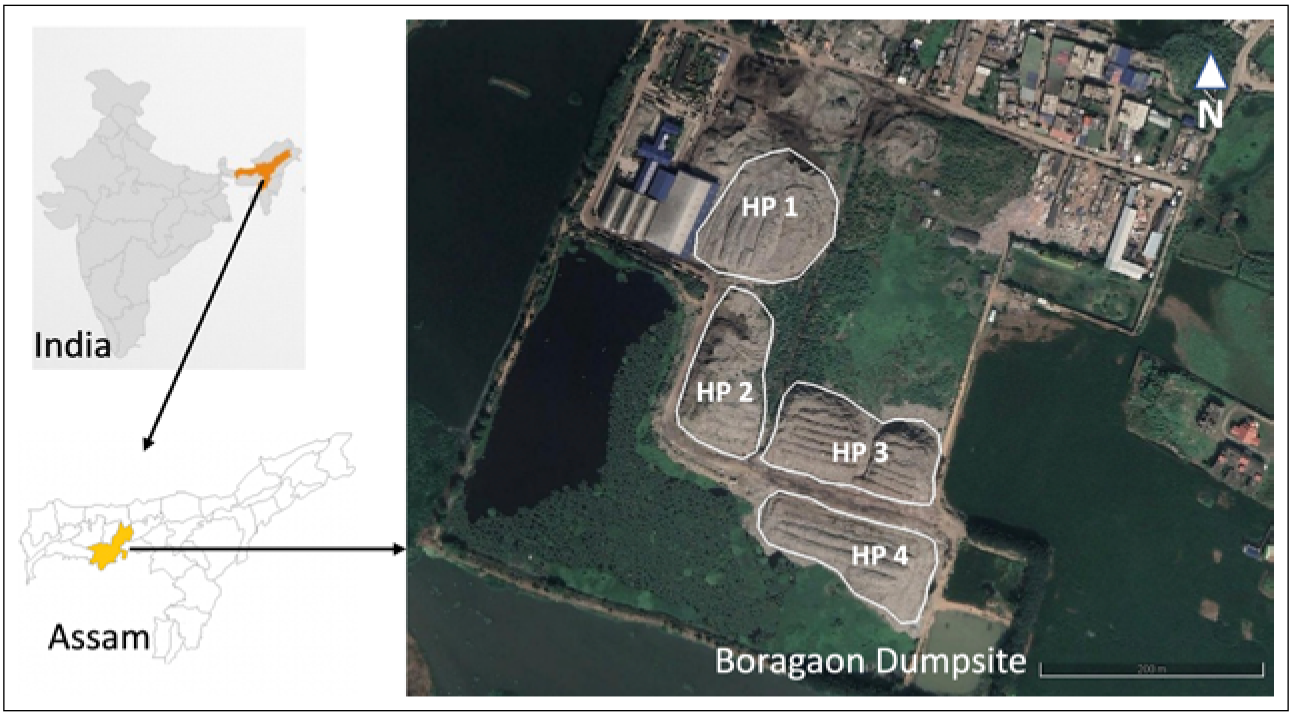

Figure 1. Map of the study area with marked heap locations (Source: Satellite image from Google Earth Pro, 2022).

decomposition of the MSW in the dumpsites releases greenhouse gases such as methane (CH_4) and carbon dioxide (CO_2), contributing nearly 80%–90% of the total landfill gas [4]. In terms of environmental risk, CH_4 is more dangerous since it has a global warming potential that is 28–36 times higher than CO_2 [5]. As a combustible gas, CH_4 also plays a significant role in fire incidents at dumpsites [6].

Indian cities are expanding to accommodate the increased population in such a way that waste disposal sites previously located in the suburbs have now become part of the city. Such disposal sites have emerged as one of the major concerns not only for environmental impacts and public health but also for the aesthetic beauty of the city [6]. Moreover, the landfill space requirement for the disposal of the MSW has increased and owing to this factor, the carrying capacity of the urban land leads to sustainability issues [7]. It has been reported that more than 10,000 ha of urban land is blocked by legacy waste dumpsites in India [8]. As a result, urban local bodies and municipal corporations are under pressure for the safe disposal of MSW. Considering the matter of sanitation seriously, the Government of India has launched Swachh Bharat Mission (SBM) to improve the health and safety of the population [9]. An integral part of this mission is cleaning up abandoned dumpsites to prevent further environmental degradation, reclamation of urban land and recovery of resources from the deposited waste. Landfill mining (LFM) is a viable method for accomplishing such goals in a sustainable manner [10]. In India, LFM is also referred to as landfill biomining, which involves excavation, stabilization and screening of dumped waste into different recoverable fractions [11]. With the help of LFBM potential, legacy waste dumpsites can also be retrofitted with sanitary infrastructure to mitigate environmental hazards.

