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Sustainability Assessment and Reuse Feasibility of Stabilized Legacy Waste in West Bengal, India: A Circular Economy Transition Perspective

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Abstract: Present solid waste management policies around the world demand higher recycling and reuse rates.Thousands of uncontrolled dumpsitesexistingworldwide either under operating or closed condition are deemed not only to be themajorsources of environmental pollution and nuisance but also occupying prime land that could be used for other purposes while containing useful materials.Reclamation of the dumpsites containing massive share of residual garbage is therefore an environmentally sensitive issue that continues to be confronted by developing nations, particularly by local metropolitan authorities in India.To address this problem, one scientific technique, i.e., the biomining approach, which refers to digging and shifting legacy garbage from dumpsites and recycling or creating energy from recovered materials, reclaiming land space, and rehabilitating/redeveloping contaminated sites could be explored.The article presents a review on feasibility studies carried ondumpsite mining operation specifically to recover legacy wasteand its reuse. Assessment of sustainability of biomining process in terms of not only the direct costs and revenues but also social benefits is discussed in details under the purview of the present study.

Keywords: Municipal solid waste; Legacy waste; Biomining; Circular Economy; Land reclamation; Soil-like material

1. Introduction

Municipal solid waste (MSW) management is an issue of worldwide concern. Globally, the generation of municipal solid waste in the world is expected to be 27 billion tonnes per year by 2050. Currently, Asia generates one-third of total MSW, with significant contributions from China (0–0.49) kg/capita/day, Japan 1.1kg/capita/day and India (0.50–0.9) kg/capita/day (Kaza et al., 2018; Kumar & Agrawal, 2020; Modak & Nangare, 2011; Niyati, 2015). City wise generation of MSW shows significant variation in the per capita waste generation (0.24 to 0.85 kg/capita/day) at an exponential rate over the period(2001 – 2018)as presented by CPCB (2018). This percapita waste generationis likely to increase shortly at a faster rate (CPCB, 2018; S. Kumar et al., 2017). In India, as per the CPCB, about 160038.9 tonnes per day (TPD)of solid waste is collected, out of whichonly79956.3 TPD (50%) of waste receives scientific treatment (Ahluwalia & Patel, 2018; CPCB, 2021a). Therefore, a significant amount of waste disposed at landfill without any treatment. As per the estimation, waste dumps require a new land area of 1400 sq. km approximately by the year 2051. With urbanisation and rapid population growth, land has become very scarce resource. Thus, it is needed to reclaim the existing open dumping grounds and now-a-days biomining technology coupled with bioreactor landfill has become the most viable solution for the reclamation (Mohan & Joseph, 2020). Biomining and bioremediation technology is advantageous compared to the capping of closed dumping site in terms of i) reduced greenhouse gas emissions, ii) reduced footprint area of landfill, iii) lesser risk of surface water and groundwater contamination, iv) improved reuse and recycling concepts and v) reduced post-closure operation and maintenance costs, which raises the need of biomining and bioremediation concepts. In this way, old uncontrolled landfills can be rehabilitated, while in operating landfills valuable space can be recovered, which means that the environment is being protected, since the need for new landfills and, thus, the occupation of new land, is restricted.

Conventionally, the concept of mining has been understood in the perspective of recovering metals from mineral ores and other valuable products from the earth. Materials recovered from MSW can be turned into raw materialsuseful for other purposes and allied industries. Globally, in legacy waste the soil or organic fraction is very less in case of developed countries and the metal and plastic fraction remain high. But in India a very few percentages of scrap metal enter the landfills as it is sold directly to scrap dealers or kawariwala from household or collected from landfill by rag pickers. Kurian et al.(2003) and Singh & Chandel (2019) reported the metal content of MSW as (0.1–0.2)% and 0.4% respectively in Indian landfill. According to Ahluwalia & Patel(2018),in India, biodegradable wastes make up 51% of MSW, plastics are of 10%, paper waste is of 7% and remaining 32% is textile, glass, metal, drain silt, street sweepings, and inert materials. About 40% of the waste at the dumpsite is organic, followed by plastic (18%) and paper (11%). Due to the mixing of street sweeping and drain cleaning waste at the dumpsite, the organic contents are slightly lower than the composition of waste collected from the residential, institutional, and commercial areas. Before mining an MSW dumpsite or a landfill, a thorough analysis is necessary, especially to assess the project's cost-effectiveness.Therefore, determining the project's economic viability is crucial when making decisions. However, up to this point, very few studies have specifically addressed the economics of landfill mining. In order to ensure that projects producing significant social benefits are not overlooked, a thorough approach for evaluating the economic viability of landfill mining should consider both the direct costs and revenues for the private investor as well as the social benefits or costs.

