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Probabilistic Resource Recovery of Legacy Waste in Dhapa Landfill: An Approach of Bio-mining in Kolkata

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Abstract: **Rapid growing competition for resources, increasing price for raw materials, diminishing natural reservoirs for valuable resources and increasing environmental problems make resource extraction from alternative sources as viable option such as Bio-mining. NGT mandated for implementation of Bio-mining of legacy waste throughout the Indian landfills for environmental impact minimization and recovery of 10,000 hectares of urban land that is locked in these dumpsites. The waste generation of Kolkata is around 4500 MT/day which further get accumulated in the major landfill site Dhapa since 1987 which turned into legacy waste. From composition analysis, an estimated recovery of 85-90% of legacy waste is possible. Material balance suggests different components of bio-mining like combustible (5.23%) and non-combustible materials (29.97%), compostable (56.04%), recyclables (0.476%) and residuals (8.642%). Whereas, from sample analysis of 100 kg material in dumpsite, different fraction of components are found as 25-30% non-combustible or C&D materials, 10-15% combustible or RDF materials, 1-2% recyclables, 15-20% bio-earth, 20-30% coarser organic fraction, 5-10% process rejects and 15-25% of evaporated moisture. A comparative analysis have been done with probabilistic data with site specific primary data. A waste to soil ratio of 40:60 is achieved. Cost estimation of different components along with revenue generation suggests a circularity solution. Recovered legacy waste will be further processed for Incineration/RDF/Co-processing, making of building materials, filling materials, waste plastics to paving blocks, compost processing and landscaping, primarily as a valuable material extraction and energy resource recovery strategy to meet the environmental sustainability towards circular economy. This generic methodology will be applicable to different landfill sites of India where Bio-mining is yet to be implemented.**

***Keywords*: Bio-mining, Bio-remediation, Landfill mining, Resource recovery, Circular economy, Kolkata.**

I. INTRODUCTION

Globally, the most common method for waste disposal is landfilling which causes great impact on environment such as long term methane emission, a potential GHG causes global warming as well as leaching of hazardous substances due to leachate contamination to vegetation and ground water. Besides, contaminating air quality due to frequent fire incidences. Methane often auto-ignites, causing fire incidences in the dumpsites, generating smoke and emissions thereby severe air pollution (CPHEEO, 2020). The methane generation from the old dumpsites contribute around 3-4% to the yearly worldwide anthropogenic ozone harming substance discharge (IPCC, 2001).Waste disposal in such manner is intrinsically problematic since natural resources are confined within the waste in which both materials and energy are wasted. These years old legacy waste deposits are source of potential resources. Space constraint associated with the landfill operation is another challenging aspect especially for densely populated areas. Rapid increasing growth rate of municipal solid waste (MSW) generation converting these landfills into virtual mountains of old legacy waste. Efficient management of the continuous flow of solid waste on a daily basis and dealing with the legacy waste which is being neglected, has turned into garbage heaps at the open dumpsites that were meant for sorting, waste processing and landfilling are the two major challenges of solid waste management in the urban cities/towns of India. As per Annual Report of the CPCB (2016-2017), there are 2120 legacy waste dumpsites in India across 23 States which need immediate remediation. Around 14,21,09,581 MT of legacy waste is dumped in 472 no. of cities (CPHEEO, 2020) From 2014 onwards, the Swachh

Bharat Mission has been giving importance on reclamation of landfill sites and minimization of adverse environmental impact adhering to the Solid Waste Management (SWM) Rules, 2016, and the guidelines published by Hon'ble National Green Tribunal. It has an objective to recover over an estimated 10,000 hectares of urban land that is locked in these Indian dumpsites. (CPCB, 2019) Urban India has been struggling to set up an integrated infrastructure in solid waste management, which requires a huge land bank for landfilling and land reclamation could truly solve this problem and enable a reverse scenario in scientific management of MSW in the country. Recently, Hon'ble National Green Tribunal (NGT) directed to propose Standard Operating Processing (SOP) for implementation of Bio-mining and Bio-remediation of legacy solid waste throughout the Indian landfills. Present worldwide situations like rapid growing competition for resources, increasing price for raw materials, diminishing natural reservoirs for valuable resources and increasing environmental problems make resource extraction from alternative sources as viable option such as Bio-mining, primarily as a valuable material extraction and energy resource recovery strategy. Bio-mining involves the excavation, waste stabilization, screening and separation of materials from landfills into various components including soil i.e. good earth or bio earth, recyclable materials, combustibles, inert and residuals with a sustainable approach to prolong the landfill life and to remediate contamination from unlined open dumps. This paper objectifies the probable extracted resource percentage, their alternative usage and economic value for a sustainable treatment technology. Both primary and secondary data have been analyzed to establish a methodology for estimating the bio-mining strategy for any old dumpsite in India.