Research on landfill reclamation and mining is being conducted worldwide to better understand the technical, financial, and societal limitations of this field. Waste composition and characterization are the most often discussed aspect of LFM research, as their potential depends on the energy and material recovery from the landfill's buried resources [12, 13]. The characteristics of waste rely on the composition of the dumped waste, which is influenced by a variety of factors, including the lifestyle of the local population, regional government regulations, the geographical location of the landfill, and climatic circumstances [14, 15]. Since the composition and characteristics of the waste vary from landfill to landfill and even within the landfill, one successful experience on an LFM project at one particular site need not be reproduced wholesale at another [16]. Therefore, it is necessary to conduct site-specific compositional and characterization analysis of the excavated waste in order to evaluate its potential for energy and resource recovery [17, 18]. A thorough understanding of the composition of the excavated waste and its treatability is also essential for planning appropriate treatment techniques for recoverable waste fractions in an LFM project. Previous literature shows that waste characterization studies yield crucial data for evaluating the potential of LFBM in India [11, 12]. Screening the waste based on distinct particle size categories and then physically or mechanically sorting at least the coarse particle into separate waste categories has been the primary method adopted in previous waste characterization studies [19]. During the characterization process, the physical and chemical properties of the segregated waste were also evaluated to identify the possible valorization routes of the waste component [12].

Figure 2. Onsite screening and segregation of the excavated waste.

Table 1. Parameters considered, methodologies adopted and instruments utilized for physicochemical characterization

Sample	Parameter/analysis	Method	Instruments used
Combustible fraction	Proximate analysis	USEPA 1684 and Dean 1974	Hot air oven and muffle furnace
	Gross calorific value	ASTM E711–87	Bomb calorimeter
FF	Moisture content	IS:2720 (Part 2)	Hot air oven
	Organic content	USEPA 1684	Muffle furnace
	Leaching potential	EN 12457-2, 2002	Rotary shaker and AAS

The present study aims to apprehend the composition of excavated waste from the recent LFBM project at Boragaon dumpsite in North-East India and to determine the physicochemical characteristics of key reclaimed fractions. The parameters crucial for the material and energy recovery from the excavated waste were the primary focus of the waste characterization. Recyclability and reuse feasibility were assessed by comparing the quality standards of waste fractions to the required quality criteria set by different regulatory agencies.

MATERIALS AND METHODS

Study Area

The dumpsite selected for the present case study is located at Boragaon (26°7'48" N, 91°39'36" E), near Guwahati city, in the Assam state of India. It has a land area of approximately (1×10^5) m^2 and consists of different waste fill heaps with filling heights varying from 3-3.5 m above the ground level, as shown in Figure 1 [20]. The non-segregated MSW collected by the city municipal corporation was dumped at the site since 2004. According to the information provided by the municipal authorities, approximately 1.7 million tonne of legacy waste is currently present at the site and distributed among those waste fill heaps. Waste disposal years for the selected heaps were as follows: Heap 1–2004 to 2008 (HP 1), Heap 2–2009 to 2012 (HP 2), Heap 3–2013 to 2015 (HP 3), Heap 4–2016 to 2019 (HP 4).