In this study, our objective has been seti) to assess the current scenario of landfill mining with the suggested use of reclaimed legacy waste around the world, ii) to explore the valorization potential of the excavated legacy waste materials for the circular economy, iii) to highlight the necessity of economic feasibility analysis and social justification of making decisions regarding biomining projects and iv)to emphasize on the current status of biomining initiative to reclaim open dumps in West Bengal.

2. Essence oflandfill mining initiatives- Global Perspective

Waste characterisation is the most discussed and significant subject in landfill mining studies. The majority of characterisation studies involve first sorting the waste by size into different categories, such as plastic, paper, textile, wood, metal, glass, inert, and soil fraction, using either manual or mechanical means (Singh & Chandel, 2019).Due to the various lifestyles, laws, and waste management practises used throughout the nation, the composition of waste will vary depending on the location. However, the variation in the waste composition can appear even at different landfills in the same country, like the situation at Lohja and Kuopio landfills in Finland(Kaartinen et al., 2013; Mönkäre et al., 2015) and even in India different landfill shows variation in its own physico-chemical characteristics (Datta et al., 2021; Somani et al., 2018).Table-1 presents the summary of several landfill mining projectscarried out in several parts of world. From Table-1it is evidentthat at majorities of the landfill sites the soil material was used after reclamation as cover at the site itself as (40–77)%of the total reclaimed material has been reported as soil-like material. However, in very few landfills the legacy wastes were suggested to be reused as construction material and refuse derived fuel (RDF).

Table-1: Summary of landfill mining projects reported in various literatures

Scenario	Country	Key findings	Suggested use of reclaimed legacy waste	Reference
International Scenario	Sweden	65% of the total waste was considered to be an indefinable soil fraction andmetal content (5%) is higher and recovery may be possible.	Covering material, soil amendment, combustion and methane gas production	Hogland et al., 2004
	Thailand	Soil fraction was 69% and the remaining 31% was composed mainly of plastics showed high potential for recycling as refuse derived fuel (RDF).	RDF	Prechthai et al., 2008
	Belgium	The number of combustibles varied between 21-50% (w/w), inert materials varied between 10-17% (w/w) and the soil type material ranged between 34- 60% (w/w). Metal content varied between 3 and 6% (w/w).	Waste to energy, reuse as soil or construction material and metal recovery	Quaghebeur et al., 2012
	Finland	Fine Fraction (FF) contributes up to 40–70% (w/w) of excavated landfill materials. The FF cannot be compared with soil, because the FF from landfills contains possible inorganic and organic contaminants.	Landscape use and after analysis used as a nutrient	Mönkäre et al., 2015
	Sweden	High concentration of stones, asphalt and limestone (36.1%), soil-type materials (27.3%) and wood (15.2%) dominate the composition of the waste materials.High concentrations of zinc, copper, barium and chromium were found.	Waste to material, metal extraction and waste to energy	Jani et al., 2016
	Beijing	The major identifiable components of the waste were plastics, stone, and glass, comprising 13.9%, 13.2%, and 8.2% (w/w), respectively. Fine particles or waste soil was 70.1% but not suitable for agricultural practice.	Resource recovery	Rong et al., 2017
Indian Scenario	Chennai	Soil fraction varies from 40% - 68%. Cr, Cu, Hg, Ni and Pb are exceeding the Indian Standard limits.	As compost to non-edible crops or as cover material after determining the geotechnical suitability.	Kurian et al., 2003
	Nagpur	Very high percentage of the organic fraction in the waste (77%) followed by plastics (11.60%), and paper (7.66%).	Use the recovered inert in Civil Engineering applications.	Mandpe et al., 2019
	Mumbai	Fine fraction dominates the dumpsite with ~45% average content. Combustible fraction constituted an average of 21% of total waste.	RDF	Singh & Chandel, 2019
	Delhi, Hyderabad and Kadapa	(60–70)% of the total excavated waste was Soil-like material and it consists of high levels of organic matter, heavy metals, soluble salts.	After treatment use as an earth fill in embankments, low-lying areas, and deep pits.	Datta et al., 2021
	Kolkata	Nearly40% was soil-like material, 30.3% shared non-combustible, C&D waste, inert, around 7.3% of combustible material, and residual	RDF, low lying areas filling, bedding of road construction	Bir et al., 2022