II. LITERATURE SURVEY

Global aspects of Bio-mining

Rapid generation of dry waste, especially plastic waste and packaging has increased at a higher pace over the years because of incremental e-commerce industry, shifting of larger to smaller stock keeping units due to variable market, rising usage of daily use plastic products, uneconomical waste collection of low value waste due to GST on recyclables. Bio-mining first reported in Israel in 1953 where rehabilitation of dumpsites and energy recovery from recovered wastes, reuse of recovered materials and reduction in the cost of post closure care and monitoring of landfill sites were achieved (Savage et al., 1993). According to Reno Sam, 2009, some of the advantageous reason for choosing Bio-mining are expansion of landfill life, increasing storage capacity followed by landfill conservation, pollution minimization and mitigation measure for the point source contamination, Bio-remediation through waste stabilization, energy and material recovery, waste management cost minimization and so on. Present economic systems, presiding production and consumption patterns in Southeast Asian developing countries not only offer insufficient amount of incentives for the resource conservation but also not oriented towards resource efficiency which in turn resulting into constant rising of waste generation and ending up with a major problem for treatment and disposal sustainably. For more sustainable production and consumption patterns, implementation of 3R concept i.e. Reduction, Reuse and Recovery as well as eco-friendly product design can improve the resource efficiency and waste generation reduction. According to Spencer, 1990; Richard et al., 1996a; 1996b, around 1990, the restoration of growing interest in landfill mining in the United States was solely due to the stringent environmental legislation put over the landfill disposal norms which dynamically closed down many landfills as well as provided strict requirements for post closure norms and long term pollutant monitoring management. In Naples landfill of Collier country, Florida, landfill mining of oversized residue consisted of plastics, glass, metals, wood and rocks. 85% of the waste material recycled through screening used as cover material. (Spencer 1990) According to Guerriero 1996 and Spencer 1990, landfill mining of industrial waste in the MSW landfill at Edinburg addressed excavation of filling materials, Uses of reclaimed materials, soil reclamation and recyclables recovery, land reclamation of one acre area and new landfill construction, health and safety monitoring. Landfill mining in the landfills of New York showed waste recovery percentage of 40-80%. The density of soil like materials found to be 1185 kg/m^3. (Krogmann and Qu, 1997) Lancaster county landfill mining resulted in 41% soil recovery and 56% of waste converted into fuel around 1991-1993. The recovery rates of ferrous, non-ferrous, plastics, paper and glass during LFM in Polygyros landfill of Greece were found to be 85-90%.

Bio-mining aspects in Indian cities

In 1989, on purpose of biodegradable waste recovery for making compost product, landfill mining in Deonar dumpsite near Mumbai was started on a pilot scale basis. Similar waste mining studies were administered at the Perungudi and Kodungaiyur landfill site near Chennai to estimate the degradation status of the waste thus to recover the good earth fraction for cover material or compost. Around 40-60% coarse soil fraction found in Indian Deonar, Kodungaiyur and Perungudi landfills. 11% plastics were recovered from Perungudi landfill whereas around 2-4% from Deonar and Kodungaiyur landfill sites. 31.5% Construction and Demolition (C&D) waste were recovered from Deonar landfill site. (Kurian et al., 2003) Study on landfill mining at Okhla landfill, New Delhi with 65-70 m height and 40 acre land area, Jawaharnagar landfill, Hyderabad, and Ukkayyapalli landfill, Kadapa, India with 10 acre area with 10-12 m height determined the finer fractions from the old legacy waste (Somani et al., 2018) This study involved excavation, sampling, preliminary field study, and laboratory analysis. From the compositional analysis, it was found that maximum soil-like material was found from the oldest aged landfill site among the three above-mentioned landfill sites named Ukkayyapalli at Kadapa. The concentration of inert waste (especially construction and demolition waste) while was found to be almost negligible in the landfill of Hyderabad. The percentage of paper was found to be almost negligible in all the landfills due to consideration of old aged waste. In 2016, India added 31 MMT of waste to the legacy waste in its dumpsites. As per the Central Pollution Control Board

(CPCB's) Annual Report 2018–19 on solid waste management, despite four years of the Swachh Bharat Mission (SBM) in 2019, India dumped 23.35 MMT of waste in existing dumpsites. Hence, bio-mining is of utmost importance not only to reclaim the huge land area but also to minimize the impact of pollutant generating from these pollution prone areas.