Compositional Analysis

During the LFBM operation, waste fill heaps were excavated and loosened up using hydraulic excavator, followed by spraying it with composting bio-cultures to hasten the decomposition of waste that hasn't been totally decomposed by microorganisms. Thus, the final product was not only become sterilized, stabilized and partially dry but also significantly reduced in volume. Stabilized waste was then fed into trommel screen, where it was segregated into three major fractions, i.e., combustible, non-combustible and FF as depicted in Figure 2. For compositional analysis, the mass of the excavated material feed into the trommel screen and the mass of the screened and segregated waste were measured. Subsequently, the composition of the screened fractions was further manually sorted into different subfractions, and the weight was determined. Since the FF was predominantly composed of degraded organic matter and could not be sorted manually, it was not separated into different streams. After hand sorting, representative samples of different subfractions and FF were collected in airtight polyethene bags and transferred to the laboratory to determine the physicochemical characteristics. Prior to analysis, the samples were kept in the laboratory at 4°C to prevent any alterations in the physicochemical properties.

Physicochemical Characterization

As combustible fraction and FF make up the majority of the total excavated waste, physicochemical characterization was mainly focused on these fractions to understand the possible energy recovery and waste-to-material valorization

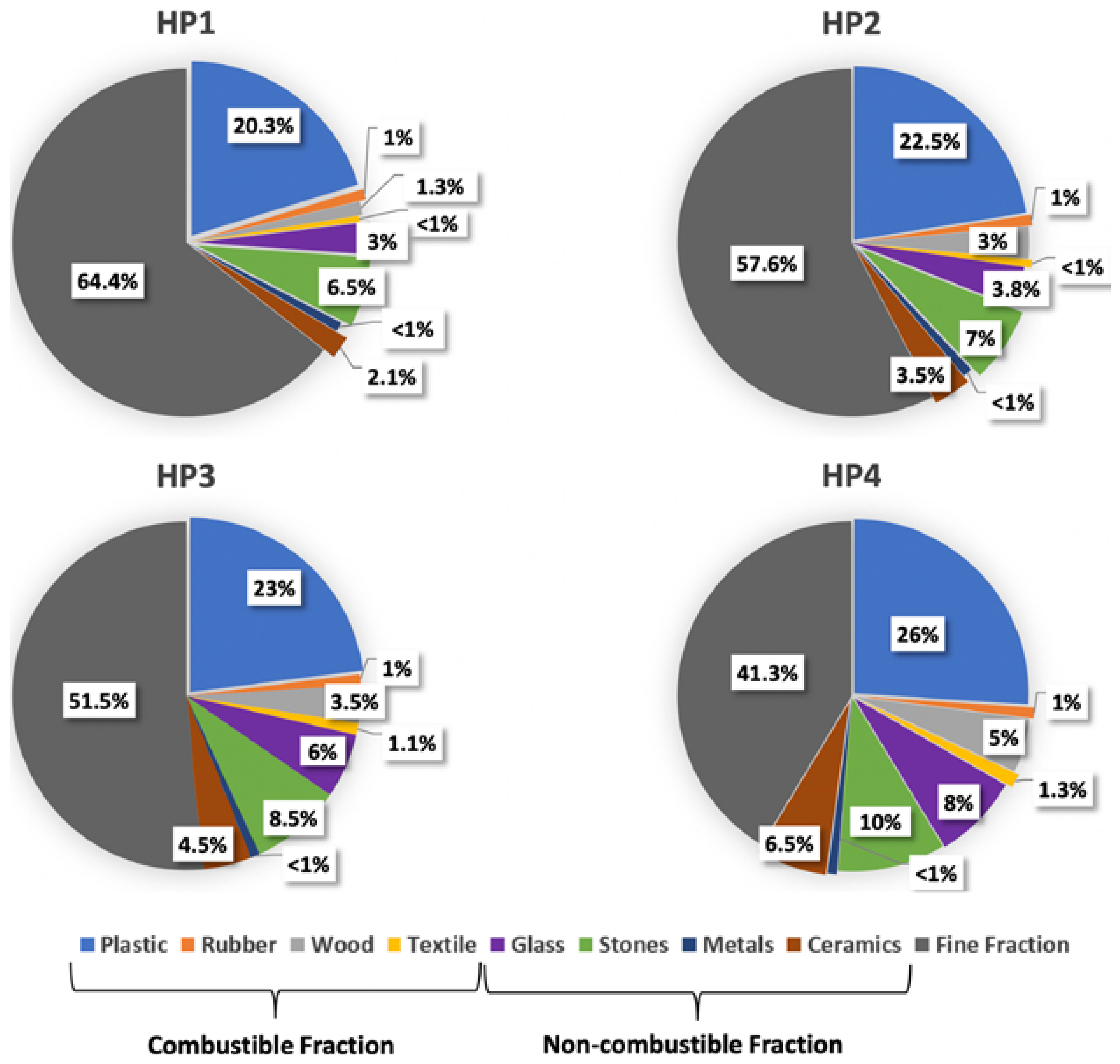

Figure 3. Composition of excavated waste from different heaps.

