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Geoenvironmental characterization of minus 6mm fraction obtained by on-site trommeling of legacy waste at a MSW dumpsite in India

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ABSTRACT

A full-scale landfill mining (LFM) of an old MSW dump (>60m high) containing more than 6 million tonnes of legacy waste is in progress in the capital city of India. In LFM, a mechanically operated rotating cylindrical screen called trommel segregates the excavated waste into different size fractions such as >30mm fraction composed of construction and demolition (C&D) fraction, and refuse-derived fuel (RDF), 30-6mm fraction and <6mm fraction. The <6mm fraction, referred to as soil-sized fraction (SSF) in the present study, was analysed for geoenvironmental characteristics. Organic content (OC), pH, electrical conductivity (EC), colour, total dissolved solids (TDS), sulphates, chlorides, leachable, and total heavy metals were assessed to evaluate the contamination potential of SSF. It has been observed that the SSF has significantly higher dissolved solids (TDS=14920-22000mg/kg, sulphate=3280-7000mg/kg, chloride=3100-4100mg/kg), EC (1.7-2.3mS/cm), OC (7.7% to 16.2%), undesirable colour (110-490 PCU) compared with the background level. Although the total content of heavy metals in the soil-sized fraction (SSF) is significantly higher than that of the background soil, the concentrations of cadmium (Cd), copper (Cu), nickel (Ni), and zinc (Zn) in the water extracts are only marginally elevated. The study has revealed that though leachable heavy metals are not alarmingly high in SSF, care should be taken to mitigate the elevated organic content, high dissolved solids, and undesirable colour emanating from the SSF.

Keywords: landfill mining; legacy waste; soil-sized fraction; contamination potential; reuse; off-site application

1 BACKGROUND

Worldwide there are thousands of uncontrolled waste dumps (open or capped) which are the potential sources of significant environmental concerns and health hazards (Danthurebandara et al., 2015; Hölzle, 2018; Kollikkathara et al., 2009; Mönkäre et al., 2015; Wagner & Raymond, 2015). Excavation of old waste dumps and recovery of material and energy termed landfill mining (LFM) is considered an effective remedial measure to restrain further contamination and prevent nearby habitats from serious health hazards (Hogland, 2002; Jain et al., 2013; Quaghebeur et al., 2013). Enhanced landfill mining (ELFM) intends to recover valuables from legacy waste dumps and reintroduce them in the economic cycle promoting a circular economy for a sustainable environment (Einhäupl et al., 2021; Jones et al., 2013; Krook, 2021; D. Wang et al., 2020). Valorization of excavated materials can be achieved by substantive processing and treatment of reusables for bulk reuse in on-site and off-site applications (Esguerra et al., 2021; Krook et al., 2012). Considerable content of soil-sized fractions (SSF) indicates the potential of recovered materials for reuse in off-site applications such as the construction of road and railway embankments, filling low-lying areas and dead mines present in the urban settlements (Somani et al., 2020).

Most of the researchers have studied only the on-site applications whereas a few studies have addressed off-site reuse (Hölzle, 2019; Hull et al., 2005; Joseph et al., 2003; Zhao et al., 2007) of excavated materials of varying sizes (0.425mm to 70mm). However, it is imperative to characterize these materials for their contamination potential before reusing them in off-site land applications.

Determination of concentration potential is an indispensable requirement while investigating the reuse potential of excavated legacy waste (Jani et al., 2016; Krook et al., 2012). Variation in waste composition among the landfills as a result of regional recycling and waste management practices, consumer habits, living standards and prevailing waste legislation in different geographic regions makes LFM uncertain and necessitates site-specific studies (Hogland, 2002; Hull et al., 2005; Joseph et al., 2003; Prechthai et al., 2008; Thitame et al., 2010).

The segregated SSF comprises about 60-70% of the total waste (Hogland, 2002; Somani et al., 2020) indicating a huge potential to reuse as a replacement for natural soils. Due to the unavailability of space, appropriate treatment technology, and lack of funds and management practices the reclaimed materials are being used for filling mine pits, low-lying areas, and road construction without any preventive measures. This has motivated the authors to study the contamination potential of SSF used in open areas in a huge quantity that may cause irreversible long-term contamination of the surrounding environment.