		amount came as approximately 7%.		

3. Valorisation of the excavated legacy waste materials

Based on the characteristics of the individual fractions separated from the legacy waste, the valorisation options were assessed. The benefits of the landfill mining activities are associated with the recovered materials and landfill air-space. The prices of the recyclables are influenced by the fluctuations in the market prices, the structure of the local market, as well as other parameters like the quality of the materials sold and the distance between the landfill and the recycling industry. The possibility of using the fine fraction of waste in the building and construction industry, road repairing, and soil nutrient, however, requires further study. Legislative gaps, dubious viability, leaching risks, and challenging geotechnical properties are issues that will need to be resolved in the future.Table2 presents the summary of monetary valorisation of excavated legacy waste reported in few landfill mining projects carried out worldwide. In the Indian context, the valorisation study on legacy waste is not anything noteworthy. In India, legacy waste is mostly composed of soil-like materials and the percentage is about (40 – 77)% (Table 1).Thus, it is difficult to calculate the direct cost of legacy waste rather than indirect cost. Bir et al.(2022) suggested some revenue generation options for the Kolkata landfill that include compost products, anaerobic digester, power generation and recycling products which will enhance the economy to meet the sustainable circularity solution.

Table 2: Summary of monetary valorisation of excavated legacy waste reported in literature

Country	Valorisation of the excavated legacy waste								References
	Ferrous metals	Non-ferrous metals	Glass	Plastics	Recovered air-spaces	Electricity price	Recycling soil-type materials	RDF	
US	–	–	–	–	40 ($/m^3)	–	–	–	Jain et al., 2013
Belgium	–	1220 (€/t)	–	–	40 (€/m^2)	45(€/MWha)	–	–	Winterstetter et al., 2015
China	48.4 ($/t)		24.2 ($/t)	–	1.77 ($/m^3)	–	9.68 ($/t)	12.1 ($/t)	Zhou et al., 2015
Greece	60 – 110 (€/t)	660 – 1200 (€/t)	10 – 15 (€/t)	100 - 300 (€/t)	35 – 30 (€/t)	–	–	–	Damigos et al., 2016a

4. Economic feasibility of landfill mining projects

Excavation, material sorting, transport, recovery/treatment plants, and plant operations and maintenance account for the majority of the costs associated with landfill mining (LFM) projects. Van Der Zee et al. (2004) evaluated the advantages and expenses of landfill reclamation. The expenses are primarily broken down into capital costs (site preparation, equipment rental or purchase, material handling facility) and operational costs (labour, maintenance, safety, hauling and final disposal). The advantages are primarily attributable to revenue from recyclables, combustibles, recovered landfill space, and reduced expenses. The cost and benefit will also depend on closure and aftercare requirements, remediation necessity, waste characteristics, waste decomposition status and local economics (cost of recyclables, land value, labour costs among others). In most of the cases, the capital and operational cost exceed the revenue generated from extracted materials (Van Passel et al., 2012;Frändegård et al., 2015;