options. A brief overview of the parameters investigated, methodologies adopted and instruments utilized for the characterization study are shown in Table 1. For combustible fraction, proximate analysis and gross calorific value have been determined. On the other hand, moisture, organic matter, and leachable heavy metals concentration have been analyzed for FF. Proximate analysis was carried out in accordance with USEPA Method 1684 and Dean 1974 to measure the percentage of moisture, volatile solids, ash content and fixed carbon in combustible fractions [21, 22]. An automated bomb calorimeter was used to determine the gross calorific values according to ASTM E711–87 standard, and the results were expressed in MJ/kg [23]. The moisture content of the FF was assessed gravimetrically by heating about 500 g of sample to a constant mass in a thermostatically controlled hot air oven at 110±5°C, as per the IS:2720 (Part 2) (1973) [24]. The percentage of moisture content was then determined by calculating the difference between the pre-and post-drying weights. The organic content of the FF was determined by heating about 100g of dried sample in a muffle furnace at 550 (±50 °C) for 2 hours as per USEPA Method 1684 [21]. The percentage of organic material was then calculated by comparing the weight of the original dried sample to that after heating. To evaluate the preliminary environmental properties and possible utilization options for the FF, a batch leaching test was conducted according to EN 12457-2, 2002 [25]. As per the test procedure, the FF sample is mixed with deionized water at a liquid-to-solid (L/S) ratio of 10 L/kg dry matter for 24 hours. The eluates of the leaching test were then filtered through whatman 42 filter paper using a vacuum filtration unit. After that, extracts from the filtered eluates were analyzed for the concentrations of Cr, As, Mn, Zn, Cu and Al by atomic absorbance spectroscopy (AAS). All experiments were performed in triplicate, and the data are presented as mean with standard deviation values to ensure the reliability of the test results.

Table 2. Proximate analysis of the combustible fraction

Parameters	Sample locations				CPCB criteria for incineration
	HP1	HP2	HP3	HP4	
Moisture content (%)	22.1±0.3	24.6±0.7	27.8±0.4	36.5±0.6	<45%
Volatile matter (%)	41.2±0.4	42.4±0.2	46.5±0.3	50.1±0.4	>40%
Ash content (%)	30.8±0.5	25.9±0.4	18.1±0.5	5.8±0.2	<35%
Fixed carbon (%)	5.6±0.2	6.9±0.3	7.2±0.1	7.4±0.2	<15%

Mean±standard deviations, n=3.

RESULTS AND DISCUSSION

Composition of Excavated Waste

A heap-wise compositional analysis was conducted in the present study, and pie charts depicting the relative percentage (wt%) of various waste components were then created, as shown in Figure 3. Each pie chart was given a name that corresponded to the physical composition of the excavated waste of varying ages. HP4 represents the waste composition of the youngest heap, and HP1 represents the waste composition of the oldest heap at the dumpsite. It was found that the composition of waste significantly varied between the heaps depending on their ages. Since the composition of the inflow materials is crucial for the evaluation of resource potential and possible recovery routes, the excavated waste was shorted into different streams and categorized into three major fractions: 1) Combustible fraction, 2) Non-combustible fraction, and 3) FF.

Plastic, wood, rubber and textiles were considered as the combustible fraction found in the excavated waste. The result showed that the total amount of combustible materials gradually increased from 23% for HP1 to 33% for HP4. Plastic was the dominant component in the combustible fraction, contributing to 20.3%, 22.5%, 23% and 26% of the total waste for HP1, HP2, HP3 and HP4, respectively. The increment of plastic content from HP1 to HP4 demonstrates a rise in plastic usage over time. Because of the significant contamination, recycling plastic from excavated waste is a complicated process and may not be a cost-effective option. Therefore, the most efficient means of valorization of plastic is waste-to-energy conversion. The quantity of wood also increased from 1.3% for HP1 to 5% for HP4. The lesser mass fraction of wood in HP1 indicates its degradation over the years at the dumpsite, and the results are consistent with the findings of previous studies [16, 26]. No significant shift in the proportion of rubber and textiles was observed from HP1 to HP4. Unlike other studies, the paper fraction in the present study was almost absent for all the heaps.