The present study has evaluated the geoenvironmental characteristics of SSF (<6mm fraction) recovered from a full-scale LFM of an old MSW dump in India. Parameters such as organic content (OC), pH, electrical conductivity (EC), colour intensity, total dissolved solids (TDS), sulphates, chlorides, leachable and total heavy metals were studied to assess the contamination potential of SSF. The studied parameters were compared with the locally available soil (Delhi silt) which is a natural material used in earth work applications in the city. The parameters studied for SSF were also analysed for the local soil and the contents present in local soil is termed as the background level for the corresponding parameter. Total excavated waste was also analysed for the compositional heterogeneity and grain size distribution (GSD) of legacy waste disposed of in decades-old (>25 years) dumps.

2 MATERIALS AND METHODS

2.1 Study site

Trommeled legacy waste was collected from a full-scale LFM of an old waste dump at Okhla (28°30'43.00" N, 77°17'01.76" E) in the capital city of India. The dump site and sampling points are depicted in Figure 1. This waste dump is one among the three biggest dumpsites in the city which are

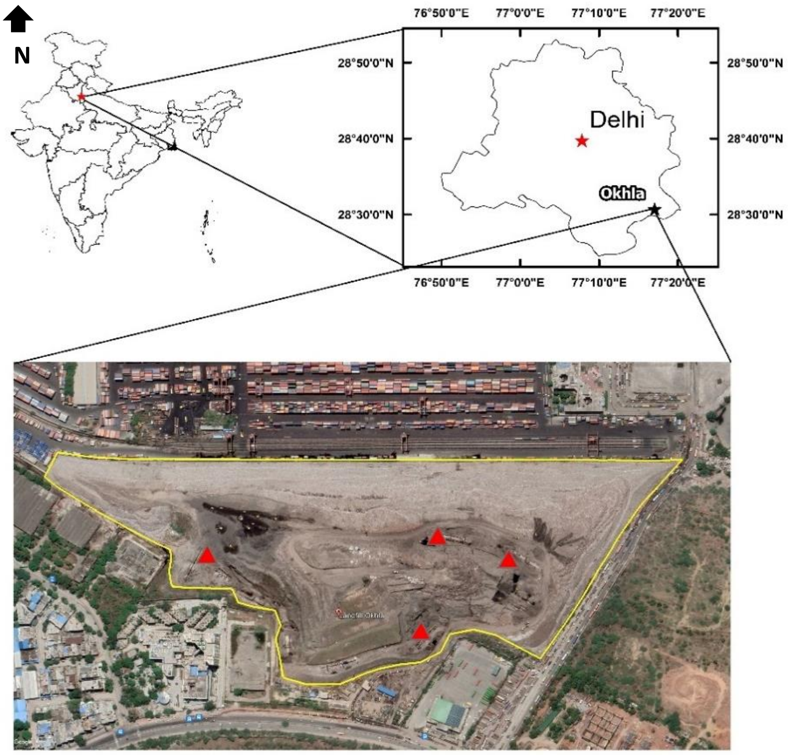

Figure 1. Location of the dumpsite and sampling points

the major contributors to the environment pollution. The site is surrounded by local habitats, green field, and commercial establishments. Since 1996 this dump site receives fresh wastes even beyond its waste-carrying capacity and maximum allowable height. More than 6 million tonnes of legacy waste are accumulated in this dump with more than 60m in height from the ground surface (CPHEEO, 2020). Steep slopes make the waste mountain vulnerable to slope failure. About 46 acres of land is covered by this dumpsite. This dumpsite has no bottom liner and leachate collection system which is considered a threat to the contamination of subsoil, groundwater, and surface water sources.

