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Preface

Geoenvironment-2020:

a unique 3-in-1 event

Geoenvironment-2020 has been organized from 17^{th} to 21^{st} February 2020 at IIT Delhi under a project sponsored by the Ministry of Environment, Forest and Climate Change titled "Capacity Building of Academic Institutions to Support Remediation Initiatives". Three activities have been conducted by the Geotechnical & Geoenvironment Group of IIT Delhi during this event, namely an International Seminar on Contaminated Sites, a concurrent Conference on Geoenvironment & Sustainability and Demonstration Sessions & Workshop on Environmental Subsurface Investigations.

A total of 12 overseas experts and 18 national experts have contributed to the International Seminar and shared their experiences on characterization and remediation of contaminated sites. About 50 researchers and practitioners have contributed research papers and field experiences on Sustainability and Geoenvironment under three themes, namely Investigations and Remediation; Landfills & Slurry Ponds and Re-Use & Sustainability.

The Proceedings herein are a compilation of the abstracts and full-length papers presented at the Seminar and the Conference.

A unique feature of Geoenvironment-2020 is the field demonstration of newly acquired state-of-the-art equipment. Six demonstration sessions have been organized on (a) environmental direct push sampling, (b) profiling by optical imaging and hydraulic pressure testing, (c) shallow depth sampling, (d) electrical resistivity imaging, (e) mapping by ground-penetrating radar as well as (f) rapid assessment by handheld X-ray fluorescence and volatile organic compounds detector.

Geoenvironment-2020 has the participation of over 150 experts, researchers and practitioners from IITs, IISC, NITs, CSIR institutions, Environment Ministry and Pollution Control Boards, and industry participants from environmental/geotechnical/site investigation consultants.

As a part of the project sponsored by MoEF&CC at IIT Delhi on "Capacity Building of Academic Institutions IIT Delhi to Support Remediation Initiatives", a Network of Experts and Resources on Contaminated Sites (NERCS) has been established and a printed Network List and directory of almost 100 national experts/resource persons has been published, listing the expertise, facilities, experience, publications/reports of each individual member. The Network List is available on the NERCS website www.nercs.in

NERCS is a virtual network that is accessible to all. It also lists the proceedings of networking workshop on "Contaminated Sites: Subsurface Investigations and Remediation" organized on 12^{th} & 13^{th} July 2018. Geoenvironment-2020 is the second major activity under the umbrella of NERCS.

The help and financial support received from MoEF&CC is gratefully acknowledged.

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Contaminated Sites – Investigation and Remediation

Quantifying Remediability - The Need and a Possible Approach

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ABSTRACT
When a site is polluted, the responsible party should be made to pay for the clean-up in exercise of the 'polluter pay' principle. If investigations at the site reveals the role of more than one party in the pollution, responsibility allocation becomes complex. As the remediability and consequently the remediation cost, will depend on the type of pollutant, its concentration and many other factors, there is a need to consider all these factors while allocating cost among polluters. This points to the need of quantifying remediability. A method is proposed to quantify remediability that will help in remediation responsibility allocation. The Remediability Index (RI) is proposed as a composite index considering the weighted impact of three types of factors that influence the remediation of a damaged site. These factors are pollutant properties, properties of the polluted medium and external factors. All these main factors shall have sub- factors to reflect their different properties. The RI can lead to more accurate allocation of remediation liability among multiple polluters

1. INTRODUCTION

An environmentally damaged site poses a serious threat to human life and environment (Reddy 2008). The environmental damage occurring may be mitigated to a certain extent by adopting different clean-up methods. Often, the polluters or responsible parties are made to pay for this clean up conforming to environmental legislations that are based on the principle of 'polluter pay'. The remediation method to be adopted at a site depends on many factors like type of contaminant, extent of pollution, properties of the contaminated medium, cost for technology, etc. The remediation liability allocation becomes challenging when multiple polluters are responsible. A structured method is required for the liability distribution among the responsible parties in such cases. The responsible parties in a pollution episode generally include, current and past owners, operators or lessees, transporters, etc. When charged with the liability, however, the responsible parties often come up with various arguments to reduce their share of the costs (Ram et al. 2005) The hearings become lengthy as a result of this and the clean-up process gets delayed (Krishna and Girish 2018). Proper procedural and legal frameworks are important for allocating compensation to the victims of pollution and for assigning the cost to the polluters, both for compensating victims and to pay for clean-up activities. This study tries to highlight the importance of quantifying remediability in the context of environmental clean-up cost allocation. Also, a strategy is proposed for the quantification of remediability.

2. NEED FOR QUANTIFYING REMEDIATION

The guidelines for Implementing Liabilities for Environmental Damages due to Handling & Disposal of Hazardous Waste and Penalty (Ministry of environment, forest & climate change 2015) provides a method for evaluating the remediation cost to be given by potentially responsible parties in case of any environmental damage done. The remediation cost is calculated based on several factors according to the guidelines namely, extent of contamination, location, depth to groundwater, toxicity, etc. These factors vary with each site and case. With regular occurrence of incidents like spillages, illegal disposal etc., a structured method of imposing liability on the responsible parties is required. The damages done to the environment must be remediated at the earliest.

Contaminants enter the environment as a result of environmental damages like spills during conveyance, leakage from waste storage or disposal sites etc. These damages have ever lasting effect on the environment (Khan et al. 2004). The damage cost includes cost for the impact of damage and cost for remediation of the site (Yao et al. 2016). The site needs to be remediated very quickly since the presence of toxic chemicals in the waste pose grave threats to human health and ecosystem. There arise situations in which, remediation measures need to be immediately taken because of the intensity of contamination. Although, remediation of contaminated sites and its technology and cost aspects have been topics of research(Broos et al. 1999; Kaufman et al. 2005; Reddy 2008; Wan et al. 2015) there were no attempts seen to quantify remediability. Quantifying remediability in terms of an index- Remediability Index- can be important to serve the following purposes:

a. To quantify the efforts and resources required for remediation:

   The effort required for remediation will depend mainly on the pollutant, properties of contaminated medium and the environmental factors at site (Khan et al. 2004; Kaufman et al. 2005; Krishna and Girish 2018). The remediability index will quantify the effort and resources required to remediate a specific pollutant in a specific environment. Higher the remediability index, lower the cost and effort required to remediate the site.

b. To apportion cost among multiple polluters:

   When a site is polluted by more than one party, the cost of remediation can be apportioned based on the remediability index. Sometimes, one polluter may be releasing a pollutant that is more difficult to remediate than the pollutant released by another polluter. In such situations, the pollutants which can be easily remediated will be removed while cleaning up the difficult to remove pollutants. However, charging remediation liability from only one polluter is not fair. In some cases, a polluter A may release a pollutant in small quantity, while another polluter B may release the same pollutant at a considerably larger quantity. Both the polluters must be made liable. Polluter A cannot escape the liability claiming the discharge was insignificant. A remediation index will help in apportioning the responsibility in such situations.