Maheshi et al., 2015; Wolfsberger et al., 2016). However, no literature is available on assessment of economic feasibility of landfill or dumpsite in Indian context. Consideringwaste characteristics under Indian context, major revenue sources would be landfill space recovery and combustible fraction(Dubey et al., 2016; Mandpe et al., 2019). One of the major revenue sources reported in most of the literatures was metal fraction, which is very low in case of Indian dumpsites(Singh & Chandel, 2019).So far, only a very few studies have focused on the economic feasibility of LFM from a private point of view and even less studies have been attempted to economically justify the need for LFM projects from a social point of view. Apart from environmental and social risks and benefits associated with LFM, economic aspects should also be taken into account. In developed countries likeEurope more than 150000 landfills are present and it has been reported that from 60 LFM projects, metals to be recovered (2.5% volume) is responsible for a significant cost reduction (≈20%) in regard to landfill mining costs (Vossen, 2013). In Florida 371,000 m^3oflegacy waste was excavated and the gross monetary benefit was approximately US$6.0 million, since the airspace recovered was valued at over US$9.0 million (Jain et al., 2013).In China,the average cost of landfill mining was 12.7 USD ton^{-1} and a net positive benefit between US$1.92 million to US$16.63 million (Zhou et al., 2015). In US 34,352 Mt of ferrous and non-ferrous metals were recovered and recycled and the conservative value of the recovered metal was estimated as $7.42 million. Mining also increased the landfill's airspace by 10,194 m^3 extending the life of the ashfill with an estimated economic value of $267,000.Thus, the estimated per-Mt cost for the extraction of metal was $158(Wagner & Raymond, 2015). InIndia, a cost–benefit analysis was carried out for twopotential scenarios (a) mining for recovery and (b) transferring MSW from the dump to a new sanitary landfillwhere in case of dumpsite mining for resource recovery, the additional cost of setting up a new dumpsite was saved, as the existing site could be used five times in a period of 50 years assuming dumpsite mining to be carried out once in 10 years. The total saving would be around Rs. 80 million if the same landfill and dumpsite mining is used over the period of 50 years(Mandpe et al., 2019).

5. Social justification oflandfill mining projects

Higher recycling/reuse targets for municipal and other wastes are being promoted by new solid waste management policies around the world, and landfilling for recoverable non-hazardous waste is being phased out gradually (e.g., plastic, paper, metals, glass and organic materials). The implementation of these policies will reduce the volume of waste sent to landfills which ultimately reduce the effects on the environment and human in the long run.Besides containing useful materials (Hermann et al., 2014; Kapur & Graedel, 2006; Quaghebeur et al., 2012),these landfills may also be a potential source of environmental contamination and nuisance and may occupy valuable land that could be utilized for other development purposes. It reduces the property value also. By reducing impacts, providing secondary raw materials from recycling, creating jobs, and other socially beneficial outcomes, a proper waste management system could eliminate these externalities and produce positive social effects. However, these advantages come at a price, including infrastructure for waste management, improved collection systems, public awareness campaigns, etc., which can be costly or at least more costly than conventional waste management methods. More importantly, particularly in developing economies, improved waste management systems may be more expensive than what society can afford(Damigos et al., 2016b).

It is important to understand how much the provision of a public good and/or an externality affects the well-being of economic agents. Since utility cannot be directly measured, an indirect measure should be taken into consideration. Individual preferences are to be taken into account as the source of perceived benefits. The willingness to pay (WTP) for a benefit and the willingness to accept compensation (WTA) for a cost are the actual metrics used to measure preferences (Pearce et al., 2006). According to the estimates, households in Africa and Asia would be willing to contribute, respectively, 0.56% and 0.16% of their annual income to better MSW management. WTP-to-income ratios in developed regions, such as Europe, North America, and Oceania (actually Australia), range from 0.04% to 0.07%(Damigos et al., 2016b). According to the empirical survey conducted at a rural area in Greeceapproximately 70% of the respondents' stated that the most important problem that they faced is unemployment, followed by the poor economy (22.4%) and the environmental pollution (4.2%). However, due primarily to the economic downturn and high unemployment, only one-fourth of the respondents are willing to pay increased taxes for LFM. The mean willingness to pay (WTP) for the entire population under investigation is approximately €12 per household per year where for willing people the WTP value is about €50 per household per year. (Damigos et al., 2016b)