2.2 Sample collection and processing

The LFM operation started in 2019 at the dumpsite following the direction of the national green tribunal (NGT) of India to curb the environmental pollution caused by this dumpsite (CPCB, 2020). As per the direction the dumped legacy wastes are excavated, dried to reduce moisture and trommeled to separate the total excavated waste into different size fractions. Trommels with 30mm and 6mm screens segregate the total waste into >30mm fraction, 30-6mm fraction and <6mm fraction (SSF). Trommel is a mechanically operated rotating cylindrical screen. For the present study, the excavated legacy waste and the SSF were collected during the LFM operation at the dump site. The methodology adopted for

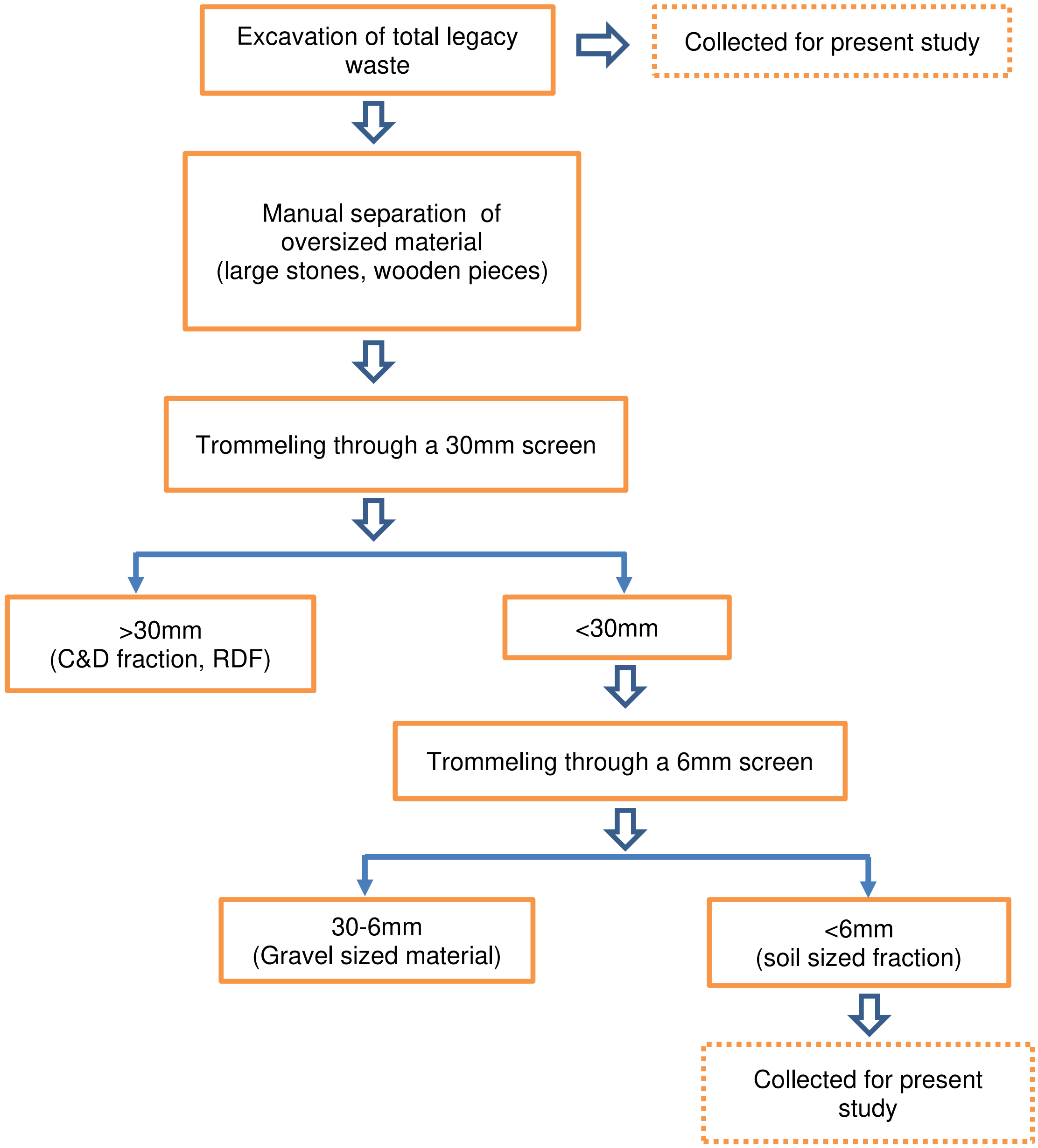

Figure 2. *Methodology adopted for landfill mining and sampling at the dumpsite*

landfill mining and sampling at the dumpsite is depicted in Figure 2. Total excavated samples were collected from 2-4m depth from the surface. The excavated samples were collected at four locations on the dumpsite where the trommels were operating. Samples were collected randomly by a backhoe excavator near the trommel locations. The excavated legacy waste was kept on a clean concrete platform and dried under a shed to reduce the moisture content for further analysis. The collected SSF was preserved at 4 °C in the laboratory immediately after collection. Representative samples of dried total waste were taken by coning and quartering.