c. Ranking of sites for taking up remediation activities:

   The authorities may want to spend the available resources most effectively. So taking up remediation based on remediability index can help. For example, if a site has very low remediability that may be addressed after considering a site that is easily remediated, etc.

d. To help develop remediation liability insurance schemes:

   In countries like the US, there are insurance schemes that takes care of remediation costs such as pollution legal liability, commercial pollution legal liability, site or premises pollution liability, Integrated General Liability and Pollution Liability Coverage, “Cleanup Cost Cap" or "Stop Loss" or "Cost Containment" Coverage, Contractor’s Pollution Liability and Errors and Omissions Insurance, etc.(Anderson 1998; Jones and Hurwitz 1999). Such schemes can use remediability index as a criterion for fixing premiums. If the remediability index of a site A is 10 and remediability index of another site B is 20, then the premium amount to be paid by the parties of site A will be higher than that of site B, since more amount is required for the remediation works on site A.

e. As a criterion for selection of site for a particular industry:

   If there are different sites available for starting an industry, one criterion for site selection can be the remediability of the site for the pollutants emitted by the industry. The sites with higher remediability index can be selected for industries.

f. Settlement of disputes:

   The remediability index helps parties to reach an out of court settlement in remediation cases if they know that costs are going to be apportioned in proportion to the remediability index. This saves money and time for the parties involved.

g. To help in allocation of orphan shares:

   Orphan shares are of parties who do not have the money to pay for clean-up or who are no longer alive. Some statutes like the CERCLA of the US, requires these shares to be allocated to the other PRP's (U.S Statutes 1980). Development of remediability index will help in a fair and justifiable allocation of orphan shares. The parties found more liable will have to contribute more for the orphan shares.

Remediation methods needs to be taken immediately after the occurrence of an environmental damage to prevent further damage to the environment A remediability index gives an insight into the seriousness of contamination. The higher, the remediability index, easier will be the remediation. A remediability index developed can help in allocating resources, allocating liabilities, settling disputes etc. as discussed earlier.

3. DEVELOPMENT OF FACTORS

Remediability index (RI) is intended to form the basis for liability allocation. The factors for framing remediability index can be formed by conducting a Delphi among experts. The weights of finalized factors may be developed by an AHP process. A trial set of factors identified are given in Table 1

Table 1 List of factors influencing remediability

MAIN FACTORS	SUB-FACTORS
Pollutant Properties	Concentration of Pollutant in the environmental medium
	Toxicity of pollutant
	Half-life of pollutant
	Mobility of pollutant
	Synergistic nature of pollutants
	Solubility of pollutant
Properties of Polluted Medium	Type of Soil
	Permeability of soil
	Grain Size of Soil
	Depth to Groundwater
	Depth of contamination
	Volume of polluted medium
External Factors	Technology available
	Annual Rainfall
	Vegetation cover
	Location of site (urban/rural/suburban)
	Accessibility of the site

The remediability index can be found using the weights and magnitude of factors as follows:

$$RI = 100 - \Sigma(wi * (\Sigma (sij * mij)))$$

Where,

wi is the weight of ith main factor

mij is the magnitude of jth sub factor of ith main factor

sij is the weight of jth sub factor of ith main factor

$\sum wi = 1$

$\sum sij = 1$

The factors are normalized to keep the value of remediability index between 0 and 100.

4. CONCLUSIONS

After the occurrence of an environmental damage, the first priority must be given for remediation. The need for quantifying remediation was discussed. A remediability index developed in each case will be helpful in settling out the issues of multiple party allocation, for allocating orphan shares among polluters, for fixing the insurance premiums, for ranking of sites etc. Most of the multiple party pollution cases takes a lot of time to settle if done through courts. These lengthy procedures can be avoided if the parties are ready to pay their share based on the remediability index.

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Groundwater Pollution Risk Assessment Correlated to Pollution Potential from the Non-Engineered Landfill Site

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ABSTRACT

The present study quantifies the groundwater pollution risk and impact of non-engineered landfill sites of Jalandhar city, Punjab region in terms of Leachate Pollution Index (LPI), Water Quality Index (WQI) and DRASTIC index values. The analysis of leachate and groundwater samples, collected around active MSW dumpsite for different physicochemical and biological characteristics revealed that groundwater quality is severely affected due to leachate percolation and many groundwater quality characteristics values exceed the permissible limits and may create a serious threat to community health. The leachate from tipped MSW was of higher pollution potential than sewerage water. High aquifer vulnerability observed for the study region may be due to high net recharge (15+ mm) and 0 – 2% slope range which allows more water to percolate easily in the soil. This study strongly recommends that open dumping of MSW should be strictly restricted and proper engineered landfill along with all principal engineering components should be made to preserve groundwater reserve. Proper channels need to be made and maintained properly for the collection of leachates in the rainy season so that leachate may be properly collected and dispose of after proper treatment to reduce its pollution potential.

Keywords: Leachate Pollution Index; Water Quality Index; DRASTIC index; Aquifer vulnerability

1. INTRODUCTION

Landfills are one of the most common sources of groundwater and soil pollution due to the production of leachate and transportation of the contamination to further points in the ecosystem. The effect of leachate on groundwater and the water resources had attained a lot of awareness. The migration of leachate from waste dumpsites or landfills and the release of various pollutants from sediments (under some circumstances) may cause a very high risk to groundwater if waste is not adequately managed. Groundwater contamination is a major concern in landfill operations because of the pollution effects of landfill leachate and its potential health risks (Sethi et al., 2013, Kaushik et al., 2010, Sethi and Kaushik, 2007).

Leachate Pollution Index (LPI) developed by Kumar and Allapat (2003b) is an innovative tool to assess the pollution potential of leachate emanating from the MSW landfill/Dumpsite. The high value of LPI signifies that the stabilization process of the MSW landfill/Dumpsite is not complete and needs to treat leachate with the appropriate method. LPI values observed for Warriana dumpsite were very high and were in the range of LPI values reported by different researchers for Indian metropolitan cities indicating high pollution risk of the surrounding ecosystem and groundwater. Leachate contamination potential of two active and two closed sites in HongKong was studied by using the LPI method by Kumar and Alappat (2005). Authors observed that leachate generated from the closed landfill can have equal or more contamination potential in comparison to an active landfill site and hence, the remediation actions and post-closure monitoring should be ensured at the closed landfill till the leachate generated is stabilized and poses no future threats to the environment. Kumar and Alappat (2003a) developed a quantitative tool used to calculate the LPI for Okhla landfill site, New Delhi. The calculated value of LPI was 42.18 (very high) compared to the standards set for the treated landfill leachate effluent LPI values (7.37). Based on observations it was concluded that a single number index value which reflects the composite influence of significant pollutant variables on leachate pollution is possible and could provide a uniform, meaningful method of assessing the leachate contamination potential of the landfill site at a particular time. The authors concluded that the LPI of the Okhla landfill site was the significantly high and proper treatment of leachate was necessary before the discharge of the effluent.