Municipal Solid Waste Characteristics of Kolkata

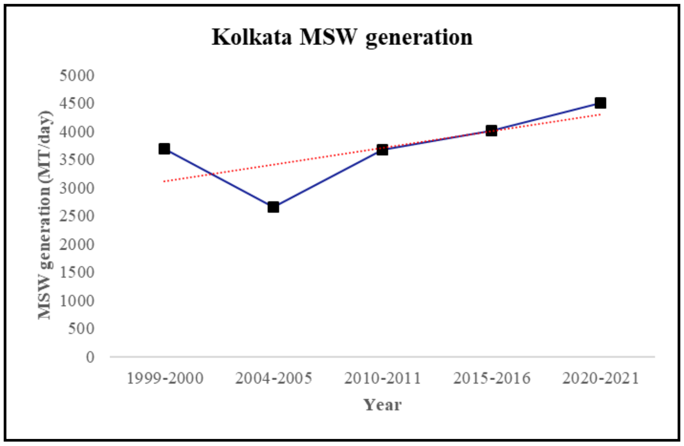

Figure 1: Trend line of Kolkata MSW generation from 1999 to 2021

The urban population in India generated about 1,14,576 MT/day of MSW in 1996 whereas 1,27,486 MT/day during 2011-12 and 1,50,000 MT /day during 2014-15 and likely to reach 260 million tons per year by 2047 (CPHEEO, 2016). Kolkata with its gross area of 206.08 sq. km with residential population more than 4.5 million and floating population 6000000 per day generate MSW of 4500 MT/day under Kolkata Municipal Corporation (KMC). Per capita waste generation for residential population is around 650 gm whereas 200-250 gm for floating population. (ADB 2005a, Chattopadhyay et al., 2007b) The incremental MSW generation trend in Kolkata is shown in Figure 1.The city's MSW is transported by KMC vehicles to the major non-engineered disposal site Dhapa in the eastern fringe of the city. The waste characteristics vary with city to city due to differentiating factors like food pattern, socio economic criteria, climatic conditions, natural and local activities and seasonal variation. (Chattopadhyay et al., 2009) In developed countries, amount of plastic and paper waste is found to be 65% in USA and 48% in Europe. (IGES, 2001) However, more than 50% of organic waste with low calorific value is characterized in the MSW of Asian developing countries along with Indian cities. (CPHEEO, 2000)

Physical characteristic of MSW in Kolkata addresses high organic content around 50-60% with more than 50% moisture content. Figure 2 and Figure 3 depicts the percentage trend of MSW components for Kolkata waste generation respectively. Inert waste (29-40%) is decreasing however biodegradable waste trend is increasing. This shows that biological treatment such as composting or bio-gasification will be suitable for this sort of waste. However, recyclables like paper (3-7%), plastics (3-6%), and coconut shell (4-9%) are on increasing trend as shown in Figure 3. Although, the calorific value of the waste composition has risen considerably post 2005 which depicts that the waste is combustible and suited for Incineration. The C/N ratio is within the range of 26-31 which is substantially alright for composting. (NEERI, 2005; Chattopadhyay et al., 2009)