An increase in the percentage of non-combustible fraction (12.5% for HP1 to 25.4% for HP4) was observed in the younger heaps. The most dominant component in the non-combustible fraction was stones, followed by glass, ceramics and metals. The stone content accounts for 6.5%, 7%, 8.5% and 10% of the total waste for HP1, HP2, HP3 and HP4, respectively. After appropriate pre-treatment, this fraction can be put to use in the construction sector [12]. Comparing the excavated waste from HP1 and HP4, a much higher percentage of glass and ceramics was found in the HP4. This may be due to the inadequate recycling of these materials by informal sectors, which results in the disposition of recyclables at the dumpsite. The negligible percentage (<1%) of metals in all the heaps could be attributed to a very efficient traditional (informal) collection system of scrap metal from households by waste collectors, often locally called 'Kabadiwalas' [27].

The proportions of FF were 64.4%, 57.6%, 51.5% and 41.3% of the total excavated waste for HP1, HP2, HP3 and HP4, respectively. This result indicates that the proportion of FF increases with age and contributes as a major fraction of total waste composition for all the heaps. Composting, aerobic, anaerobic degradation and other related processes break down the biodegradable fraction of the dumped waste into soil-like material or FF [28]. With more time passing, additional biodegradable components disintegrate, leading to a higher amount of FF in the more aged heaps of waste. In the Indian context, the higher mass of FF was also reported at the legacy waste dumpsites in Delhi, Mumbai and Chennai [12, 29, 30].

Physical and Chemical Characteristics

The previous LFM study revealed that an extensive range of laboratory analyses was used to assess the acceptability of recovered fractions [19]. However, time and resource constraints necessitate reducing the number of physicochemical parameters measured. Principal characteristics analyzed for the combustible fraction include moisture content, volatile solids, ash content and calorific value. The most critical parameters investigated for FF are moisture content, organic content and heavy metals concentration.

Proximate Analysis of Combustible Fraction

The most common approach to fuel characterization is the proximate analysis which involves the measurement of parameters like moisture content, volatile matter, fixed carbon, and ash content. The combustible components (plastic, wood, rubber and textiles) of the old waste were generally contaminated with fine particles of organic and inorganic matter that were attached to their surface (known as surface defilements or impurities) [31]. In the present research, combustible fractions were subjected to proximate analysis without any pre-treatment to more accurately reflect the current field practices. Table 2 shows the proximate analysis results of as-received combustible fractions from four different waste-filling heaps on dry basis.

Table 3. Calorific value of the combustible fraction

Sample locations	Gross calorific value (MJ/kg)
HP1	18.4±0.2
HP2	16.9±0.5
HP3	13.8±0.7
HP4	12.1±0.4

Mean±standard deviations, n=3.

Table 4. Moisture and organic content in FF

Samples location	Moisture content (%)	Organic content (%)
HP1	29.36±1.89	18.81±1.26
HP2	30.62±1.42	19.14±1.85
HP3	32.68±1.31	20.48±1.58
HP4	34.39±1.55	22.76±1.15

Mean±standard deviations, n=3.

In general, the presence of moisture is always an undesirable component of any combustible material. Heating capacity, combustion efficiency, and combustion temperature are all affected by moisture content [32]. As per the Central Pollution Control Board (CPCB) of India, feedstock for incineration must have a moisture content of less than 45% [33]. The moisture content of the combustible fraction for the four different heaps ranged between 22 to 37%. Hence, all samples meet the CPCB criteria of moisture content for incineration. Furthermore, it was observed that the moisture content of the combustible fraction exhibits a decreasing trend with increasing age. The youngest heap HP4 contained the highest moisture (36.5±0.6%), while the oldest heap HP1 contained the least moisture (22.1±0.3%).