Swamee and Tyagi, 2007 concluded in an Improved method for aggregation of water quality sub-indices that the Aggregate Index decreased with time spanning. Most of the aggregate indices suffer from three shortcomings mainly as eclipsing, ambiguity and rigidity. Eclipsing occurs when the aggregate index fails to reflect the poor quality of one or more water quality variables. Ambiguity occurred when all the sub-indices indicated acceptable water quality for the given use but the aggregate index does not. Rigidity problem occurred when additional variables are induced in the index to address specific water quality but the faulty aggregation function might reduce the value of water quality index (WQI) such that it does not accurately reflect the true water quality. Bhalla et al., 2012 performed studies on the Assessment of groundwater quality near municipal solid waste landfill by an Aggregate Index Method based upon the leachate generated from municipal solid waste landfill sites of Jalandhar city, Punjab which affected the groundwater quality in the adjacent areas through percolation in the subsoil. As the aggregate index was an increasing function of the distance from the landfill site, the groundwater quality improved as one move away from the landfill site. The aggregate index also decreases with an increase in time. Thus, water quality went down with time. It may be due to the reason that over time the solid waste material gets degraded and the waste constituents percolated down along with rainwater thereby polluting groundwater. Hence, the author advised some remedial measures to prevent further contamination of groundwater in the vicinity of the landfill. Wong et al. (2012) used a basic risk map and value-weighted risk maps for Beijing plain, China. The basic risk map was produced by overlaying the hazard map and intrinsic vulnerability map whereas the value-weighted risk map was produced by overlaying the basic risk map and a groundwater value map. The thematic maps suggested that the landfills, gas stations, oil depots. and industrial areas were of most high potential contamination sources. Both the map risk ranked the western and northern parts of the plain risk as the highest indicating that those regions should deserve the priority of concern. The authors also pointed out the importance of GIS technology in groundwater vulnerability assessment and concluded that their thematic maps should be updated regularly because of the dynamic characteristics of hazards. Lathamani et al. (2015) also assessed groundwater aquifer vulnerability of Mysore city using the DRASTIC model and incorporated values into GIS. In the study area, the DRASTIC index value was recorded < 70 >100.

This study was performed to evaluate the status of groundwater quality (pre-monsoon and post-monsoon), leachate (in terms of WQI for Groundwater; LPI & Sub-LPI_s for leachate), Sewage Water and Municipal Solid Waste (MSW) based on physico-chemical and microbiological characterization (particularly heavy metal concentrations) for the assessment of the relationship between the dumping site management, groundwater, and public health risks. The obtained results and the chemical speciation of heavy metals in Leachate and Groundwater were used to determine the fate of containments based on hydrogeological factors by inculcating the "DRASTIC model" using ArcGIS software to calculate "Groundwater Pollution risk".

2. METHODOLOGY

The various physicochemical characteristics of groundwater were determined as per the standard methods/procedures given in the “Standard method handbook” for the examination of water/wastewater samples by APHA, AWWA, and Manual of water quality analysis by NEERI Nagpur, India.

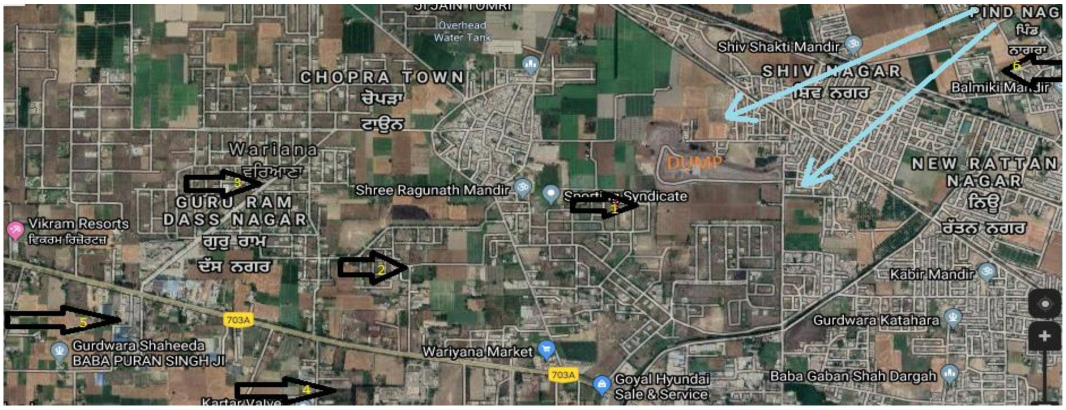

Fig. 1 Groundwater Sampling locations around dumpsite (1 to 5 downstream, 6 upstream)

Groundwater samples were collected from the disposal site at ‘Warriana’; Jalandhar which spreads over the area of 12 acres. The different samples of groundwater were collected from the submersible pumps (hand pumps) and Tube wells. Groundwater sampling points were chosen at different distances. The groundwater quality (to assess the impact o MSW dumpsite on the groundwater resource) was assessed at six stations around the Warriana dumpsite (active dumpsite) of Jalandhar city, Punjab. Initially, the groundwater samples were collected during June and July (pre-monsoon) and Sept-Oct. (post-monsoon) for conjunctive three years (2012-14) followed again after a gap of two years for conjunctive two years (2017-18). Groundwater characteristics for “Background Well” located far away from the dumpsite (approx. 11 km) were also observed for comparison of characteristics values with the background level. Thematic maps were drawn using ARC-GIS vs 10.2 by using groundwater samples analysis results for mapping of the delineate areas susceptible to contamination producing a risk assessment map around the Warriana MSW dumpsite of Jalandhar city, Punjab.

LPI was formulated using Rand Corporation Delphi Technique (Kumar and Allapat (2003a) as a useful technique to assess the contamination potential hence detrimental effects of the uncontrolled landfill site and can be calculated with the following equation

$$\text{LPI} = \sum_{i=1}^{n} Wi \, . \, Pi$$

Where, LPI= the weighted additive leachate pollution index, Wi = the weight for the ith pollution variable, Pi = the subindex value of the ith leachate pollutant variable, n = number of leachate variables used in the calculation. The calculation of overall LPI consists of (i) calculation of sub-index scores for each of the parameters (ii) aggregation of the subindex scores for inorganic, organic and heavy metals sub-LPIs (iii) aggregation of three sub-LPIs to get overall LPI.

$$\text{LPI} = a\text{LPI}_{IN} + b\text{LPI}_{OR} + c\text{LPI}_{HM}$$

a, b, c is the weight factor values of the eighteen pollutants included in contributions for subindex calculation of $_{IN}$, $_{OR}$, $_{HM}$, and overall LPI as developed by Kumar and Allapat (2005). Aggregate

Index Method suggested by Swamee and Tyagi, 2000 was also coupled in the calculation of subindex and index scores.

