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Integrated Bio-remediation Approach for Legacy Waste Management at Urban Dumpsites: Case study of Nagpur

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***Abstract*— Before the 1970s, India had very limited engineered waste disposal facilities, and municipal refuse largely consisted of biodegradable organic matter that was traditionally composted and reused in agriculture, supporting a circular nutrient flow between urban and rural systems. The widespread introduction of plastics altered waste composition, leading to mixed disposal of organic and non-biodegradable materials, which impaired soil permeability and fertility when applied to farmland, forcing farmers to discontinue waste reuse. Consequently, urban local bodies resorted to unregulated open dumping beyond city limits, resulting in the accumulation of large volumes of legacy waste over decades. These dumpsites now function as major point sources of environmental pollution, generating contaminated leachate that degrades soil and groundwater, emitting methane that contributes significantly to greenhouse gas emissions, and causing recurrent fires that deteriorate air quality. Recognizing the increasing risks, the Hon'ble National Green Tribunal mandated compliance with Clause 'J' of Schedule I of the Solid Waste Management Rules, 2016, prompting local authorities, in line with CPCB guidelines and Swachh Bharat Mission advisories, to initiate bio-mining and bioremediation of legacy waste to mitigate environmental impacts and restore land usability.**

***Index Terms*— Legacy Waste Management, Bio-mining, Refuse Derived Fuel (RDF), SWM Rules 2016, Waste Characterization, Resource Recovery, Land Reclamation.**

I. Introduction

Nagpur is a city named after Nag River or Nag people, and also its historical development can be traced back to prehistoric, Vedic, and Mauryan eras. It was established by the Gond ruler of Delgado, who encircled it with a fortification wall along Nag River and became in 1743 a capital of the kingdom owned by Roghoji Rao Bhonsale, which was characterized by the political stability, economic and cultural rise including cottage and handloom industries. Nagpur is strategically placed at the geographical centre of India, therefore, it has got extreme climatic conditions whereby the summer temperatures reach up to 480C which is locally referred to as Nava Tappa in May, and the winter temperatures fall to approximately 40C in December. Urban development was planned when in 1936 Nagpur Improvement Trust (NIT) was set up. The city has now come up with an excellent and comprehensive road network as part of the Integrated Road Development Project (IRDP) and cement concrete road projects [1].

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Nagpur, the second capital of Maharashtra and the capital of the Vidarbha region is the third largest urban agglomeration in the state, after Mumbai and Pune. The city has a population of approximately 6 percentage of the urban population of Maharashtra and approximately 76 percentage of the urban population of the district with more than half of the population of the district living within the municipal boundaries. It is true that Nagpur historically used to attract migrants in the surrounding districts to get an education, work, and trade but this has been moderate in the past years. The present rate at which Nagpur City is producing is about 1,381 tonnes per day (TPD) of municipal solid waste. In 2011, part of the old waste at the dumpsite was moved and a small, capped site of approximately 4 ha (40,630 m2) was developed with the rest remaining in operation as a sanitary landfill where waste is deposited. Another landfill cell was earlier built to dispose the rejects of MSW processing in a safe manner. The site lies among residential settlements on the east, north and west sides, a sewage treatment plant on the southeastern side and so environmental management is critical[2]. The current engineered landfill site, including SLF-1 (4.0 ha), SLF-2 (3.5 ha), and SLF-3 (1.4 ha) was designed in 2015, and it occupies almost 10 ha. A major fire incident in March 2017 raised serious concerns regarding landfill operations and safety. Available infrastructure includes a 50-tonne weighbridge, internal concrete roads, street lighting, and a boundary wall that is damaged in several sections, allowing unauthorized access. Equipment at the site consists of one front-end loader, one excavator, and one dozer, supported by limited manpower including one sanitary inspector, two supervisors, and twenty-six municipal workers. By May 2023, the landfill cells were observed to be operating beyond their designed capacity, indicating an urgent need for bio-mining, remediation, and site rejuvenation to enable future waste management operations. The Local Body has already completed Bio-mining of 6.00 lacks MT of legacy waste in first phase. Further to this, Local Body had undertaken the work for remediation of remaining 15.30 lacks MT Legacy Waste through Bio-mining process for land reclamation, resource recovery and suitable disposal of residual inert from the Existing dumpsite[1][4]. Figure 1 represents the geographical location and spatial layout of Nagpur city which is important to understand the waste generation patterns and site selection for dumpsites. Table 1 summarizes the demographic and geographical characteristics of Nagpur city, including city population, area covered, and climatic conditions, influencing waste generation and management strategies.