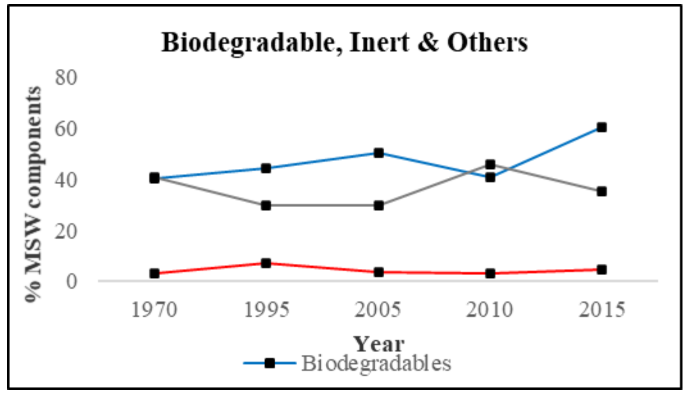

Figure 2: Biodegradable and Inert percentage from 1970 to 2015 in Kolkata

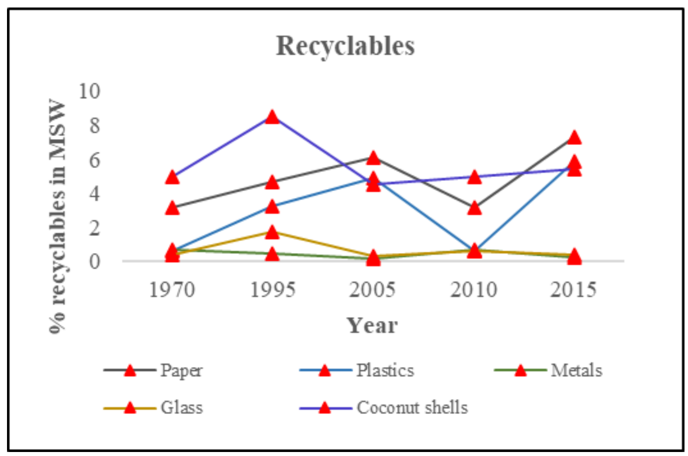

Figure 3: MSW Recyclables percentage from 1970 to 2015 in Kolkata

Study area on Dhapa dumpsite

Dhapa landfill, situated in Kolkata (latitude 22º34/N, longitude 88º24/E), the largest metropolitan city in eastern India, located on the east bank of river Hooghly and is 30 km away from the Bay of Bengal with an average population of 5 meter above the mean sea level. It consists of two unlined dumpsites, spaced 500 m apart, one closed dump of area is 12.14 ha which is bio-capped as per SWM rule, 2016. Another dump of area 24 ha is consist of 40 lakh MT of legacy waste which is treating with bio-mining. This dumpsite also commenced operations in 1987 and is going to be reclaimed after bio-mining. The disposal operation of huge quantity of waste created a huge waste mountain which has already crossed the 20 meter threshold value. (WBPCB, 2014)

III. METHODOLOGY TOWARDS BIO-MINING & RESOURCE RECOVERY

As, Hon'ble NGT has mandated Bio-mining of legacy waste for old dumpsites in India, a Bio-mining project has already started at Dhapa dumpsite in Kolkata. The city's waste which further get disposed in the major landfill site Dhapa, followed open dumping since more than 25 years. The condition of Dhapa dumpsite has exhausted to carry any extra surcharge of MSW. Other major landfill site is hard to establish due to lack of existing land area in the outskirts of the Kolkata city. The pollution strength is also huge due to this old dumpsite. Contamination to air through landfill gas, surface water, and groundwater contamination through landfill leachate is a humongous problem for the city. For this reason, Bio-mining is highly recommended. In this paper, the main focus will rely upon the two major uncertainties for Bio-mining i.e. waste composition of landfills and estimation of recovered waste. Probabilistic approach is necessary for many old dumpsites where bio-mining is not yet been implemented. Secondary data can be used to estimate the probable recovery along with the project cost. However, comparative study have been done with site specific primary data analysis for viability of this probabilistic study. Two methodological approach have been shown here followed by their comparative approaches.

Probabilistic approach

The basic methodology for predicting the waste recovery using past data to be followed are-

Study of past trend of waste composition: To find out different percentage of waste components disposed throughout more than 25 years to the Dhapa landfill site.

Estimation of probabilistic average physical composition: To estimate the average physical composition of the years long legacy waste dumped into the landfill site and analyzing the nature of commingled waste.

Estimation of recyclables and composition of mixed MSW for landfill: Segregating the MSW at source and at landfill site to separate out recyclables.

Analysis for biodegradability of the decomposable waste: To estimate the biodegradation of the decomposable waste round more than 25 years using decay model.

Preparing material balance for the legacy waste: To calculate the futuristic waste to soil ratio of the legacy waste by balancing every single component of the mined waste.

Calculation of expected recovery rate of Bio-mining: To estimate total compostable, recyclable, combustible, non-combustible and residual recovered from the legacy waste.