3. RESULTS AND DISCUSSION

3.1 MSW Landfill Leachate

A total of 6 leachate samples (during pre-monsoon and post-monsoon) were collected from the leachate holding tank situated at the base of the Warriana (MSW) dumpsite towards the composting plant side. High COD values were observed due to the high organic content. The presence of phenols was also observed in the leachate. High BOD/COD ratio of leachate samples observed for the study, was in accordance with the values reported by Kale et al. (2010), observed for the Pune landfill. Kaushik et al. (2015) reported that a high BOD/COD ratio may be due to the high content of easily dissolved organic and inorganic materials, high moisture content (with higher average annual precipitation) and increased temperature and microbial action during the summer season. Additionally, leachate samples were characterized with high levels of Ammonical nitrogen which may create toxicity to living organisms, deplete dissolved oxygen levels and simulate the algae growth whereas high TKN values observed indicate high organic pollution potential of leachate.

3.2 Groundwater samples

The effect of pH on the chemical and biological properties of water makes its determination very important. Table 1 shows the groundwater quality (post-monsoon and pre-monsoon) in comparison with Leachate, Sewerage water, Background water, and water quality standards. The pH values varied from 7.0 to 7.9 during pre-monsoon and 7.0 to 8.1 during post-monsoon. Alkaline values are due to the leaching of dissolved constituents in the groundwater. The EC values varied from 750 to 2150 µS/cm during pre-monsoon and 700 to 2100 µS/cm during post-monsoon which are higher than the permissible limit (400 µS/cm) of water for human consumption. The groundwater samples collected nearer and present towards the downstream side to MSW dumpsite recorded for higher EC values may be due to nutrient enrichment. The TDS values ranged from 450 mg/l to 1300 mg/l during pre-monsoon and 350 to 1250 mg/l during post-monsoon which are higher than the permissible limit (500 mg/l) for drinking water as per BIS (1991) limits. The BOD values ranged from 30 to 350 mg/l during pre-monsoon and 30 to 380 mg/l during post-monsoon. Hence, the groundwater at the sampling site was contaminated with biodegradable substances from the Leachate of MSW dumpsite. The COD values ranged from 40 to 450 mg/l during pre-monsoon and 40 to 500 mg/l for the post-monsoon period. These values are also reasonably high for the sampling locations at the downstream side of the dumpsite, the closeness of locations to the dumpsite and lower water table level. The concentration of chloride ions ranged from 35 to 410 mg/l during pre-monsoon and 30 to 400 mg/l during post-monsoon which exceeds the permissible limit of 250 mg/l as per BIS (1991). Chloride concentration for sampling point S_1 (for Well 1) is high since its distance is less than 1.2 km from the Warriana site and it lies at the downstream side of the dumpsite Chlorides presented in leachate are usually not attenuated by soil and are highly mobile under all conditions and thus have a special significance as the tracer element of "leachate plume" joining the groundwater aquifers. The possible sources of chlorides in the leachate are kitchen wastes from households, restaurants, and hotels (Kale et al. 2010). The Concentration of sulphate ions ranged from 15 mg/l to 120 mg/l and 25 to 150 mg/l during the post-monsoon season and these values are within the permissible limits of 200 mg/l as per BIS (2012). A higher concentration of chlorides and sulphates in groundwater is considered to be an indicator of pollution due to human/animal waste (dumping of sewerage pipe network sludge on the dumpsite along with MSW). Chlorides get into groundwater from solid waste when it comes to contact with rainwater.

The total hardness values for the water samples obtained from sampling sites during pre-monsoon season were ranged from 48 mg/l to 624 mg/l. Total hardness values were higher than the acceptable limits specified by BIS (2012).

Hence, the groundwater of the study area is not suitable for drinking purposes. Hard water consumption makes water undesirable for consumption due to its strong dry taste and concentration. Kugali et al. (2013) reported that hard water can cause certain adverse effects on the human body due to the presence of other minerals that do not benefit the body directly such as copper and lead. From the analysis, it is clearly evident that the concentrations of contaminants were found to be high in the sampling sites which are near to the Warriana Dumpsite. Interestingly, groundwater contamination drops fast with an increase in distance from the Warriana dumpsite.

3.3 Heavy metals characterization

The heavy metal concentration levels for the Warriana dumpsite and groundwater samples are also shown in Table 1. The highest average concentration levels were observed for Iron (56±34.15) followed by Zinc (29±18.76) and lead (Pb^{+2}) (2.9±1.09). The Iron concentration level reported in this study was comparatively higher than those reported for the Okhla, Bhalswa and Ghazipur landfill sites in Delhi. The lead concentration of the groundwater samples obtained from sampling sites ranged between 0.03 to 0.31 mg/l (*higher than the standard limit 0.015 mg/l prescribed by WHO, EU for drinking water). According to WHO (2010), humans are at risk of exposure to lead from water sources and lead poisoning also accounts for 0.06% of the global burden of diseases. The Copper, Chromium, Mercury, Cadmium, and Cyanide concentration levels for the groundwater samples collected around the dumpsite were below detectable limits. The age and volume of waste might be the reason as the pH was near to neutral; the metals were not soluble in water. Overall, for this dumpsite, the landfill contamination levels are comparatively higher which may be due to the low water table in the area and geology of the area.

3.4 LPI and Sub-LPIs

Leachate Aggregate Index Method is a method used to evaluate the quality of groundwater around any MSW dumpsite. The generation of leachate from any MSW landfill site affects mainly the quality of groundwater. Leachate constituents percolate downward usually along with the rainwater and pollute the groundwater (Parameswari et al., 2012). The leachate aggregate index method is a simple method to evaluate groundwater quality. The quality of groundwater mainly depends upon the ranges in which the aggregate index lies. Many water quality indices may be used for calculating aggregate index such as OWQI (Oregon water quality index), NSFWQI (National Sanitation Foundation Water Quality Index), SHI (Stream Health Index) (Swamee and Tyagi, 2007).