6. Senario Study for West Bengal

West Bengal is thefourth-most populous statein India with almost9.13crorepopulation(ORGI, 2011).Currently, West Bengal has around 125 ULBs and these ULBs generate about 13709.412TPD MSW according to the information available from WBPCB, 2021areport. Fig. 1 presents the MSW generation by different municipal areas of West Bengal. On an average, per capita waste generation in West Bengal is 592 gm/day(WBPCB, 2021b).Due to variation in both geographic origin and the socio-economic conditions, the compositions of MSW are likely to be different in various regions.West Bengal is no exception from this case. As per CPCB (2021),Kolkata Municipal Corporation and Howrah Municipal Corporation generated 4500 TPD and 720TPD of MSW respectively, of which only 515 TPD and 61.5 TPD were processed,therefore,gap inMSWgeneration and treatment was3985 TPD and 658.5 TPD respectively. In case of Asansol Municipal Corporation MSW processing is absent and all the wastes are directly disposed as open landfilling. It is estimated that in 2035 Kolkata Municipal Corporation will generate daily near about 8805 MT of solid waste. But on an average, it has been assessed that roughly only 700 ton of these generated waste are collected and stored every day(Ali, 2016). So, there is a huge gap between waste production and waste treatment, which create several environmental issues. In West Bengal,source segregation is not 100% practiced and after collection the wastes are mainly dumped at the landfill site thereafter covering it with a nominal daily cover, without any treatment creating different geo-environmental and health problems. In Kolkata and surrounding municipality areas open landfill sites are surrounded by wetlands and residential colonies, slum area as well as high rise buildings also. Slum regions are plagued by extra concerns such as excessive population density, traffic, air and water pollution, open landfilling next to water bodies, and other problems that are related to public health.For this purpose, it is compulsory that a thoroughanalysis and expert consultation be initiated as soon as possible for this purpose without further delay.In compliance of the directions of the Hon'ble NationalGreen Tribunal (NGT), biomining work has also startedat 78 out of 107 legacy dumpsites throughout the West Bengal, which includes the Promod Nagarand Mollar Bheri Dump sites. Biomining of legacy waste at Dhapa dumpsitehas been started by KMC and so far, 1,31,606 Mt legacy waste has been processed with 3.2 hectare of the dumpsite land has yet been reclaimed (NGT, 2022). However, after 3 years of issuance of NGT order there is insufficient study on characterisation on legacy waste and reuse feasibility of stabilized legacy waste.

Fig. 1: Waste Generated by Municipal Corporations in West Bengal *(Source:WBPCB, 2021b)*

7. Conclusion

For decision-makers MSWmanagement is a fundamental problemto develop anaffordable system which could appropriatelyprotect public health and the ecosystemfrom unreasonablerisk of damage due to uncontrolled waste dumping, mixed type of waste streams, unscientific disposal and most importantly aesthetics and health impact on the neighbourhood settlement.Economic feasibility and social justification are crucial aspects of making decisions regardingbiomining projects over conversion of open landfillconsideringthe cost associated with the closure and post closure management.However, veryfew studies have been so far undertaken on the economic issue of conversion of open landfill to biomined landfill and in respect to West Bengal the result is almost insignificant.Developed Countries have minimised the quantity of wastes to be open landfilledby implementing a combination of recycling, composting, anaerobic digestion, recycling, RDF, pyrolysis, gasifcation, engineered landflls, etc. In Indian context, MSWconsists of (40–60)% of organic matter, which can beused for compost or biogas production.The selection of waste management system depends on population size, the quantity of waste, waste characters, the economics of waste processing, environmental condition, country's policiesregarding waste recycling and recovery etc.There is a fundamentaldilemma that the economic incentive will not be adequate forprivate landfill mining operators, despite the social or publicbenefits of landfill mining beingextraordinarily high.Therefore, proper economic feasibility analysisis requred for checking sustainability of the project. Biomining will not provide exhumationthat only reclaimed landfill space but it has external benefit e.g. improving the urban landscape and ground waterquality, building new parks on the old landfill, andincreasing employment opportunities etc. which should also be taken into account during policy making.