For incineration treatment, the amount of volatile matter in waste samples is a strong indicator of the presence or absence of combustible components. As per the CPCB guidelines on criteria for selecting waste processing techniques, the volatile matter content in the waste sample must be higher than 40% for effective utilization of incineration technology [33]. The mean volatile contents in the combustible fraction from HP1, HP2, HP3 and HP4 were 41.2%, 42.4%, 46.5%, and 50.1%, respectively. The decline in volatile matter from HP4 to HP1 indicates that the amount of organic matter in the waste decreases over time as it decomposes into soil-like substances.

The ash percentages of the combustible fraction for the four different heaps varied from 6 to 31%. CPCB suggests below 35% ash content for mass-burning incinerators to maintain better efficiency [33]. The ash content of the combustible fraction significantly increased from the youngest heap HP4 (5.8±0.2%), to the oldest heap HP1 (30.8±0.5%). The higher amount of FF in the aged waste can be the main reason behind the elevated ash content in the combustible fraction from older heaps. Over time, the decomposition of organic matter results in the subsequent increase of FF, which gets attached to the surface of combustible materials and increases ash content [34]. The fixed carbon content varied from around 6 to 7.5%. Fixed carbon refers to carbon in its uncombine state which burns as solid mass in the combustion process [32]. The high proportion of fixed carbon implies that the incinerator needs more time for complete combustion. As per the CPCB guidelines, the fixed carbon content should be less than 15% for incineration.

Calorific Value of Combustible Fraction

Waste-to-energy conversion is the most favoured application for combustible fractions. The average gross calorific values on the dry basis of the mixed combustible fractions from the four heaps are shown in Table 3. Based on the results, HP1 has the highest calorific value (18.4±0.2 MJ/kg), followed by HP2 (16.9±0.5 MJ/kg), HP3 (13.8±0.7 MJ/kg) and lastly, HP4 (12.1±0.4 MJ/kg). The variations in the calorific values of the samples were mainly caused by their physical composition and inherent moisture content. The higher amount of moisture (36.5±0.6%) in the combustible fractions of HP4 relatively lowered its calorific value. For solid waste to be used as an energy resource or RDF in an incinerator facility, the CPCB suggests that it should have a calorific value of more than 6.3MJ/kg [33]. Therefore, combustible fractions from the four heaps can be used as RDF in a mass burn incineration facility. An increase in the calorific value of RDF samples can also be achieved through proper sorting, pre-cleaning and pre-drying of the recovered waste [35]. However, pre-treatment system development is resource intensive and requires specialized equipment and personnel for waste segregation.

Moisture Content and Organic Content in FF

Moisture and organic content are the two highly interconnected parameters influencing the processing routes and possible end-uses of the FF. Higher organic matter can increase the sorption of the water molecules, which in turn raises the moisture content for the FF. As smaller pores are more effective at holding water than larger ones, moisture is usually found in the FF due to capillary action [28]. For this reason, the moisture content is a pivotal factor in the management of the FF. The results of moisture content and organic content in FF from various heaps are shown in Table 4 on dry basis. The moisture content in FF was found to vary between 29.36% to 34.39%, with the least value at HP 1 and the highest value at HP 4, whereas the organic content was found to vary between 18.81% to 22.76%, with the least value at HP1 and highest value at HP 4. The relatively high level of moisture in the FF affects the processing efficiency of the other material (combustible and non-combustible fraction) recovered from the dumpsite. FFs were easily impregnated on the surface of the other course fractions primarily because of their high moisture levels. It must be emphasized that when the FFs were in their raw state, the presence of moisture promoted the creation of agglomerates and increased the proportion of surface defilements in the larger particles [28]. Along with the amount of mois-

Table 5. Leaching of heavy metals from FF in comparison with the regulatory levels

Heavy metals	Samples location				Regulatory levels						
	HP1	HP2	HP3	HP4	2003/33/EC			LAGA M20			
					Inert	Non-hazardous	Hazardous	Z0	Z1.1	Z1.2	Z2
Cr (μg/L)	143±2.83	169±3.61	179±7.09	242±2.83	50	1000	7000	15	30	75	100
As (μg/L)	BDL	BDL	BDL	BDL	50	200	2500	10	10	40	50
Mn (μg/L)	130±4.95	157±1.41	195±6.36	252±4.14	NSE	NSE	NSE	NSE	NSE	NSE	NSE
Zn (μg/L)	228±1.56	257±1.84	311±2.62	392±6.17	400	5000	20000	100	100	300	400
Cu (μg/L)	118±1.35	129±7.15	138±1.55	144±6.39	200	5000	10000	50	50	150	200
Al (mg/L)	16.6±0.65	23.3±0.63	25.5±0.6	27.4±0.84	NSE	NSE	NSE	NSE	NSE	NSE	NSE