Local soil samples (Delhi silt) were considered as reference background material to assess the potential contaminants in the SSF. Local soils were collected from 1-5km away from the periphery of the dumpsite and 0.5m below the ground surface to ensure the collection of uncontaminated soils.

2.3 Composition and grain size distribution of total fraction

The air-dried total fraction was segregated into different components by manual sorting for compositional analysis. ASTM D5231 was followed for the compositional analysis of unsegregated total fractions. About 200-400 kg of dried samples were taken for this analysis to comply with the minimum weight of sample requirement (91-136kg) as specified in the standard. The samples were first sieved through a 13.2mm screen to separate the finer fraction which is strenuous by manual sorting.

Figure 3. *Screening (left) and manual sorting (right) of excavated legacy waste*

The coarse fractions (>13.2mm) were sorted manually into construction and demolition (C&D) fractions, combustibles (paper, plastic, wood, textile, other organics) and non-combustibles (glass, ceramics, metals). Similar studies were also reported by (Kaartinen et al., 2013; Somani et al., 2020; Sormunen et al., 2008; Zekkos et al., 2010). The on-site screening before sorting and manual sorting of the total fraction are shown in Figure 3.

On-site grain size distribution (GSD) of the total fraction was performed by using the screens available at the dumpsite (75mm, 35mm, 20mm, 4.75mm). The fraction passing through the 4.75mm screen was further sieved through a set of fine sieves (2mm, 1mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm) in the laboratory. Washed sieving of the total fraction was also performed in the laboratory. On-site sieving of the total fraction is shown in Figure 4.

2.4 Laboratory studies of SSF

The freshly collected SSF from the trommeling of legacy waste was analysed for moisture content (MC) and OC. The MC and OC were determined by following method-A and method-C specified in ASTM

D2974, respectively. This method was also followed by (Burlakovs et al., 2016; Mönkäre et al., 2016; Y. nan Wang et al., 2021).

Figure 4. *On-site sieving of the dried excavated legacy waste*

One-stage batch leaching test was performed to obtain water extract from SSF using an end-to-end rotary agitator. Double distilled water was used as an eluant for the batch leaching of SSF. A liquid-to-solid ratio (L/S) of 10 was maintained by following the procedure specified in SS-EN 12457-4 (2002). For leaching, 100gm of oven dried SSF was mixed with 1000ml of distilled water (L/S=10) and the mix was agitated for 16-18 hours at 30rpm. The water extract was filtered through a 0.45-micron syringe filter for subsequent analyses. The filtered water extract was analysed for pH, EC, TDS, sulphates, chlorides, and leachable heavy metals. The colour intensity of the water extract was measured by a tintometer (Lovibond tintometer) in a platinum cobalt unit (PCU). For the analysis of dissolved solids and associated parameters in water extract APHA (2012) was followed. TDS was measured by gravimetric method in which 50ml of the eluate was oven dried at 105 °C for 24 hours and the mass of solids settled in the container was weighed. Water soluble sulphate was measured by the turbidimetric method whereas chloride was measured by the titrimetric method. Leachable heavy metals were determined by inductively coupled plasma mass spectrometry (ICP-MS) (AGILENT 7900) which was also adopted by (Aruta et al., 2022; Somani et al., 2020).

The total content of available heavy metal in SSF was determined by the aqua-regia method followed by microwave digestion. In aqua-regia digestion, nitric acid, and hydrochloric acid in 1:3 proportion were used for the complete digestion of solids. For acid digestion, the size of SSF was reduced to <0.075mm by ball milling. About 0.2gm of pulverized SSF was taken for digestion. In the microwave digester (GO 7000, Anton Paar) the sample with acids was gradually heated to 180 °C, maintained for 20 minutes and then gradually cooled to room temperature. The digested samples were filtered through a syringe filter (0.45-micron) in a volumetric flask and diluted to the desired volume. The filtrates were then analysed by ICP-MS to determine the total heavy metal content in SSF.