References

Ahluwalia, I. J., & Patel, U. (2018). Working Paper No . 356 Solid Waste Management in India An Assessment of Resource Recovery and Environmental Impact Isher Judge Ahluwalia. In *Indian Council for Research on International Economic Relations* (Issue 356).

Ali, S. A. (2016). Status of Solid Waste Generation and Management Practice in Kolkata Municipal Corporation, West Bengal. *International Journal of Environmental Sciences*, *6*(6), 1173–1186. https://doi.org/10.6088/ijes.6112

Bir, T., Banerjee, S., & Dutta, A. (2022). Legacy Waste Characterization: Bio-mining Solution for Landfills and Resource Recovery Towards Circularity. In *Environmental Science and Engineering*. https://doi.org/10.1007/978-3-030-96554-9_43

CPCB. (2018). MSW Trend in 46 Cities in India List 2018-CPCB Report 2018. In *CPCB*. https://doi.org/10.1002/9780470999677.ch8

CPCB. (2021a). *Annual Report 2020-2021 on Implementation of Solid Waste Management Rules , 2016, Central Pollution Control Board, Delhi*. https://cpcb.nic.in/uploads/plasticwaste/Annual_Report_2019-20_PWM.pdf

CPCB. (2021b). *Supplementary Report on Solid Waste Management in The Matter Of O.A No. 606 Of 2018, Titled Compliance of Municipal Solid Waste Management Rules, 2016 And Other Environmental Issues*. https://doi.org/https://cpcb.nic.in/uploads/MSW/Reports_swm_7.pdf

Damigos, D, Benardos, A., Menegaki, M., Kaliampakos, D., Papagrigoriou, S., Gaitanarou, Z., & Stasinos, S. (2016). Assessing the economic viability of landfill mining projects in Greece. *Conf. on Sustainable Solid Waste Management*, 23–25.

Damigos, Dimitris, Kaliampakos, D., & Menegaki, M. (2016). How much are people willing to pay for efficient waste management schemes? A benefit transfer application. *Waste Management and Research*, *34*(4), 345–355. https://doi.org/10.1177/0734242X16633518

Datta, M., Somani, M., Ramana, G. V., & Sreekrishnan, T. R. (2021). Feasibility of re-using soil-like material obtained from mining of old MSW dumps as an earth-fill and as compost. *Process Safety and Environmental Protection*, *147*, 477–487. https://doi.org/10.1016/j.psep.2020.09.051

Dubey, A., Chakrabarti, M., & Pandit, D. (2016). Landfill Mining as a Remediation Technique for Open Dumpsites in India. *Procedia Environmental Sciences*, *35*, 319–327. https://doi.org/10.1016/j.proenv.2016.07.012

Frändegård, P., Krook, J., & Svensson, N. (2015). Integrating remediation and resource recovery: On the economic conditions of landfill mining. *Waste Management*, *42*, 137–147. https://doi.org/10.1016/j.wasman.2015.04.008

Hermann, R., Baumgartner, R. J., Sarc, R., Ragossnig, A., Wolfsberger, T., Eisenberger, M., Budischowsky, A., & Pomberger, R. (2014). Landfill mining in Austria: Foundations for an integrated ecological and economic assessment. *Waste Management and Research*, *32*(9), 48–58. https://doi.org/10.1177/0734242X14541168

Hogland, W., Marques, M., & Nimmermark, S. (2004). Landfill mining and waste characterization: a strategy for remediation of contaminated areas. *Journal of Material Cycles and Waste Management*, *6*(2), 119–124. https://doi.org/10.1007/s10163-003-0110-x

Jain, P., Townsend, T. G., & Johnson, P. (2013). Case study of landfill reclamation at a Florida landfill site. *Waste Management*, *33*(1), 109–116. https://doi.org/10.1016/j.wasman.2012.09.011