Table 1 Groundwater Quality (Post-monsoon and Pre-monsoon) in comparison with Leachate, Sewerage water, Background water, and water quality standards

Parameter	Post-monsoon						Pre-monsoon						Sewerage water	MSW dumpsite Leachate (Active dump site)	Background water well (BW)	Water Quality Standards		
	Downstream wells					Upstream well	Downstream wells					Upstream well				Absolute values (BIS)	Absolute values (WHO)	EU Std. values
	W1	W2	W3	W4	W5	W6	W1	W2	W3	W4	W5	W6						
Distance from dump site (km)	1.2	2	3	2.5	4.5	2.5	1.2	2.3	3	2.5	4.5	2.5		0	11			
Depth (ft.)	180	200	175	350	480	180	180	200	170	350	480	180		0	200			
Type of well (S, T)	S	S	S	T	T	S	S	S	S	T	T	S	-	-	S			
pH	8.2	7.7	8.1	7.6	7.7	7.3	7.9	7.6	7.8	7.4	7.4	7.3	6.9±0.1	8.1±0.61		6.5-8.5	< 8	6.5 – 9.5
EC(µS/cm)	2100	1764	1574	1580	710	410	2000	1750	1550	1540	700	400		12000±400.16	450±40	800	-	2500
TDS	1250	1150	937	960	500	220	1328	1050	937	960	472	250	850±120	113045±5788.5	250±50	500	500	
Chlorides	410	282	323	183	155	35	347	279	243	203	185	35	240±30	1318±200.18	35±15	250	250	250
Sulphate	150	130	110	85	55	15	120	100	100	85	45	15	120±45	538±143.35	12±1.5	200	250	250
T. Hardness	550	500	480	450	330	48	624	510	450	470	320	48		1079±309.08	45±42	200	500	
COD	480	500	440	420	427	40	468	454	450	470	427	40	1000±250	14612±6433.37	NIL	0	0	
BOD	380	370	361	353	348	30	350	335	340	347	350	30	410±50	8058±4482.67	NIL	0	0	
TKN	54	48	65	25	23	BDL	78	80	75	45	48	BDL	385±25	2136±1171.30	20	0	0	
Ammonical Nitrogen	54	52	50	20	25		52	65	55	28	27	BDL	180±85	1314±719.82	BDL	0	1.5	0.5
Phenols	3.1	2.7	1.5	1.5	0.25	BDL	3.25	2.5	1.75	2.5	0.5	-	BDL	2.58±0.75	BDL	0.001	-	
Total Coliform /100 ml	5	5	3	5	2	0	5	5	2	5	2	0	2212300± 42800	150700±20170	0	0	0	0
Heavy metals																		
Iron	1.2	1.0	1.0	0.8	0.8	0.8	1.2	1.0	1.0	0.8	0.8	0.8	2.5 ±1.5	56±34.15	1.0±0.1.	0.3	0.3	0.2
Copper	BDL						BDL						0.4 ±0.2	0.58±0.34		0.05	1.0	2
Nickel	0.2	0.15	0.15	0.2	0.2	0.01	0.2	0.2	0.2	0.2	0.1	0.1	0.8±0.2	0.45±0.09		-	0.02	0.02
Zinc	1.5	0.8	0.5	0.5	0.2	0.12	2	1.2	0.5	0.5	BDL	0.2	1.2±1.0	29±18.76		5	3	-
Lead	0.31	0.28	0.25	0.12	0.12	0.03	0.31	0.28	0.25	0.12	0.12	0.03	1.2±0.8	2.9±1.09		0.05	0.015	0.01
Arsenic	0.1	0.1	BDL	0.1	BDL	BDL	0.12	0.1	BDL	BDL	BDL	BDL	0.2±0.1	0.10±0.05	0.015	0.01	0.001	0.01
Mercury	BDL						BDL						1.2±0.2	0.12±0.085		0.001		0.001
Chromium	BDL						BDL						0.4±0.1	0.2±0.15		0.05		0.05
Cadmium	BDL						BDL						BDL	BDL		0.01	0.003	0.005
Cyanide	BDL						BDL						BDL	BDL		0.05	0.07	0.05

S= Submersible pump: T= Tube well

Characteristics values are in mg/l (ppm) except pH, EC, and Total Coliform

Groundwater quality characteristics values are the average values of multiple tests performed on samples collected from the same location at different time intervals {June and July (pre-monsoon) and Sept-Oct. (post-monsoon) for conjunctive three years (2012-14) followed by June and July (pre-monsoon) and Sept-Oct. (post-monsoon) for conjunctive two years (2017-18). Standard deviation is shown only for the MSW dumpsite (active site) leachate and sewerage water samples analyzed periodically during the entire study period.

Aggregating index has been used to identify the effect of MSW leachate on the water quality of Jalandhar Warriana dump site, but Aggregate Index Method (suggested by Swamee and Tyagi, 2007) coupled with LPI and Sub-LPIs pollutant weight values (suggested by Kumar and Allapat (2005) may provide most reliable, properly corrected terms therefore selected for the present study. Three sub-LPI values as estimated for Warriana dump sites demonstrated high in organic content (LPI_{OR}) and less in the metal residue (LPI_{HM}) through the appreciable amount of Fe, Zn and Pb found in the MSW dumpsite samples. Table 2 shows the groundwater variable and their sub-indices for all the listed parameters in the above-mentioned water quality characteristics variables.

3.5 Water Quality Index (WQI)

By studying the selected experiences/tragedies of leachate contaminant migration into the groundwater reserves, it is well understood that there is a need to assess the ground conditions and Water Quality Index. The Water Quality Index (WQI) in this present study was determined by using the Oregon Water Quality Index, BIS 10500 and National Sanitation Foundation Water Quality Index (NSFWQI) methodologies. The water quality assessment by means of BIS 10500 standard and NSFWQI analyses showed that the water samples collected from close locations in the immediate proximity of dumpsite were of moderate to fair quality and quality of the water improves with increasing distances from the dumpsite.

WQI range for Groundwater of Warriana Dumpsite region in the pre-monsoon ranged from 20 to 91, in that 5% of water samples showed ‘Excellent water”, 60% of the samples proved “Good water”, 25% o the samples proceed as “Poor water” and 10% of the water samples proved as “very poor water” whereas in the post-monsoon WQI ranged from 25 to 115, in which 2% of water proved as “Excellent water” 35% water as “Good water”, 43% as “Poor water” and 15% of water proved as “very poor water”.

3.6 Aquifer Vulnerability studies using DRASTIC model

Aquifer vulnerability refers to the sensitivity of an aquifer system to possible deterioration due to external action. In the last few decades, many techniques have been developed (index, rating, hybrid, statistical and simulation models) but, the DRASTIC model is considered most reliable for vulnerability mapping of the porous aquifers. For the DRASTIC model, seven parameters were considered such as avg. depth of water (150 - 210 ft), avg. net recharge rate (5 to 7 inches), aquifer media (medium-grained, gray adamellite with avg. rating 7), soil media (gravelly clay soil with avg. rating 4), topography (0 - 2 % slope with avg. rating 10), impact of vadose zone (clayey loamy soil with avg. rating 2) and hydraulic conductivity (100 - 300 m/day with avg. rating 2). The Vulnerability range was categorized based on DRASTIC index values; less than 70 as very low, 70-80 low, 80-90 as moderate, 90 -100 as high and more than 100 as very high. The DRASTIC model values for the study region as evaluated as over 70 and below 100. The vulnerability maps obtained or one year based upon the DRASTIC model for Warriana dumpsite, Jalandhar revealed that October month shows high vulnerability due to high net recharge (15+ mm) and 90% of the area is having 0 – 2% slope ranges. The slope percentage allows more water to percolate easily in the soil of the region.