Mean±standard deviations, n=3; NSE: No standard established; BDL: Below detection limit.

ture, the amount of organic matter in FF affects its density, compressibility and decomposition rate [36]. As the organic matter decomposes due to the presence of moisture, the amount of organic content in the FF decreases. This results in a continuous shift in the fundamental engineering and biochemical characteristics of FF until the organic matter is unavailable to microorganisms and cannot be degraded any more. For example, if the organic matter in FF is high, it can cause long-term creep settlement in earthworks, as reported in previous studies [37]. As per the Indian standard code (IRC-37-1984) for road construction, the upper limit of organic content for soil to be used as subgrade material should not be more than 1–3% [38]. This means that if the FF is utilized as an earth-fill material, it will likely cause long-term settlements owing to its gradual decomposition over time.

Leaching Potential of Heavy Metals From FF

An assessment of the leaching potential of heavy metals from the FF is essential for evaluating its suitability before off-sites applications [39]. The leaching test results can provide important information about whether or not the standards set up for various purposes are being met. Many leaching experiments are available to characterize materials or to perform regularity controls to ensure that the materials in question are suitable for use. The European Standard EN 12457-2 batch leaching test was conducted in the present study to evaluate the leaching potential of heavy metals from the FF in normal water under experimental conditions. According to the European Union (EU) regulations, the analysis of leachate composition is crucial for determining the landfill acceptability as well as contamination potential of waste materials like the FF. The results of leachable heavy metals from the EN 12457–2 batch leaching test are shown in Table 5. The leached concentration of Cr, Mn, Zn, Cu and Al from FF were found to vary between 140-245, 125-255, 226-398, 116-150 and 1600-2800 μg/L, respectively. The comparison of the concentration of metals in leachate shows that aluminium is the most abundant heavy metal, followed by zinc, chromium, manganese and copper. Arsenic concentrations were found below the detection limit for all leachate samples. In India, there are no regulatory threshold limits (RTLs) of heavy metals concentration for the reuse of mining waste. Therefore, the leached concentrations of heavy metals from the FF were compared with the RTLs of the EU council decision (2003/33/EC) and the German technical bulletin (LAGA M20) [40, 41]. The EU legislation classifies waste materials based on the concentrations of different heavy metals into three categories, i.e., inert, non-hazardous and hazardous. As per the leaching test results, all FFs are classified as non-hazardous but not inert due to elevated leaching of Cr than the RTLs imposed by the EU council decision. The German technical bulletin, LAGA M20, distinguishes the reuse potential of waste materials in four distinct ways. The class Z0 allows reuse without any restrictions, Z1.1 allows reuse without any sealing to avoid groundwater contamination, Z1.2 allows reuse if the waste material is separated from the groundwater table by a layer of cohesive soil, and Z2 allows reuse if the top layer is sealed. On comparing the results with LAGA M20, it was observed that the FF could not be used directly under any class mentioned in the standard due to significantly higher levels of chromium. The concentration of copper and zinc was also found to exceed the Z1.1 class for all FF samples. This indicates that the unrestricted reuse of FF as earth-fill material can increase heavy metal concentrations in the underneath soil and groundwater.