Composition analysis of legacy waste

1. Estimation of average physical composition of legacy waste

From the past trend analysis, different waste generation data for Kolkata municipal solid waste management system from 1995 to 2020 have been analyzed. These years long MSW is disposing to the Dhapa landfill site from 1987. So, the average physical composition of legacy MSW is shown in the following Table 1. (NEERI, 2005; Chattopadhyay et al., 2009)

TABLE 1
Average physical composition of legacy MSW

Total compostable	Recyclables				Others including inert					
	Paper	Plastics	Metals	Glass	Inert	Rubber/ Leather	Rags	Wood	Coconut Shell	Others
50.17	4.79	4	0.365	0.925	28.615	2.30	2.23	0.8	5.27	0.54

(All values are expressed in percentage and wet weight basis)

2. Estimation of recyclable materials and mixed MSW composition for landfill

Most of the MSW had gone to the landfill site, however some portions are recycled at source or vat points or at dumpsite. Table 2 depicts that around 60-80% recycling has been maintained both at source level and at landfill site. (Chattopadhyay et al., 2009) Table 3 represent the composition of commingled MSW for Dhapa landfill site excluding the recyclables. Table 3 shows total decomposable and non-decomposable material. 8.156 MT of recyclables out of 100 MT of MSW has been analyzed.

TABLE 2
Recyclable materials

Materials	Actual composition	% recycled	Residue fraction for landfill
Paper	4.79	80%	0.958
Plastic	4	70%	1.2
Glass	0.925	80%	0.185
Metal	0.365	80%	0.073
Rubber/Leather	2.3	60%	0.92
Total	**12.38**		**3.34**

TABLE 3
Composition of mixed legacy MSW

Decomposable / Biodegradable					Non decomposable						Total
Food Waste	Paper	Rags	Wood	Coconut shell	Inert	Rubber/ Leather	Plastic	Glass	Metal	Others	
50.17	0.958	2.23	0.8	5.27	28.615	0.92	1.2	0.185	0.073	0.54	**90.96**

Bio-mining & biodegradability of decomposable waste

Transformation of legacy waste within the landfill

From composition analysis of mixed MSW in landfill (Table 3), 65% of waste component is decomposable in nature. Cumulative degradation of these components have occurred since the initial phase of landfill, however fresh waste have also deposited there which have not degraded totally. Considering all these factors, the waste decay for Organic waste, papers, rags, wooden matters, and coconut shells have been contemplated for 25 years landfill period. The waste transformation in the Dhapa landfill is assumed to be decayed for a particular fraction of deposited waste due to incorporation of recent fresh waste in the dumpsite. Such processes may be best fitted mathematically into an exponential decay function by estimating the waste decay rate using a 1st degree Kinetic equation:

$$LW^{t}_{Xi,\ remaining} = LW^{t}_{Xi} \times e^{-kt}$$

Where,
$LW^{t}_{Xi,\ remaining}$ is the amount of dry matter of legacy waste fraction *i* remaining after time *t*, MT.
LW^{t}_{Xi} is the amount of dry matter of legacy waste initially, MT.
k is the first order decay rate constant for waste fraction *i*.
t is the landfill degradation period, years.

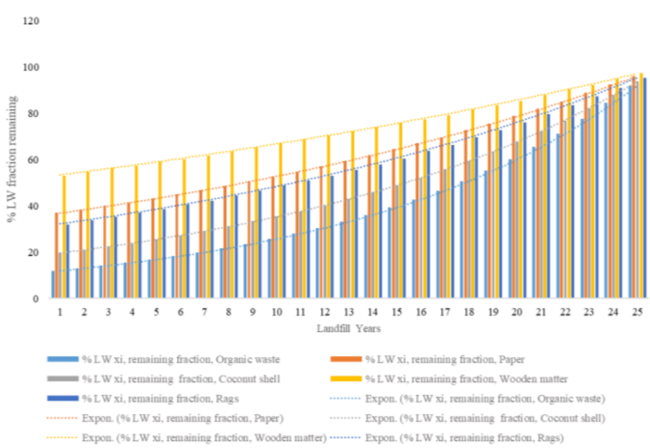

Figure 4: Biodegradation of decomposable legacy waste component in landfill

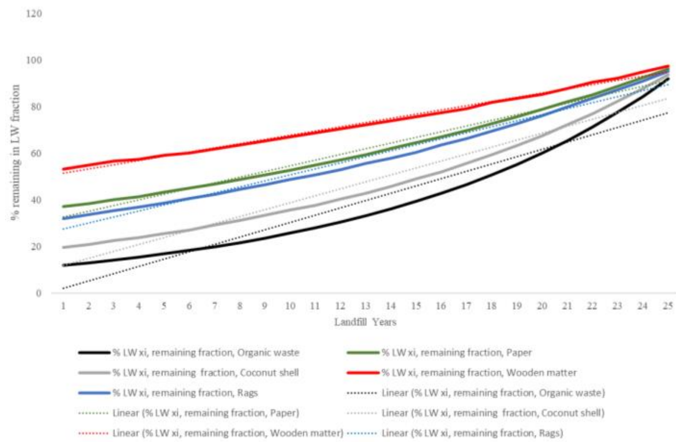

Figure 5: Trend analysis of percentage decomposable legacy waste remaining in landfill