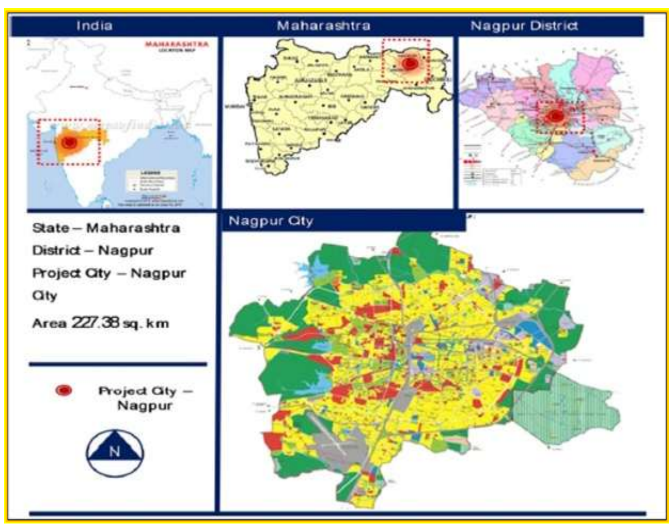

Figure 1: Nagpur City Map

TABLE I: BASIC INFORMATION II

Latitude	21° 8' 47.8788" N
Longitude	79° 5' 19.8960" E
Altitude	310 M Above Mean Sea Level
Total Area	227.38 Sq. Km
Population (2011)	24,48,000 (As Per 2011 Census)
Estimated Population (2026)	33,88,492 (Based On Census 2011)
Slum Population	8,59,487 (As Per 2011 Census)
Average Rainfall	1161.54 Mm
Temperature	Max: 48°C (March To May)

II: PRESENT SCENARIO OF SOLID WASTE MANAGEMENT IN NAGPUR

As depicted in Table 2, the average values indicating a steady increase in population which directly impacts future waste generation rates are estimated using different forecasting methods.

TABLE II: POPULATION TREND IN NAGPUR CITY

Year	Arithmetic Increase	Incremental Increase	Geometric Increase	Average of Three Methods
2022	--	--	--	--
2023	3,192,328	3,183,697	3,225,161	3,200,396
2026	3,346,796	3,319,822	3,440,155	3,368,924
2031	3,604,242	3,532,312	3,830,794	3,655,783
2036	3,861,688	3,726,819	4,265,792	3,951,433
2041	4,119,134	3,903,344	4,750,185	4,257,554
2043	4,222,112	3,968,919	4,959,008	4,383,346

A. Waste Generation

An overall evaluation of the current Solid Waste Management (SWM) system was conducted to determine the municipal services by the Local Body which were waste collection, transportation, treatment and disposal [2]. To ensure successful planning and operational control, a Mass Balance Diagram (MBD) was prepared in order to measure the flows of waste at various levels of handling [2].

The Local Body has engaged the services of two private agencies to collect and deliver the municipal solid waste from their door to the available dumping yard, and the zonal division is also to be divided into two categories to balance the workload and service quality.

The Zones 1-5 will fall under a single service package, whereas Zones 6-10 will fall under the second service package.

Besides the residential sources, about 66, 000 business outlets, such as shops, vegetable markets, restaurants, and street vendors are incorporated into the SWM service network. The city is further subdivided into 10 zones and 38 electoral wards with an area of 227.38 km2.