Table 2 Pollutant weight for the Water Quality Variable and their Sub-indices

Water Quality Variables (q)	Significance	Pollutant weight (Wi)	q_i	M	q_c	q_r	q_*	n	P	R	Subindex S_i
pH	3.509	0.055	8.0	-	-	-	7.0	4.0	6.0	0	0.80
Turbidity (JTU)	-	-	6.0	1.5	50	-	-	-	-	-	0.84
Total Dissolved solids (mg/l)	3.196	0.050	150	-	-	-	25	1.0	1.0	0.8	0.89
Temperature (℃)	-	-	24	-	-	-	20	0.5	7.0	0	0.92
Chlorides (mg/l)	3.078	0.048	-	-	-	-	-	-	-	-	-
Ammonical Nitrogen (mg/l)	3.250	0.051	-	-	-	-	-	-	-	-	-
TKN (mg/l)	3.367	0.053	5.0	3.0	40	-	-	-	-	-	0.70
Phosphate (mg/l)	-	-	0.6	1.0	0.7	-	-	-	-	-	0.53
Fluoride (mg/l)	-	--	1.3	-	-	5.0	1.0	4.0	4.0	0	0.62
D.O. (mg/l)	-	-	0.75	-	-	0.01	1.0	3.0	1.0	0	0.87
BOD (mg/l)	3.902	0.061	4.0	3.0	20	-	-	-	-	-	0.58
COD (mg/l)	3.963	0.062	-	-	-	-	-	-	-	-	-
Coliform (MPN/100ml)	3.289	0.052	10	0.3	4.0	-	-	-	-	-	0.69
Iron (mg/l)	2.830	0.045	0.05	-	-	0.1	-	-	-	-	0.89
Arsenic (mg/l)	3.885	0.061	0.04	-	-	0.05	-	-	-	-	0.52
Cadmium (mg/l)	-	-	0.0003	-	-	0.0005	-	-	-	-	0.78
Chromium (mg/l)	4.057	0.064	0.035	-	-	0.05	-	-	-	-	0.66
Copper (mg/l)	3.170	0.052	0.04	-	-	0.05	-	-	-	-	0.52
Zinc (mg/l)	3.585	0.056	3.0	-	-	5.0	-	-	-	-	0.78
Lead (mg/l)	4.019	0.063	0.4	-	-	0.05	-	-	-	-	0.52
Manganese (mg/l)	-	-	0.03	-	-	0.05	-	-	-	-	0.78
Mercury (mg/l)	3.923	0.062	0.0005	-	-	0.001	-	-	-	-	0.89
Selenium (mg/l)	-	-	0.007	-	-	0.01	-	-	-	-	0.66
Aluminium (mg/l)	-	-	0.15	-	-	0.2	-	-	-	-	0.59
Nickel (mg/l)	3.321	0.052	-	-	--	-	-	-	-	-	-
Cyanide (mg/l)	3.694	0.058	0.03	-	-	0.05	-	-	-	-	0.78
Phenols (mg/l)	3.627	0.057	-								

where W_i= pollutant weight, q = quality variable, q_c = characteristics value of q, m= a positive number, n= sub- index number, S_i = sub index of i^{th} parameter, q_r and q_*= variables.

4. CONCLUSIONS AND RECOMMENDATIONS

Proper channels need to be made and maintained properly for the collection of leachates in the rainy season so that leachate may be properly collected and disposed to reduce its pollution load. The non-biodegradable organic matter and the alternated metals of the MSW can be removed by mining and metals in the soil by using appropriate chemical-biological processes to alter the form of metal contaminants to decrease their toxicity and/or mobility. Open dumping of MSW should be strictly restricted and proper engineered landfill along with all principal engineering components should be made to preserve groundwater reserve.

Although the concentration of few contaminates does not exceed drinking water standards even the groundwater quality represents a significant threat to public health. Local Government should instruct the local authorities to release guidelines to avoid using groundwater drawn from nearby wells located in the proximity of the Warriana dumpsite of Jalandhar city, Punjab. Post closure monitoring and proper surveillance must be undertaken regularly to prevent pollution hazards and to safeguard community health.

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Electrokinetic Treatment (EKT)- A Laboratory Study for Remediating Soils Contaminated with Leachate

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ABSTRACT
Electrokinetic treatment (EKT) is one of the effective techniques to decontaminate impervious soils such as clayey soils. Also, real-time monitoring of the electrical resistivity of soil can be a useful tool in controlling the removal of leachate contaminants during decontamination using this technique. Field conditions were simulated in a laboratory environment using a Perspex box of dimensions 350 mm x 100 mm x 150 mm filled with compacted soil. Tests were performed on compacted kaolin samples with a void ratio of 0.9 mixed with leachate obtained from a landfill site. After the saturation, the soils were electro-kinetically treated under constant voltage gradients. Electrical resistivity was measured during the EKT. The profiles of this property are indirect measurements of the amount of leachate. They allowed quantifying changes in its concentration during EKT. The results show an efficient removal of contaminants from the soils, in particular in the areas close to the electrodes.

Keywords: Electrokinetic treatment; Decontamination; Leachate; Clayey soil

1. INTRODUCTION
Electrokinetic Treatment (EKT) is an effective technique for decontamination and dewatering in fine soils such as clays. This is because of: (i) the electroosmotic drag of ions and water molecules under electrical gradient, and (ii) in clayey soils, electroosmotic permeability is larger than saturated hydraulic permeability, and for this reason, water percolates faster than if only a hydraulic gradient would be applied [Adamson et al. (1965), Esrig (1968), Alshawabkeh, et al. (1999), Reddy(2010)]. This technique has proven to be competent for the removal of salts from the soil and other construction materials [Hall and Jayasekara (2007), Ottosen et al. (2015)], with relatively less cost.

The electrical resistivity of soil is connected to the presence and number of ions in the pore fluid, which consequently affect the electrical conductivity of this fluid. The evolution of electrical resistivity during the treatment can be used as a real-time monitoring tool to track the movement of contaminants. In this paper, the analysis is done considering resistivity changes, however, it is known that factors like changes in temperature, pH and conductivities of the soil triggered due to precipitations and chemical reactions affect the resistivity readings [Saichek and Reddy (2003)]. For better interpretation, only pH changes were considered.

The above principle was used in this study performed using a laboratory-scale setup for EKT. Tests were performed on compacted kaolin spiked with leachate collected from a landfill in Lisbon, Portugal, to which constant voltage gradients were applied. Monitoring of EKT was done by measuring electrical resistivity in the soil, and pH and electrical conductivity (EC) of the pore fluid. These measurements permitted indirect monitoring of leachate concentration after the comparison the values measured in the EKT setup with those from a calibration curve, obtained using samples prepared similarly but saturated with leachate solutions having different concentrations.