Jani, Y., Kaczala, F., Marchand, C., Hogland, M., Kriipsalu, M., Hogland, W., & Kihl, A. (2016). Characterisation of excavated fine fraction and waste composition from a Swedish landfill. *Waste Management and Research*, *34*(12), 1292–1299. https://doi.org/10.1177/0734242X16670000

Kaartinen, T., Sormunen, K., & Rintala, J. (2013). Case study on sampling, processing and characterization of landfilled municipal solid waste in the view of landfill mining. *Journal of Cleaner Production*, *55*, 56–66. https://doi.org/10.1016/j.jclepro.2013.02.036

Kapur, A., & Graedel, T. E. (2006). Copper mines above and below ground. Estimating the stocks of materials in ore, products, and disposal sites opens up new ways to recycle and reuse valuable resources. *Environmental Science & Technology*, 3135–3141.

Kaza, S., Yao, L., Bhada-Tata, P., & Woerden, F. Van. (2018). What a Waste 2.0 A Global Snapshot of Solid Waste Management to 2050. In *World Bank*. https://openknowledge.worldbank.org/handle/10986/30317

Kumar, A., & Agrawal, A. (2020). Recent trends in solid waste management status, challenges, and potential for the future Indian cities – A review. *Current Research in Environmental Sustainability*, *2*, 100011. https://doi.org/10.1016/j.crsust.2020.100011

Kumar, S., Smith, S. R., Fowler, G., Velis, C., Kumar, S. J., Arya, S., Rena, Kumar, R., & Cheeseman, C. (2017). Challenges and Opportunities Associated with Waste Management in India. *Royal Society Open Science*, *4*(3), 1–11. https://doi.org/10.1098/rsos.160764

Kurian, J., Esakku, S., Palanivelu, K., & Selvam, A. (2003). Studies on Landfill Mining At Solid Waste Dumpsites in India. *Ninth International Waste Management and Landfill Symposium, In Proceedings Sardinia*, *3*(October), 248–255.

Maheshi, D., Steven, V. P., & Karel, V. A. (2015). Environmental and economic assessment of “open waste dump” mining in Sri Lanka. *Resources, Conservation and Recycling*, *102*, 67–79. https://doi.org/10.1016/j.resconrec.2015.07.004

Mandpe, A., Kumar, S., Lakshmikanthan, P., & Hettiarachchi, H. (2019). Mining for recovery as an option for dumpsite rehabilitation: Case study from Nagpur, India. *Journal of Environmental Engineering and Science*, *15*(2), 52–60. https://doi.org/10.1680/jenes.19.00021

Modak, P. R., & Nangare, P. B. (2011). Quantitative and Qualitative Assessment of Municipal Solid Waste for Nagpur City. *Journal of Engineering Research and Studies*, *2*(2), 55–61.

Mohan, S., & Joseph, C. P. (2020). Biomining: An Innovative and Practical Solution for Reclamation of Open Dumpsite. In *Recent Developments in Waste Management* (pp. 167–178). Springer Nature Singapore Pte Ltd. https://doi.org/https://doi.org/10.1007/978-981-15-0990-2_12

Mönkäre, T. J., Palmroth, M. R. T., & Rintala, J. A. (2015). Characterization of fine fraction mined from two Finnish landfills. *Waste Management*, *47*, 34–39. https://doi.org/10.1016/j.wasman.2015.02.034

NGT. (2022). *Before The National Green Tribunal Eastern Zone Bench , Kolkata Miscellaneous Application No . 05 / 2021 / EZ In Original Application No . 33 / 2014 / EZ*.

Niyati, M. (2015). *A comparative study of municipal solid waste management in India and Japan*. *25*, 48–61.