All the amount of waste of approximately 1,381 TPD would be collected using a mix of door-to-door services, community collection bins and the public collection points and then transported to the centralised waste management plant at the current dumpsite where it is processed and disposed [3]. Table 3 indicates the current status of waste generation (wet, dry, and hazardous fractions).

TABLE III: OVERVIEW OF SOLID WASTE GENERATION AT EXISTING SITE

Criteria	Value
Census Population 2011	2405665
Current Population 2025	3310557
Estimated Population 2026 (2.3% Decadal Growth)	3388492
Total Waste Generation @ 20225 (Tpd)	1381.00
Total Wet Waste Generation @ 2025 (Tpd)	895.00
Total Dry Waste Generation @ 2025 (Tpd)	482.50
Total Domestic Hazardous @ 2025 (Tpd)	2.0
Total Sanitary Waste Generation @ 2025 (Tpd)	1.5
Total Other Waste Generation @ 2025 (Tpd)	0.00
Per Capita Generation @ 2025 (Grams)	407.50

B. Future Solid Waste Generation

For solid waste management projections, the per capita waste generation rate of 288 g/day recorded in 2011 was adopted as the baseline. Based on projected population growth and the same per capita generation rate, the total municipal solid waste generation for the year 2026 has been estimated at approximately 1,600 TPD. Waste quantities were projected up to 2026, and corresponding annual waste generation was computed to support long-term planning.

These projections were used to determine the infrastructure requirements for primary and secondary collection systems, transportation fleet, landfill capacity, and waste treatment facilities [3]. The estimated infrastructure needs have been incorporated into sector-wise development plans to ensure adequate capacity for future solid waste management operations [4].

From Table 4 it is evident that there will be an increase of approximately 1,600 TPD by 2026, necessitating capacity enhancement in waste management infrastructure.

TABLE IV: ESTIMATION OF SOLID WASTE GENERATION IN NAGPUR TILL 2026

Year	Projected Population (In Lakhs)	Per Capita Waste Generation (In Gms)	Average Per Day Waste Generation (TPD)
2011	2,405,665	288	705
2022	3,089,350	388.68	1200
2026	3,388,492	485.85	1646

III. SUMMARY OF EXISTING WASTE MANAGEMENT SITE

A. Details of Existing Waste Management Depot

Since January 2017, the Local Body has initiated processing of legacy waste along with limited quantities of fresh waste using bio-remediation and bio-mining techniques at the existing dumpsite. Approximately 0.6 million tonnes of waste were processed by forming 311 windrows of 1.5–1.8 m height, followed by mechanical turning, segregation, and periodic application of bio-cultures to accelerate biodegradation. This intervention resulted in partial reduction of dumpsite height; however, limited market demand for compost-like output and soil fractions adversely affected large-scale material utilization[2]. A major landfill fire incident in March 2017 further highlighted operational and safety deficiencies at the site. The dumpsite has a simple infrastructure; that is, 50TM weighbridge, internal concrete roads, street lighting and a border wall which is compromised at various points allowing unauthorized access. Machinery available will include one front-end loader, one excavator and one dozer with little manpower consisting of one sanitary inspector, two supervisors and twenty six municipal workers. Though previously a sanitary landfill cell had been built to dispose the rejects of waste processing, the modern day practice of disposal is characterized by uncontrolled dumping with poor compaction, lack of daily cover, and no leachate collection and treatment system which is a major threat to the contamination of soil and groundwater[4]. Constant fires in landfills that occur in summer lead to air pollution, odor nuisance and other negative health effects in the surrounding residential homes. In April 2023, field investigations revealed that the sanitary landfill cell had reached its design capacity, which required immediate cleaning and restoration. After the bio-mining of about 0.6 million tonnes of historical waste in Phase I, the Local Body has embarked on additional remediation of the left over historical waste with systematic bio-mining of the land to reclaim the land, recover resource and disposal of inert residues in the current dumpsite in a scientific manner[5][6].