The decay rate constant *k* possesses different values for different waste component depending upon the climate zone, Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP). For Kolkata, India, the *k* value addresses under *tropical* climate zone with MAT>20°C and MAP>1000 mm. *k* value for Paper and Rags is 0.07, for Wooden matter, *k*= 0.035, for Coconut shell, *k*= 0.17 and for organic waste, *k*= 0.4. (Pipatti et al., 2006) Exponential decaying of these years long waste shows the following result as shown in Figure 4 and Figure 5. From the analysis of Figure 4 and Figure 5, the estimated remaining %of Organic waste=8%, 92% of organic waste has been transformed into soil like material or good earth. Remaining %of Paper and %of Rags= 45.2%, %of Coconut shell= 21% and %of Wooden matter= 65%. These remaining waste components from decomposable segment can be recovered into category "*Waste recovery"* as various components of bio-mining. Rest of the transformed segment of decomposable part will be addressing in the "*Soil like material"* category.

Futuristic bio-mining of non-decomposable waste

Non-decomposable waste recovery and their assumptions

Other than the decomposable waste components, non-decomposable fractions like plastics, glass, metals, inert, rubber & leather are analogous to different Bio-mining components like making of RDF, application in Co-processing and recycling industries and so on. Earlier 1990's, before the introduction and anticipation of recycling of legacy waste, all the recoverable metals, glass and organic waste were disposed into the landfills. With the increase in consumer society and market value in between mid-1960s to mid-1990s, the wastes were considered to be of largest amount of recoverable materials for a landfill mining project towards resource recovery. According to Savage et al., 1993, plausible recovery rate of metals are as high as 80-95% whereas 70-90% for plastics. According to World Resource Foundation report (Strange, 1998), expected recovery rates for soil like material is 85-95%, 70-90% of ferrous metals and 50-75% of plastics based on available review, information and mechanical processing efficiencies.

Metals

Probable recovery for recycling from non-decomposable fractions are primarily associated with the metals i.e. both ferrous and non-ferrous. Resource like metals can be recycled iteratively without losing its quality. Metal scarp recycling business is one of the highest profitable businesses in Indian market which needs adequate investment. Assuming some fraction of metal oxidation and mixing with fine like substances based on literature study, probable recovery rate for metal from Dhapa landfill is assumed to be 75%. (Savage et al. 1993; Law et al. 2014)

Plastics

Abrasion of plastic in legacy waste turns into smaller pieces (eventually into micro plastics) due to prolonged exposure to environmental factors such as moisture, heat, light, or microbial action. (Law et al., 2014) From literature study, average decaying and degradation of HDPE and LDPE are less in landfill in comparison to marine environment. Assuming 80% recovery of plastics among which HDPE is recyclable and LDPE is considered to be combustible. (Savage et al. 1993)

Inert & Glass

C&D waste, inert and other waste have a robust market which can be reused as building material, filling material, aggregate, road paving blocks. However, the quality of these legacy inert and C&D waste will be poor compared to the processed C&D waste at site. Considering 5% inert mixed with the fine like material, 95% remains unchanged. (WRF, 1998) Glass will be able to be separated from other inert materials with a high degree of purity. Glass recovery rate is assumed to be 75%. (Law et al., 2014)

Soil like material

Particle size less than 20 mm in trommel address Soil like material. The quality of this fraction will differentiate as per waste characteristics. For Dhapa landfill, degraded 92% organic waste, 38% paper, 30-50% of wooden matter and coconut shell will enhance its quality as compost material, filler material, landscaping material or soil conditioner. However, further recovery of fine glass, metals, paper through fine screening would amplify the product quality and directs toward circular economy. Rest of the reject material will turn out to be residual which will be further landfilled. (CPCB, 2019)

IV. RESULTS

Estimation of legacy waste recovery using probabilistic approach

From basic composition analysis in Table 1 and Table 3, out of 100 MT MSW, it was assumed that 90.96 MT is disposed to the landfill and owns as legacy waste. So the following flow chart Figure 6 depicts the detail plausible waste recovery percentages from Dhapa landfill site. The findings suggest that 56.04% of compostable, 29.97% of non-combustible, 5.23% of combustible, 0.476% of recyclable and 8.642% of residual from the waste processing with wet waste basis. The major components of landfill mining recovery are of five categories.