3 RESULTS AND DISCUSSION

3.1 Manual sorting and GSD of total fraction

The components of excavated legacy waste separated by manual sorting are shown in Figure 5. The percentage content (on weight basis) of each component of the total fraction is presented in Table 1.

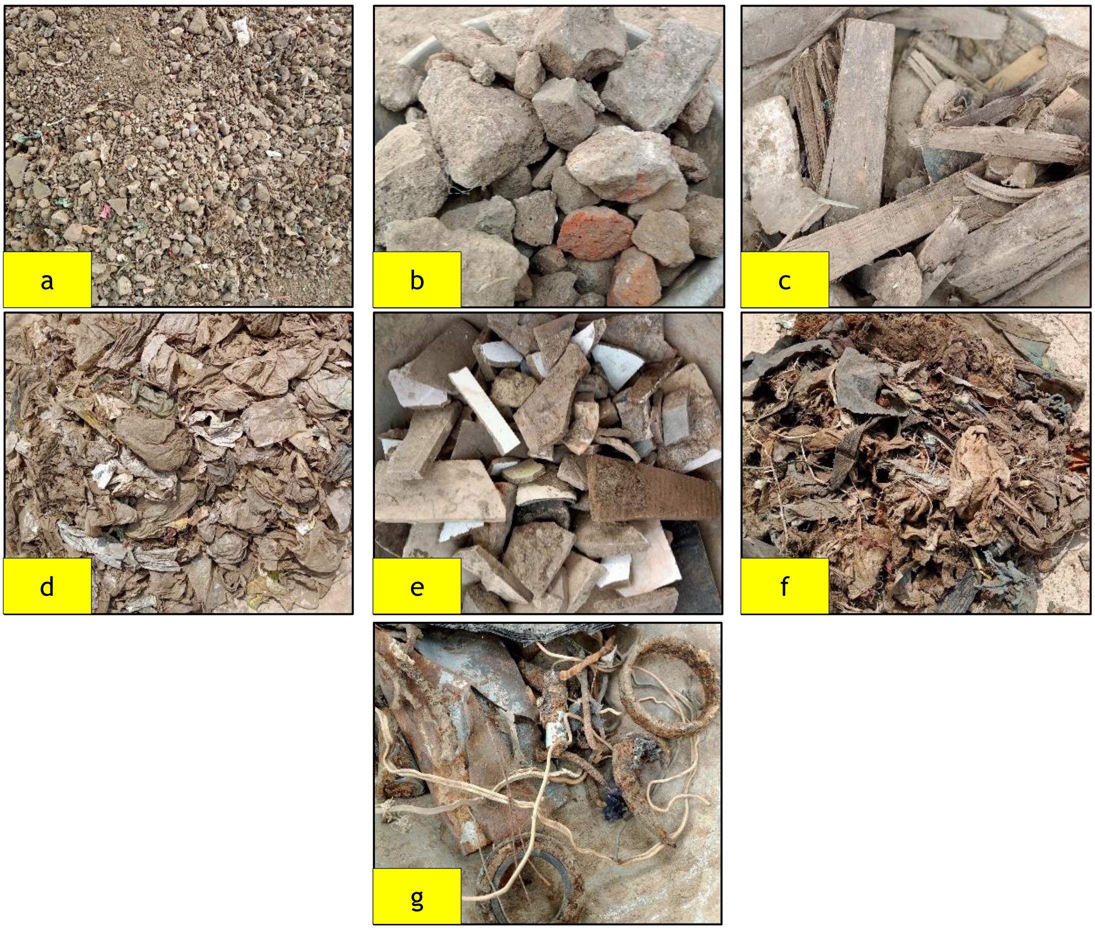

Figure 5. *Composition of excavated legacy waste by manual sorting: a) fine fraction (<13.2mm); b) C&D fraction; c) wood; d) plastic; e) ceramics; f) textile; g) metal*

The fine fraction (<13.2mm) constitutes about 68-80% of the total fraction which is predominantly composed of SSF and gravel sized fractions. The C&D fraction, which is composed of fine and coarse gravel sized fractions and brickbats is 17-29% of the total fraction. The significant content of fine fraction (<13.2mm) and C&D fraction (95-97%) indicates the potential of excavated legacy waste to be used in earthwork applications. The content of combustibles and non-combustibles is insignificant (0.73-2.06%) in the legacy waste which can be attributed to the extensive collection of recyclables by the rag pickers during open dumping of fresh waste.