B. Bioremediation & Biomining Waste Management

Provision in SWM Rule 2016

The Government of India made known the Solid Waste Management (SWM) Rules, 2016, so that there would be scientific and environmental proper management of the municipal solid waste[5]. As provided by Rule 15, local authorities and Panchayats are required to review all old and active dumpsites to determine their appropriateness to bio-mining and bio-remediation and carry out such remediation wherever possible[6]. Where bio-mining/ bio-remediation is not technically feasible, dumpsites should be capped scientifically in line with the landfill closure requirements in order to avoid further erosion of the environment[4,5,6]. It applies to every urban local body, cantonment board, Panchayat, industrial township and institutional establishment. In addition to this, Schedule I (Clause j) of the SWM Rules, 2016 is specific that dumpsites that have become incapacitated or are no longer in use should be closed and rehabilitated in accordance with appropriate measures that could include: (i) bio-mining and processing of volume of waste followed by disposal of residues in engineered landfill or site capping; (ii) capping dumpsites with soil or geomembrane layers to facilitate collection of landfill gases and their later use or flaring; (iii) enhanced containment measures like cut These are some of the provisions that highlight that it is urgent to remediate the past waste to safeguard the health and environmental resources of the people.

IV. METHODOLOGY

Treatment and disposal of legacy municipal solid waste can be effectively achieved through bio-remediation and bio-mining techniques [5]. Prior to implementation, a total station survey or drone-based topographic mapping of the dumpsite is essential to assess site geometry, waste volume, and operational planning. A comprehensive precursor study should include historical site assessment and detailed compositional analysis of the waste. Baseline environmental monitoring of surface and subsurface soils and water, including heavy metal concentrations, along with assessment of rainfall patterns, soil characteristics, surface drainage, topography, and prevailing wind direction, should be conducted before and after bio-mining operations[6]. In addition, post-remediation monitoring is necessary to evaluate potential residual environmental impacts and to ensure long-term site safety and regulatory compliance.

A. Bioremediation & Bio-Mining of Old Municipal Dumpsites-

This systematic framework involving site assessment, waste excavation, windrow formation, biological treatment, and final material recovery mentioned through Figure 5 ensures efficient handling and processing of legacy waste while minimizing environmental impacts [2], [5].

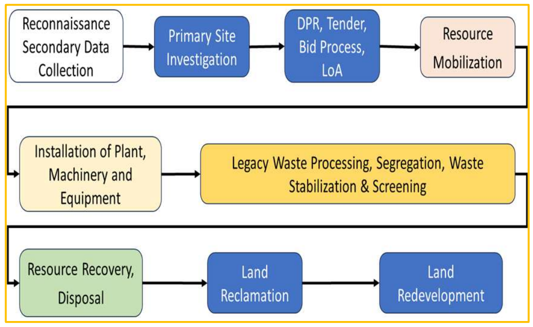

Figure 5: Project Execution Methodology- Components to be considered in planning and site preparation

The is presented in Figure 6, highlighting sequential operations. The integrated process of bio-remediation and bio-mining including mechanical turning, aeration, microbial degradation, and screening enhancing stabilization of biodegradable fractions and facilitate segregation of recoverable materials such as RDF, recyclables, and inert fractions [3], [6] are depicted in Figure 6.