2. MATERIALS AND METHODS

2.1 Materials

EKT test was performed with kaolin compacted with leachate obtained from a landfill managed by AMARSUL, Assessment and Treatment of Solid Waste Company in Setubal municipality, near Lisbon in Portugal. This leachate is composed of organic and inorganic matters, having a pH of 8.3 when collected. Its composition can be seen in Table 1. The clay was mixed with the fluid to achieve a moisture content of 25% and compacted at a void ratio of 0.9. Kaolin clay was used in the research for a better understanding of the electrokinetic processes during the EKT. The material was supplied in powder, with 68% silt and 31% clay. Specific gravity is 2.61.

Liquid limit is 52% and the plasticity index is 22% when measured with distilled water, therefore the material classifies as highly plastic silt (MH) accordingly with the Unified Soil Classification System. The zeta potential value (ZP) for this soil decreases for acidic pH whereas it increases for basic pH. It values -22 mV for pH=7. The coefficient of electroosmotic permeability of kaolin measured with distilled water is 1×10-9 m2/V/s [Gingine and Cardoso (2016)].

Table 1 Leachate Parameters

Organic parameters/ Compounds			Heavy metals/ metals		
Parameter	May-15	Nov-15	Parameter	May-15	Nov-15
COD (mg O_2 / l)	11,000	7,100	Copper (mg Cu/l)	0.020	0.009
BOD (mg O_2 / l)	1,100	1,400	Chromium VI (mg Cr (VI)/l)	<0,25	<0,0050
TOC (mg C/l)	3,518	2,350	Calcium (mg Ca/l)	74	152
AOX (Cl mg/l)	2.82	1.21	Lead (mg Pb/l)	<0,01	0.04
Ammoniacal nitrogen (mg NH_4 /l)	4,600	3,200	Manganese(mg Mn/l)	0.116	0.2973
Chlorides (mg Cl/l)	4,800	3,500	Mercury (mg Hg/l)	<0,01	<0,01
Sulphates (mg SO_4/l)	4400	4100	Arsenic (mg/l)	0.364	<0,01
Sulphides (mg S/l)	14.8	15.8	Nickel(mg Ni/l)	0.200	0.22
Fluorides (mg F/l)	0.77	0.44	Zinc (mg/l Zn)	0.386	0.50361
Cyanides (mg CN/l)	0.02	0.02	Iron (mg Fe/l)	5.69	7.59
Nitrates (mg NO_3/l)	48	38	Sodium (mg/l)	3,382	2,432
Nitrites (mg NO_2/l)	1.3	<0,10	Potassium (mg K/l)	3,183	2,420
Bicarbonate (HCO_3 mg/l)	22,418	880	Magnesium (mg Mg/l)	90	92

The soil prepared with Leachate shows a liquid limit of 60% and a plasticity index of 24%. The electrical resistivity of kaolin with the compaction water content is 6.3 Ω-m and decreases to 5.1 Ω-m after the saturation with leachate. This can be explained by the chemical composition of the leachate, which ions present are interaction with the clay minerals [Gingine and Cardoso (2016)]].

2.2 Calibration curve

The electrical resistivity of kaolin soil mixed in different concentration of leachate (in distilled water) 0%, 1%, 5%, 10%, 50% and 100 % was measured to find a calibration curve. These curves will be used to indirectly convert the measured resistivity data from the curves into the leachate concentration. Small samples (having 25 mm diameter and 60 mm length) prepared inside PVC tubes and to which steel nails were inserted as electrodes were prepared with void ratio (0.9) and water content (25%). They were saturated with the different leachate solutions and the electrical resistivity test was performed using the Wenner method [Gingine (2017)].

2.3 Setup for EKT

The laboratory-scale setup developed for EKT is shown in Figure 1. The setup comprises of a soil cell of dimension 350 mm x 100 mm x 150 mm, with two chambers attached to the ends of the cell (Perspex material), a power source Aim-TTi EX354RD 280W (0-35 V and 0-4 A), graphite as anode and steel as the cathode. Electrical resistivity of the soil was measured using electrodes inserted in the entries, followed by the measurement of pH and electrical conductivity of the pore fluid collected from the entries. The electrodes used are made of Nickel coated Stainless Steel.

The clay was compacted into the soil cell. After compaction, it was saturated by promoting the percolation of the leachate through the application of variable water head, by filling one of the electrode reservoirs. The electrical resistivity of the soil was measured during the saturation phase to check the degree of saturation. This also simulates field conditions. A detailed plan of the test is shown in Table 2.

Techniques like Current intermittence (CI) and Enhanced treatment (Et), were used to reduce power consumption and increase EKT efficiency [Micic et al. (2001)]. CI consists of applying a voltage at a predetermined on/off intervals instead of continuous DC supply. In Et, the fluid in the electrode chambers is replaced by tap water at regular intervals to maintain the pH near the electrodes to 7.

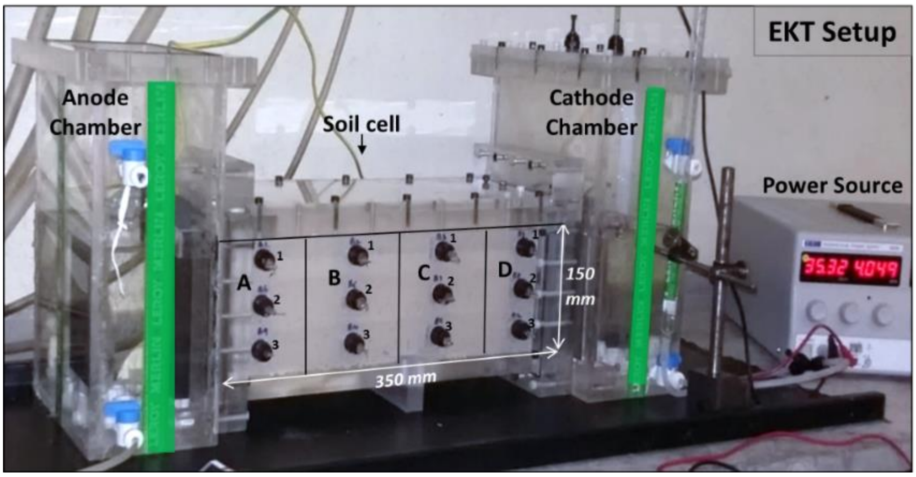


Fig. 1 EKT setup

2.4 Test Plan

Table 2 shows the plan adopted for the EKT tests on leachate contaminated kaolin soil. Factors such as CI against the continuous supply of voltage, Et against the unenhanced treatments and different voltage gradients were studied in the EKT tests on contaminated soil. Each subtest was conducted for at least three continuous days and the soil was left to stabilize for the next 3-4 days. The duration was not changed unless harmful conditions were observed. Based on the literature, it was suggested a voltage gradient of 1V/cm or less for treating the soils having ionic concentrations. In this paper, temperature effects were not considered.

As shown in Figure 1, for data treatment the soil was vertically divided into four zones named A, B, C, D starting from the Anode. Each zone has 3 entries on each of its sidewalls with a vertical spacing of 40 mm, further dividing the soil into 3 levels. The horizontal spacing between the entries in each zone is 100mm. The entries on both sidewalls are identified as A1, A2, A3, B1, B2…D3 (shown in Figure 1) and A1´, A2´, A3´, B1´, B2´…D3´ (in the back).