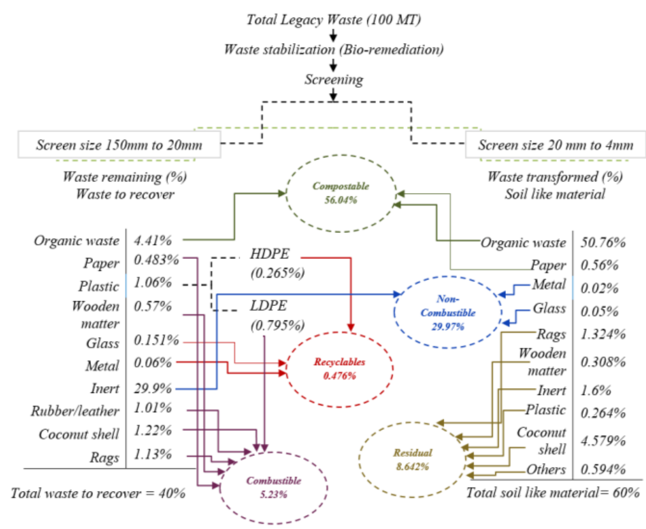

Figure 6: Material Balance Flow Chart of probable waste recovery in Bio-mining process

Recyclables like Metal, Glass, and HDPE plastic. Combustible waste e.g. Wood, Light plastic, Coconut shell, Rags, Rubber/ Leather, and Paper. Compostable like Food waste, finer fractions of plastic, and degraded food waste into soil. Non-combustible materials like Inert including construction and demolition waste, fined fraction of glass, and metal. Lastly Residual waste contain finer fraction of plastic, inert, rags, c/shell, wood, others waste.

Site specific bio-mining approach at Dhapa dumpsite

The legacy waste processing in Dhapa dumpsite has started on late 2021. It refers to legacy waste excavation, windrow formation, addition of bio-culture, windrow turning for moisture evaporation, stabilization (bioremediation process) there after screening of the stabilized waste for resource recovery. The stabilized waste are being segregated through different trommels and ballistic separators. The screen size of 150 mm, 75 mm, 20 mm and 4 mm are being used for waste segregation. All valuable resources like organic fines, bricks, stones, plastics, metals, clothes, rags etc. are being extracted and using as alternative resource for sustainable management through recycling, co-processing, road making, landscaping, soil conditioning etc.

Composition of legacy waste

Raw legacy waste samples were collected from different sampling point at a depth of 0 m, 2 m, and 3 m from the top surface of the heap during August 2021 to December 2021. From laboratory analysis, the various physical component of legacy waste are wood (0.35-0.45%), tharmocol (0.37-0.42%), animal bone (0.7-0.75%), soil or organics (50-60%), ceramic (1-2%), plastic (10-12%), coconut (0.5-1%), gravels (9-10%), textile fabric (0.4-0.5%), glass (0.5-1%), kankar (9-11%).

Onsite estimation of legacy waste recovery through bio-mining

Six different type of bio-mining components are being segregated at Dhapa dumpsite i.e. recyclables, combustible as refuse derived fuel (RDF) materials, C&D waste as non-combustible materials, coarser fraction as filler materials, bio-earth or good earth as compostable or soil conditioner and process rejects as residual. The fraction passing through 20 mm screen and retaining on 4 mm screen is termed as coarser fraction which contains organics, sand and silt. Whereas, the fraction passing through 4 mm screen is termed as bio-earth or good earth. Stabilized legacy waste sample of 100 kg was collected directly from the windrow at dumpsite. The waste is stabilized and dried using windrow formation and addition of bio-culture. This process is called bio-remediation of legacy waste. Moisture evaporation happened with 2-3 times turning of windrow per 10 days for proper air exposure. Three set of samples from different sampling locations were analyzed by screening through different screen sized trommels. From sample analysis of 100 kg material, different fraction of components are found as 25-30% non-combustible or C&D materials, 10-15% combustible or RDF materials, 1-2% recyclables, 15-20% bio-earth, 20-30% coarser organic fraction, 5-10% process rejects and 15-25% of evaporated moisture as shown in Figure 7.