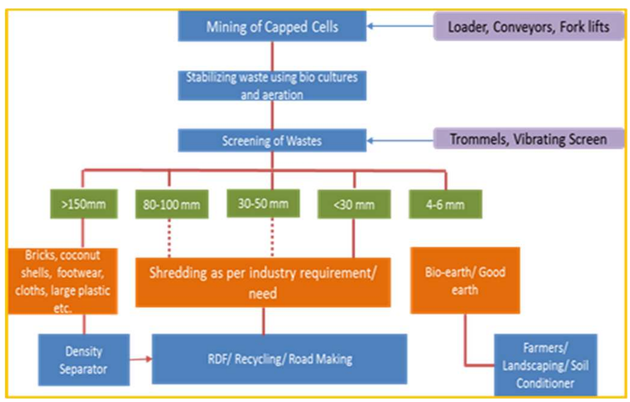

Figure 6: Overview of Bioremediation and Biomining

B. Bioremediation & Bio-Mining of Old Municipal Dumps Bio-remediation Techniques for Stabilization of Legacy Wastes-

Aerobic stabilization of legacy waste is commonly achieved by exposing waste to atmospheric oxygen through mechanical agitation and formation of windrows, a practice adopted since the late 1990s[3]. Waste is typically arranged into elongated heaps of approximately 2 m height to maximize the surface-area-to-volume ratio, and 3–4 mechanical turnings are generally required to ensure uniform aeration and stabilization of internal waste layers. In one approach, the top 150 mm of waste is repeatedly loosened using tractor-mounted tillers, followed by light mist-spraying of bio-cultures to enhance microbial dispersion and control odor. Bulky inert materials such as stones, coconut shells, and textiles are manually removed prior to shaping the waste into windrows using earth-moving equipment[5]. These windrows are mechanically turned at 5-day intervals, and after 2–3 weeks, when moisture and particle cohesion are sufficiently reduced, the stabilized waste is screened using multi-deck vibrating screens or trommel units to separate material fractions by size.The other in-situ aeration technique will be through excavation of 2-2.5 m deep vertical trenches with 1.5-2 m separation over waste mounds by excavators. Waste faces are exposed and bio-cultures are sprayed onto the face to facilitate the growth of microorganisms and the excavated slices are turned into terrace-like windrows that are periodically transferred and mixed to facilitate aeration [6,7]. The screening process is triggered when the moisture levels are sufficient to allow a mechanical separation. Repeated lifting and dropping of waste heights between 2-3 m with excavators is also another method that is used to create mechanical aeration and decrease compaction. On the formed conical heaps, bio-cultures are spread and the waste re-agitated after 1-3 days. Where there is sufficient space, the cones are reformed into parallel windrows, and mechanically turned on a weekly basis, and merging of heaps takes place as the volume decreases during stabilization. In the case of waste relocation on the site, the waste can be laid in thin layers (approximately 150 mm), and subjected to bio-cultures, where the passive aerobic decomposition of the waste can occur, like in the case of leaf litter. Mechanical turning will not be necessary in this case provided there is adequate aeration. In the changing environment of dumpsite remediation methods, remediation technological differences can be used as site-specific and economy-wise owing to the fact that the technological differences meet sufficient levels of stabilization, environmental protection and legal requirements [6,7].

C. Processing Equipment for Legacy Waste Treatment

Treatment of old municipal solid waste needs equipping with proper mechanical systems used to excavate, reduce sizes, separate, and handle the materials. The large equipment classes that are involved in bio-mining activities consist of excavation, screening, air classification, ferrous separation and conveyance of materials, and different equipment will be selected according to the conditions of the site, the characteristics of the waste and the fractions desired [5]. Primary screening is normally done on trommel screens, vibrating screens or disc/star screens to separate fine soil-like particles and oversized fractions. Trommels are useful in the processing of heterogeneous and moist waste whereas vibrating and star screens have greater throughput and better size classification efficacy. The front-end loaders are used to feed and stockpile materials, and the belt or bucket conveyors and lifting systems are used to transfer material between stages. With these systems there is a constant movement of waste between excavation, screening, segregation, and recovery units, thereby improving operational efficiency and reducing manual handling [6,7].

IV. LEGACY WASTE ANALYSIS

Solid waste dumping ground of Nagpur city was selected because of the representative samples of legacy municipal solid waste that were collected and subjected to in-depth lab studies. The samples were physically and chemically characterized in the Environmental Engineering Laboratory in accordance with the standard testing methods. The common legacy waste amounts to approximately 20 kg, which was gathered at various points of the dumpsite namely zone F, C, D and E to ensure that spatial changes in the waste composition are taken into consideration. To identify material fractions and physicochemical properties of the legacy waste[4,5], the obtained samples were segmented by component and further analyzed to achieve it. The contour map through Figure 7 provides essential information for estimating waste volume, planning excavation activities, and designing appropriate remediation strategies. [1], [3].