The particle size distribution of excavated legacy waste is presented in Table 2. The on-site dry sieving and laboratory wet sieving have revealed that the excavated legacy waste consists of about 45-55% and 60-70% of <4.75mm fractions, respectively. This result is consistent with Mönkäre et al. (2016) and Quaghebeur et al. (2013). However, it must be noted that the fine fraction considered in the previous studies is different from the present study. Considerable content (25-38%) of gravel-sized materials (fine and coarse) is present in the legacy waste. The content of oversized fractions that include boulders, large stones, and wooden pieces is insignificant (1.6-6.5%) in the excavated total waste.

Table 1. *Composition of total fraction*

Components	Content (wt.%)
Fine fraction (<13.2mm)	68.4-79.7
C&D fraction	17-29
Combustibles	1.8-2.0
Non-combustibles	0.7-1.6

The total fraction has 25-37% of fines (<0.075mm) obtained by laboratory wet sieving analysis indicating the considerable presence of silt and clay content. Fine particles (<0.075mm) attached to the surface of the large particles get washed in weight sieve analysis resulting in different values of percentage fines compared to the dry sieving analysis. Fines have more surface area than the coarse fractions resulting in higher affinity to contaminants which can cause contamination of the sub-surface when applied on land without any preventive measures. It can be noted that the legacy waste has considerable content of silty sand with gravel.

Table 2. *Particle size distribution of total fraction*

Size in mm	Content (%)	
	Dry sieving	**Washed sieving**
>75 (Cobbles and boulders)	10.9-18.5	1.6-6.5
75-20 (Coarse gravel)	13.8-20.5	11.8-23.6
20-4.75 (Fine gravel)	17.0-20.3	12.0-14.4
4.75-0.075 (Sand)	39.5-45.2	32.3-37.9
<0.075 (Silt and clay)	5.6-9.4	25.5-37.3

3.2 Geoenvironmental analysis of SSF

3.2.1 Moisture content and organic content

The MC and OC of the SSF are presented in Table 3. The Indian guideline for mining legacy waste (CPCB, 2019) suggests sufficient drying of excavated legacy waste before trommeling. High MC (16.6-23.1%) of SSF as observed in the present study can affect the trommeling efficiency causing clogging of the trommel screen. The significant content of fines (25.5-37.3%) might have caused high MC in SSF.

The OC of SSF (8.0-16.2%) is considerably higher than the local soil (0.9-1.2%). Compared with the permissible limit of OC for road embankment (1-3%) in India, the SSF is found to be not suitable for the obtained OC. Such high OC indicates the presence of slowly degradable matters in the legacy waste (>25 years old). The use of SSF in filling applications without any treatment measure can result in long-term settlements due to the presence of high OC.

3.2.2 Leaching analyses

The water extract obtained from SSF by one-stage batch leaching was analysed for pH, EC, colour, dissolved solids and associated parameters, and heavy metals. The physicochemical parameters determined in the water extract are presented in Table 3.

The pH of SSF (7.1-8.0) is comparable with that of local soil (7.1-7.2) and it can be inferred that the SSF is slightly alkaline. The obtained pH of SSF can be attributed to a relatively stable waste indicating significant degradation of biodegradable matter. In contradiction, the presence of high OC indicates the availability of biodegradable matter.