Figure 7: Different bio-mining component at Dhapa landfill

Resource Recovery towards Circular Economy

Total amount of legacy waste consuming Dhapa landfill is around 4000000 MT. Waste density is 0.85 MT/m^3. 4705882.355 m^3 volume of legacy waste need to be treated for mining operation. Detail cost analysis and the respective quantities of the bio-mining components is depicted in the following Table 4. Processing cost and operational cost of legacy waste and its different components have been considered. Weight of different components have been considered based on 40% volume reduction after waste stabilization. (CPCB, 2019) Only 60% of dry stabilized legacy waste is going to be treated for further processing units. Total project cost is INR 260 Crore.

TABLE 4
Detail rate analysis and cost estimation of Bio-mining of Dhapa landfill, Kolkata

Sr. No.	Unit description	Rate (INR Rs/MT of waste)	Quantity (MT)	Total projected cost (INR Rs)
1	Cost of excavation, loading, unloading, weighing, storage	180.00	4000000	720000000
2	Processing cost by mechanical means	320.00	4000000	1280000000
3	Processing cost by manual means and other manpower	100.00	4000000	400000000
4	Statutory clearance cost	1.00	4000000	4000000
5	Leachate treatment cost	9.02	4000000	36080000
6	Environmental monitoring system cost	2.00	4000000	8000000
7	Firefighting system cost	2.00	4000000	8000000
8	Miscellaneous cost including contingency	54.00	4000000	216000000
9	Non-combustible material operational cost	49.45	719280	35568755.64
10	Recyclable material operational cost	0.21	11424	2450.28
11	RDF & Combustible material operational cost	23.54	124992	2941686.72
12	Inert operational cost	12.96	207408	2688629.9
13	Compostable material operational cost	103.67	1337736	138688442.06
Total capital and operational cost incurred (A)		2851969964.6		
1	Revenue from compost product	156.25	1337736	209021250
2	Revenue from RDF materials	349.00	124992	43630957.44
3	Revenue from recyclable materials	5.24	11424	59816.06
Total revenue generated from recovered materials (B)		INR Rs 252712023.5		
Total projected cost of Bio-mining (A-B)		INR Rs 2599257941		

Different components are being sent to different agencies for their respective usage as an alternative resources. RDF is being send to cement manufacturing industries/ power plants as RDF pellets for co-processing. The recyclables are being transferred to authorized recyclers of different materials of Pollution Control Board as per the SWM rules and CPCB guidelines. Recovered non-combustible waste or C&D is being transferred to different construction agencies. Compostable are segregated into coarser organic fraction and good earth or soil conditioner or compost material. The recovered material such as coarser organic fractions are being utilized in the various non-structural construction application in the different infrastructural projects. The C&D waste is being utilized in various infrastructure work for non-structural purpose such as basement filling, low lying area filling, filling of basement/plinth structures, in bedding of road making etc. Revenue generation from compost product, power generation through WTE and recycling products will enhance the economy which meets the need of a sustainable circular economic solution.

V. CONCLUSIONS

From the above probable material balance flow chart of bio-mining process, the anticipated *Waste: Soil* ratio is intended to be *40:60* which meets with the original onsite data. From the landfill mining study of Deonar, Kodungaiyur and Perungudi landfill of India, Filborna landfill of Sweden and Edinburg landfill of USA (Kurian et al., 2003) addressed that total non-combustible constituents were 20-30% which is reliable with our expected percentage (29.97%) as well as site specific primary data collected. The combustible fraction (5.23%) is however a bit less estimated due to lower percentage of plastics obtained in probable composition (Table 3). However, if bio-mining needs to be implemented, then probabilistic analysis is one such approach through which estimation of percentage recovery of different components can be achieved. This study is also significant as it is obtaining the real time data and have been compared with the probabilistic approach. Economic aspect suggests that huge revenue can be achieved by using these components in multiple strategy. This can enhance the concept of circularity. This analysis portray the feasibility of bio-mining for lifetime expansion and bio-remediation. The prime consideration behind the study was composition analysis of the legacy waste, history of operation, waste decaying rate and degradation through environmental exposure, market of products and usage of the recovered materials. Incorporating the bio-mining into the different old dumpsite will transform the city's Solid Waste Management system to a more resourceful and economical model through alternative resource recovery.

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