A. Characterization/ Components of Legacy Waste-

- The percentage of RDF is 20-25%,
- Soil C&D and inert is 30-35%
- Moisture is 30-35%
- Recyclables is 5-10%

B. Quantum of Legacy Waste

Figure 7: Contour Map of SLF Area

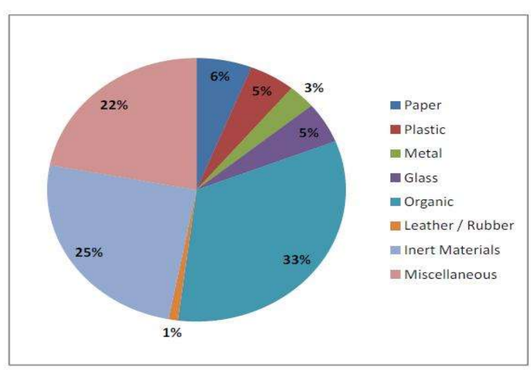

Figure 8: Components of Legacy waste

Figure 10 highlights the composition of legacy waste showing the proportion of RDF, inert materials, moisture content, and recyclables. The density of waste is considered 1.5MT/cum as per survey report of October 2022, Total weight is 15.30 Lakh MT and Total volume around 10.20 Lakhs MT. This composition is crucial for determining resource recovery potential and selecting appropriate treatment techniques. Similar compositional distributions have been observed in landfill mining studies [3], [7].

C. Comparative Analysis of Seasonal variations in the Components of legacy waste-

The seasonal variations in physicochemical properties of the soil-like fraction obtained after bio-mining are summarized in Table 6. The analysis includes parameters such as pH, heavy metal concentration, and organic content, which are critical for assessing its potential reuse in land reclamation or as landfill cover material. Proper evaluation ensures compliance with environmental standards and minimizes ecological risks [3], [6].

TABLE VI: CHEMICAL TESTING OF SOIL

Chemical Testing of Soil from Biomining Site																		
Season	Month	PH	Electrical Conductivity	Total Nitrogen	Total Phosporous	Total Pottasium	C:N Ratio	Total Organic Carbon	Henavaelnt Chromium	Copper	Mercury	Cadmium	Arsenic	Lead	Zinc	Nickel	Chromium
Rainy	Jul-24	6.38	0.81	1.78	0.05	0.07	1.17	2.08	1.26	51.90	Absent	0.98	Absent	19.58	94.02	6.85	11.75
Rainy	Aug-24	7.94	0.29	1.17	0.23	0.38	1.83	2.14	2.06	193.35	BLQ	4.18	BLQ	80.23	655.30	30.30	39.62
Rainy	Sep-24	6.32	0.85	1.53	0.40	0.35	1.37	2.11	4.26	137.41	BLQ	1.78	1.78	53.53	238.24	17.85	24.09
Average		**6.88**	**0.65**	**1.49**	**0.23**	**0.27**	**1.46**	**2.11**	**2.53**	**127.55**	**0.00**	**2.31**	**0.59**	**51.11**	**329.19**	**18.33**	**25.15**
Season	Month	PH	Electrical Conductivity	Total Nitrogen	Total Phosporous	Total Pottasium	C:N Ratio	Total Organic Carbon	Henavaelnt Chromium	Copper	Mercury	Cadmium	Arsenic	Lead	Zinc	Nickel	Chromium
Winter	Oct-24	6.32	0.99	1.20	0.09	0.10	1.95	2.34	7.86	59.78	BLQ	BLQ	2.70	24.27	279.58	12.14	25.58
Winter	Nov-24	6.63	1.10	1.12	0.16	0.12	2.00	2.25	BLQ	2.19	0.14	ND	ND	ND	0.23	ND	17.32
Winter	Dec-24	6.01	0.98	1.12	0.22	0.43	1.84	2.07	BLQ	126.14	0.94	0.94	1.88	51.77	262.64	17.89	28.24
Winter	Jan-25	6.78	0.92	1.26	0.41	0.00	1.97	2.48	BLQ	122.96	0.54	1.60	BLQ	42.12	199.62	15.17	29.54
Winter	Feb-25	6.26	0.90	1.26	0.44	0.31	1.95	2.46	BLQ	194.02	0.08	1.94	2.21	52.49	285.91	12.00	39.41
Average		**6.40**	**0.98**	**1.19**	**0.26**	**0.19**	**1.94**	**2.32**	**1.57**	**101.02**	**0.34**	**0.90**	**1.36**	**34.13**	**205.60**	**11.44**	**28.02**
Season	Month	PH	Electrical Conductivity	Total Nitrogen	Total Phosporous	Total Pottasium	C:N Ratio	Total Organic Carbon	Henavaelnt Chromium	Copper	Mercury	Cadmium	Arsenic	Lead	Zinc	Nickel	Chromium
Summer	Mar-25	7.12	0.89	1.29	0.29	0.36	1.86	2.41	BLQ	101.06	0.06	3.14	2.19	55.01	210.13	11.91	26.26
Summer	Apr-25	7.56	0.98	1.32	0.32	0.30	1.82	2.41	BLQ	141.00	0.05	1.90	2.01	46.41	261.17	20.06	22.96
Summer	May-25	7.06	0.94	0.98	0.29	0.31	2.35	2.30	BLQ	142.09	0.05	2.32	1.59	43.69	180.02	10.29	22.21
Summer	Jun-25	6.46	1.09	1.09	0.58	0.99	2.07	2.26	BLQ	148.82	0.09	1.89	2.11	46.41	279.49	12.41	25.20
Average		**7.05**	**0.97**	**1.17**	**0.37**	**0.49**	**2.03**	**2.35**	**0.00**	**133.24**	**0.06**	**2.31**	**1.98**	**47.88**	**232.70**	**13.67**	**24.16**