Table 3. *Physicochemical parameters*

Parameter	Unit	SSF	Background level
Moisture content	%	16.6-23.1	-
Organic content	%	8.0-16.2	0.9-1.2
pH	-	7.1-8.0	7.1-7.2
Electrical conductivity	mS/cm*	1.7-2.3	0.2-0.3
Colour intensity	PCU*	110-490	25-30
Total dissolved solids	mg/kg	14920-22000	500-700
Sulphate	mg/kg	3280-7000	300-350
Chloride	mg/kg	3100-4100	200-250
Sodium	mg/kg	1878-3048	200-250
Magnesium	mg/kg	321-636	40-60
Potassium	mg/kg	1598-2449	30-70
Calcium	mg/kg	204-463	120-180

*mS/cm- milli Siemen per centimetre, PCU- platinum cobalt unit

Significantly high EC of SSF (1.7-2.3mS/cm) compared to the background level (0.2-0.32mS/cm) indicates the presence of high dissolved ions. The salinity of soil and water can be predicted from the EC values.

The colour intensity of water extract (110-490) is about 10-15 times higher than the background level in local soil. High colour intensity can affect the visual perception of groundwater and surface water. It is highly objectionable to use or consume coloured water. Appropriate treatment measures for SSF should be adopted to inhibit the colouration of surface and groundwater sources before use in earthwork applications.

The total dissolved solids and associated parameters are alarmingly high compared to the background level. Sulphates and chlorides are observed to be the major constituents comprising 50% of the TDS. It can be inferred that the SSF is highly contaminated by the dissolved solids, therefore needs rigorous treatment before disposal or reuse in off-site applications.

3.2.3 Assessment of heavy metal contamination

Leachable heavy metals in the water extract of SSF were determined by ICP-MS. The total available heavy metals were determined by acid digestion followed by the analysis of the digested sample (filtrate) by ICP-MS. The leachable heavy metal and total available heavy metal concentration of SSF are presented in Table 4. The leaching of arsenic and manganese, among the studied heavy metals, is observed to be elevated compared to the background level. In contrast, the total available heavy metals, except arsenic, in the solid phase of SSF are significantly high compared to that of the background level.

The mobility of individual heavy metals from the solid phase to the liquid phase of SSF can be assessed by determining the leaching ratio (LR) expressed in percentage. The calculated LR of each heavy metal is presented in Table 4.

Table 4. *Contents of heavy metals and leaching ratio*

Heavy metals	Leachable content (mg/kg)		Total content (mg/kg)		Leaching ratio (%)
	SSF	Background level	SSF	Background level	
Arsenic (As)	0.02-0.18	0.04-0.06	1.4-2.7	3.5-7.5	1.1-9.8
Cadmium (Cd)	BDL	BDL	0.3-1.5	0.05-0.1	n.a
Chromium (Cr)	<0.02	<0.02	202.8-420.5	12.8-25.0	n.a
Copper (Cu)	0.11-0.24	0.25-0.52	93.3-297.6	12.0-24.5	0.04-0.32
Manganese (Mn)	0.31-0.88	BDL	248.3-378.2	88.0-112.0	0.10-0.29
Nickle (Ni)	0.03-0.16	0.13-0.21	68.0-162.7	15.0-23.0	0.02-0.10
Lead (Pb)	BDL	0.03-0.06	23.5-37.7	4.4-7.0	n.a
Zinc (Zn)	0.02-0.17	0.22-0.67	140.0-383.0	44.0-61.3	<0.05

BDL = below detection limit, n.a = not available

The insignificant LR indicates the low potential of heavy metal contamination of SSF by leaching. However, the possibility of excessive leaching cannot be overlooked as an acidic environment can trigger the leaching of heavy metals from the solid phase. Therefore, precautionary measures such as protective barriers at the bottom and top should be provided when the SSF are disposed of or reused in land applications.

4 CONCLUSIONS

Following conclusions can be drawn from the study.

- The significant content of SSF and gravel-like material in excavated legacy waste indicate the potential for bulk ruse in off-site applications.
- The high content of fines (<0.075mm) is responsible for considerable presence of salts in SSF making the material vulnerable for contamination of surrounding environment.
- The consequential content of organic matter can induce long-term settlements when SSF is used in earth-filling applications.
- The undesirable colour intensity and high dissolved solids in the SSF can contaminate the subsoil, groundwater, and surface water sources if SSF is used in off-site applications without appropriate treatment and containment systems.
- The SSF has no potential for heavy metal contamination by leaching, however, precautionary measures are advisable to prevent possible leaching of heavy metals in acidic environments.

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