ORGI. (2011). *Office of the Registrar General & Census Commissioner, India. Primary Census Abstract. Table Basic Population Figures of India/State/District/Sub-District/Village - 2011*. Office of the Registrar General & Census Commissioner, India. https://censusindia.gov.in/nada/index.php/catalog/42560

Pearce, D., Atkinson, G., & Mourato, S. (2006). Willingness to Pay vs. Willingness to Accept,. In *Cost-Benefit Analysis and the Environment Recent Developments* (pp. 155–167). https://doi.org/10.1787/9789264010055-12-en

Prechthai, T., Padmasri, M., & Visvanathan, C. (2008). Quality assessment of mined MSW from an open dumpsite for recycling potential. *Resources, Conservation and Recycling*, *53*(1–2), 70–78. https://doi.org/10.1016/j.resconrec.2008.09.002

Quaghebeur, M., Laenen, B., Geysen, D., Nielsen, P., Pontikes, Y., Van Gerven, T., & Spooren, J. (2012). Characterization of landfilled materials: Screening of the enhanced landfill mining potential. *Journal of Cleaner Production*, *55*, 72–83. https://doi.org/10.1016/j.jclepro.2012.06.012

Rong, L., Zhang, C., Jin, D., & Dai, Z. (2017). Assessment of the potential utilization of municipal solid waste from a closed irregular landfill. *Journal of Cleaner Production*, *142*, 413–419. https://doi.org/10.1016/j.jclepro.2015.10.050

Singh, A., & Chandel, M. K. (2019). Effect of ageing on waste characteristics excavated from an Indian dumpsite and its potential valorisation. *Process Safety and Environmental Protection*, *134*, 24–35. https://doi.org/10.1016/j.psep.2019.11.025

Somani, M., Datta, M., Ramana, G. V., & Sreekrishnan, T. R. (2018). Investigations on fine fraction of aged municipal solid waste recovered through landfill mining: Case study of three dumpsites from India. *Waste Management and Research*, *36*(8), 744–755. https://doi.org/10.1177/0734242X18782393

Van Der Zee, D. J., Achterkamp, M. C., & De Visser, B. J. (2004). Assessing the market opportunities of landfill mining. *Waste Management*, *24*(8), 795–804. https://doi.org/10.1016/j.wasman.2004.05.004

Van Passel, S., Dubois, M., Eyckmans, J., De Gheldere, S., Ang, F., Tom Jones, P., & Van Acker, K. (2012). The economics of enhanced landfill mining: Private and societal performance drivers. *Journal of Cleaner Production*, *55*, 92–102. https://doi.org/10.1016/j.jclepro.2012.03.024

Vossen, W. van. (2013). Feasibility Study Sustainable Material and Energy Recovery from Landfills in Europe. In *Istanbul International Solid Waste, Water And Wastewater Congress, Halic Congress Center, Istanbul, Turkey, 22-24 May* (pp. 347–349).

Wagner, T. P., & Raymond, T. (2015). Landfill mining: Case study of a successful metals recovery project. *Waste Management*, *45*, 448–457. https://doi.org/10.1016/j.wasman.2015.06.034

WBPCB. (2021a). State of Environment Report-II West Bengal 2021. In *Department of Environment Government of West Bengal*. https://www.wbpcb.gov.in/files/Fr-09-2021-09-10-01SoE Report VOL 02.pdf

WBPCB. (2021b). State Plan Environment West Bengal Based on District Environment Plans. In *Department of Environment, Government of West Bengal*. https://www.wbpcb.gov.in/files/Fr-04-2021-04-11-32State Environment Plan and District Enviornment Plan West Bengal.pdf

Winterstetter, A., Laner, D., Rechberger, H., & Fellner, J. (2015). Framework for the evaluation of anthropogenic resources: A landfill mining case study - Resource or reserve? *Resources, Conservation and Recycling*, *96*, 19–30. https://doi.org/10.1016/j.resconrec.2015.01.004

Wolfsberger, T., Pinkel, M., Polansek, S., Sarc, R., Hermann, R., & Pomberger, R. (2016). Landfill mining: Development of a cost simulation model. *Waste Management and Research*, *34*(4), 356–367. https://doi.org/10.1177/0734242X16628980

Zhou, C., Gong, Z., Hu, J., Cao, A., & Liang, H. (2015). A cost-benefit analysis of landfill mining and material recycling in China. *Waste Management*, *35*, 191–198. https://doi.org/10.1016/j.wasman.2014.09.029