The chemical characteristics of the refuse-derived fuel (RDF) fraction as represented through Table 7 indicate the suitability of RDF for energy recovery applications, particularly in cement kilns and waste-to-energy plants. The observed values are consistent with findings reported in previous studies on landfill-derived fuels [6], [7].

TABLE VII: CHEMICAL TESTING OF RDF

Chemical Testing of RDF from Biomining Site						
Season	Month	Moisture (%)	Ash(%)	Fixed Carbon(%)	Volatile Matter(%)	Gross Calorfic Value (ARB)(%)
Rainy	Jul-24	3.25	19.51	3.21	74.03	4429
Rainy	Aug-24	50.30	26.13	2.11	21.46	934.00
Rainy	Sep-24	49.07	23.31	5.63	21.99	3936.00
Average		34.21	22.98	3.65	39.16	3099.67
Season	Month	Moisture (%)	Ash(%)	Fixed Carbon(%)	Volatile Matter(%)	Gross Calorfic Value (ARB)(%)
Winter	Oct-24	2.47	17.97	4.37	75.19	4387.00
Winter	Nov-24	2.83	35.74	2.06	59.37	4079.00
Winter	Dec-24	2.81	39.13	1.27	56.79	3986.00
Winter	Jan-25	3.23	17.55	17.27	61.95	4579.00
Winter	Feb-25	2.85	28.99	6.65	61.51	4426.00
Average		2.84	27.88	6.32	62.96	4291.40
Season	Month	Moisture (%)	Ash(%)	Fixed Carbon(%)	Volatile Matter(%)	Gross Calorfic Value (ARB)(%)
Summer	Mar-25	8.06	38.23	3.64	50.07	4466.00
Summer	Apr-25	2.99	15.94	6.58	74.49	4026.00
Summer	May-25	2.18	27.18	13.75	56.89	4832.00
Summer	Jun-25	26.92	24.03	4.34	44.71	3912.00
Average		10.04	26.35	7.08	56.54	4309.00