LFBM Potential for India

The Ministry of Housing and Urban Affairs (MoHUA) estimates that there are 142 million tonnes of legacy waste lying at different dumpsites across 472 cities in India [8]. Most of these dumpsites were constructed before municipal solid waste regulations were enacted, so they lacked essential environmental sanitation facilities. Implementing LFBM operation can provide environmental benefits by rehabilitating the existing dumpsites and offers many possibilities to recover secondary resources and land value spaces. But several obstacles need to be overcome before LFBM project can be executed efficiently. The primary obstacle is encouraging stakeholders to pursue LFBM initiatives, and the secondary obstacle emerges during the valorization of recovered waste. Most international research has indicated that the profits of LFM are related to the recycling of metallic portions [16, 18, 42]. However, the excavated waste from the Indian dumpsites mainly consists of FF and combustible fractions, while the amount of metal is very low [12, 29, 30]. Finding sustainable ways to utilize FF and combustible fractions is very important for the success of the LFBM project. As a sustainable option, FF can be used as earth-fill material in infrastructure development projects such as road and rail embankments, filling low-lying areas and old quarry sites for land reclamation. This practice of reusing FF could reduce the overexploitation of virgin and non-renewable materials like native soil and river sand. However, the prospect of their reuse remains unresolved due to the vast amount of leachable heavy metal availability and high organic content, which causes groundwater contamination and settlement failures, respectively. It is still a challenge for engineers and scientists who are trying to find a way to solve this problem. Although the waste-to-energy conversion shows great promise for the combustible fraction, it may be difficult to sell as fuel due to variations in feedstock quality caused by contaminants. For example, the cement manufacturing sectors are sometimes unwilling to purchase RDF prepared by the combustible fractions as fuel for co-firing because of quality concerns. This fraction could be put to efficient use by the application of pre-cleaning procedures such as sorting, cleaning, and drying. LFBM operation has the potential to create local environmental impact and public health risk due to the release of high strength leachate, landfill gas, odour and dust during excavation and material handling [43]. The severity of these impact depends on various factors related to nature of the excavated waste, the extent of the exposed working face, local weather condition, duration of the LFBM operation, and proximity to surface or groundwater resources and neighbouring residential populations. Appropriate mitigation measures are needed to be taken before implementation of the LFBM project.

The Indian government has taken several initiatives to improve its waste management systems. The government can play a significant role in encouraging entrepreneurs to undertake LFBM projects by providing subsidies. From the Indian context, the potential of LFBM would be the valuable space recovery, rehabilitation of the existing dumpsites and utilization of combustible fraction as fuel.

CONCLUSION

The present study provides an overview of the compositional analysis and physicochemical characteristics of excavated waste obtained during LFBM at a legacy waste dumpsite. The results demonstrate that the composition and characteristics of the excavated waste vary based on the disposal year of the fresh MSW at different heaps within the dumpsite. The proportion of combustible and non-combustible fraction of the excavated waste shows a declining trend from the youngest heap HP4 to the oldest heap HP1due to the variations in purchasing power and consumption habits of the local community and the inadequate recycling of recyclable materials by informal sectors. In contrast, the proportion of FF shows an increment from HP4 to HP1, suggesting increased biodegradation of the easily degradable MSW over the years. The potential for valorization of the combustible and FF was evaluated based on their physicochemical properties. For the combustible fractions, RDF preparation was found to be the most viable option since the amount of surface defilements was too high for good-quality material recovery. The proximate and energy content analysis suggests that the use of pre-cleaning methods can decrease the ash content and enhance the heating value of RDF. Moisture and organic content are interconnected parameters of crucial importance, as processing routes and potential end applications for FF depend to some extent upon their quantities. The elevated amount of organic matter in FF will likely cause long-term settlements during its utilization as earth-fill material. Leaching tests of the FF reveal a significant release of Al, Zn, Cr, Mn and Zn in all leachate samples. Comparison of the heavy metal concentration in leachate with the RTLs of EU and German technical bulletin emphasized that the unrestricted reuse of FF as earth-fill material can cause heavy metal contamination in the underneath soil and groundwater. To stop the spread of contaminants, it is important to look into the pre-treatment methods for FF before they are reused or to explore novel valorization strategies for this resource.

From this study, it is clear that compositional analysis and characterization of the excavated waste are essential steps in developing plans and formulating new proposals for recycling and recovery technologies that can be implemented during the mining of a legacy waste dumpsite. Even though every dumpsite is different, the results from this case study can contribute to the development of approaches for the characterization of legacy waste and the identification of critical issues that need more research. Apart from resource recovery from the dumped waste, if the purpose is also to remediate the legacy waste dump sites and reclaim the land, then LFBM is not far from cleaning a potentially contaminated area, freeing up the contaminated masses and creating new space with high value and new possibilities, which often is considered as a very expensive operation.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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