V. RESULTS AND DISCUSSION

Compositional and physicochemical characterization of the heritage waste gives important information on the technical feasibility and environmental efficiency of the bio-mining of the available sanitary landfill site in Nagpur. The seasonal analysis showed that the average moisture content was 15.69, this is good in terms of screening and air classification operation, because extreme moisture material may greatly decrease the efficiency of screening and may also increase the amount of energy used in the operation[3][6]. The medium level of moisture detected means that massive mechanical segregation may be performed without the necessity of massive pre-drying, which will enhance the efficiency of the process and make the treatment more affordable. The mean of volatile matter is 52.89 per cent which indicates that over 50 per cent of the mass of the excavated waste is biodegradable organic matter, which indicates the applicability of aerobic bio-stabilization and composting-based remediation procedures[3][7]. This percentage can be turned into stabilized bio-soil which can be used to cover landfills or to condition soils, but this has to be done in compliance with the laws of heavy metals and pathogens. The existence of a significant proportionality of biodegradable matter also suggests that anaerobic degradation over extensive periods of time in the dumpsite has not stabilized the waste completely and this supports the key point of active remediation to mitigate on the environmental risks over long periods. The proximate analysis showed that the average calorific value is about 3,900 kcal/kg, which is higher than the minimum limit that should be obtained to be used as refuse-derived fuel (RDF) in cement kilns and waste-to-energy power plants[6][7][8]. This supports the fact that the burnable part of the excavated waste has huge energy recovery which is used to generate revenue and subsidize a proportion of the bio-mining operations. The fraction of recoverable energy in this way increases the overall economic viability of the project. After-screening material distribution indicated that the waste could be treated into RDF about 20 percent, soil, construction and demolition debris and inert materials, 40 percent, moisture-related fines, 40 percent and materials that could be recycled like plastics and metals, 5 percent respectively. These percentages imply that almost 60-65 percent of the total waste mass would be avoided in final disposal to a landfill by using material recovery and reuse routes and would lead to major landfill volume and long term environmental impacts. The resulting fine fraction (soil-like) may be reused as daily cover or to restore the site and recyclables may be channeled to recognized recycling facilities, thus encouraging the practices of a circular economy. Based on feasibility, the mixture of recoverable RDF, recyclable material and reuseable soil fractions ensures that the volume of waste to be disposed of through engineered land fill disposal is significantly less, and that the current landfill infrastructure is able to last longer[8][9]. Also, it helps to restore the landfill area to develop the waste processing plant or green buffer area in the future, which increases the socio-environmental positive benefits of the intervention even more. Nevertheless, the successful sustainability of bio-mining activity in the future requires the presence of stable downstream markets of RDF and compost-like products and the implementation of continuous monitoring of the environment to exclude the secondary pollution. In general, the analysis findings are highly indicative of bio-mining and bio-remediation as technically appropriate and environmentally required in the Nagpur dumpsite. The wastes observed are in line with the remediation strategies as suggested by CPCB and material recovery potential has good chances of sustainable and economically viable management of legacy wastes[2][6][9].

VI. SUMMARY AND CONCLUSION

The paper suggests that the legacy waste on the site has an estimated amount of 25 percent of biodegradable organic content and a large portion of it with good calorific value that can be used to recover resources. Approximately 25 percent of the material can be bio-stabilized and used as soil conditioner to either be applied to the agricultural land or to be used in land reclamation, on condition that they meet regulations. Almost one-fifth of the waste produced is of sufficient calorific value to be used as a refuse-derived fuel (RDF) in cement kilns to aid in recovery of energy, as well as the elimination of reliance on fossil fuels. Inert material would make about 10 percent of the waste, which would then be safely used to fill the low-lying areas outside Nagpur on condition of environmental appropriateness whereas about 5 percent of the waste will be recyclable material, which will be channeled to the approved recycling centers in Nagpur. The resources provided by the Swachh Bharat Mission as well as other government funding programs can be used efficiently to carry out massive cleanup of the old waste. The suggested working model includes the systematic excavation, formation of windrow, bio-cultures, mechanical screening and controlled storage of separated fractions before they can be utilized or discarded altogether. The suggested bio-mining processing plant through these funds is likely to see a considerable reduction in non-compliance to the environment and fines placed on the local bodies by the

National Green Tribunal (NGT), as well as the opportunity to restore the dumpsite in a way that is eco-friendly and enable the recovery of valuable land resources.

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