Table 2 Plan of the EKT tests conducted on Kaolin

Pore Fluid	Subtest	Duration (Hrs)	V/cm	Fluid in Electrode Chambers
Leachate	4 I	72 (CI)	1	Tap water
	4 II	72	2	Tap water
	4 III	72	2	Tap water (Et)

3. RESULTS AND DISCUSSIONS

3.1 Longitudinal Electrical Resistivity of Soil

The longitudinal resistivity ρlong (Ω-m) was measured along the length of the soil cell using Wenner method [BS 1377-3 (1990)]. A current (I) of 10 mA was applied between the outer electrodes of both the sidewalls A1-D1, A1´-D1´, A2-D2, … and A3´-D3´ and the resistance between the inner two electrodes B1-C1, B1´-C1´, B2-C2 and B3´-C3´. Eq. (1) was used to calculate the resistivity, where V is the voltage measured. The resistivity electrodes were inserted to a depth of 30 mm and at a distance (d) of 100 mm. The average of the resistivity values along the duration of the tests for leachate can be seen in Figure 2.

$$\rho = \frac{2\pi V}{I} d \tag{1}$$

Since Et was not applied for 4-I and 4-II, the pH at the end of the test rose to 3.3 at anode and 11.3 at the cathode. The dissociation and association with water molecules lead to a high diffusion coefficient. The ionic mobility for H+ and OH– ions reins the chemistry across the soil structure when EKT is not enhanced. Since the ionic mobility of H+ is more than OH- ions, an acidic front flow from Anode to Cathode and decreases the charge of the soil thus reducing its electroosmotic permeability. Acidic pH is formed due to H+ which reduces the zeta potential (ZP) of the soil and hinders the EKT, whereas basic pH can help in the formation precipitating compounds which can also create impedance in EKT. Therefore, both the acidic and basic conditions need to be avoided during the EKT, which can be done by implementing Et.

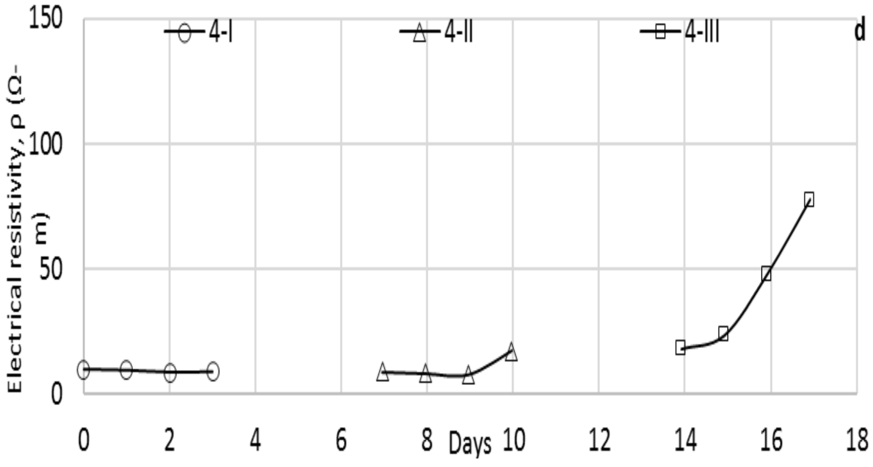


Fig. 2 Longitudinal electrical resistivity ρ_{long} for Leachate

3.2 Lateral Electrical Resistivity

To track the changes in the resistivities in each zone, electrical resistivity was measured in the angle perpendicular to the length of the soil cell. In this way, the information in the entire volume of the soil can be known.

The lateral electrical resistivity ρlat (Ω-m) was measured transverse to the direction of the electrical flow along the length of the soil. To do this, a voltage (V) of 5 V was applied between A1-A1´, B1-B1´, etc. The current (I) flowing between the soil area (A) around the entry was measured in mA unit. The tip to tip distance (L) of the two electrodes in the transverse direction is 60 mm. Using Ohms law, the lateral electrical resistivity was calculated using Eq. (2). An average value of the three entries (A1-A1', A2-A2' and A3-A3') was used for that zone.

$$\rho = \frac{V}{I}\frac{A}{L} \qquad (2)$$

3.3 Calibration Curve

The determination of Leachate concentration after the EKT test was attempted by using the lateral electrical resistivity values of soil. Calibration curves for resistivity of kaolin were determined for decreasing concentrations of leachate in solutions in kaolin and three different pH (7-8.5, 1-2 and 13-14), as already discussed.

The plot values at the end of the subtests 4-I, 4-II and 4-III (Figure 3) were converted into respective leachate concentrations at the respective zones using a calibration equation. Calibration curve presented in Figure 4 can be used to convert resistivity (ρ) to the leachate concentration in %. equation from calibration curve in Figure 4. The concentration values are presented in Figure 5 (a). For all zones, except zone A, the leachate concentration in soil was found to be declining as EKT test advances from subtest 4-I to 4-III. The factors like changes in pH due to dissociation on H+ and OH- and release of oxygen gas, both caused by electrolytic reactions of water affects the soil properties. Hence the effect of pH on the resistivity values during the calibration curve should be taken into consideration.

The pH values for a different amount of leachate vary between 7-8.5. But during the test, the pH values decreased to acidic near the anode and basic near the cathode. Hence to tackle the effect of pH, extra calibration curves were prepared for acidic pH 1-2 and basic pH 13-14. Both the new calibration curves showed good correlation between the two properties. Since the acidic pH was very conductive, the curve with acidic pH was short with a small range of resistivity from 7 to 30 Ω.m. The range for basic pH was 7 to 85 Ω.m [Gingine (2017)].

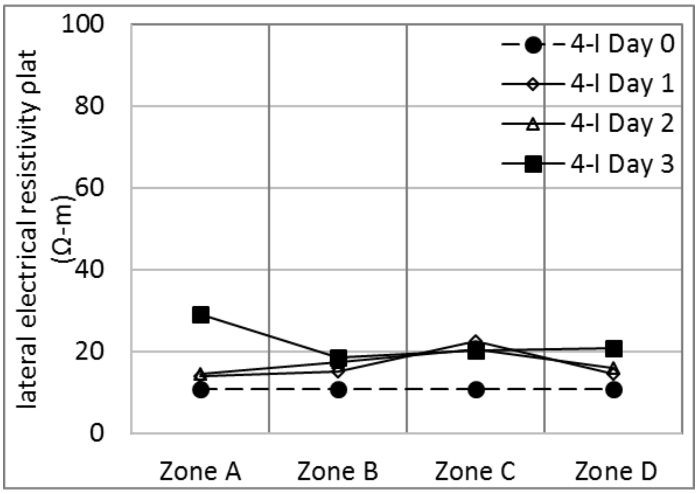
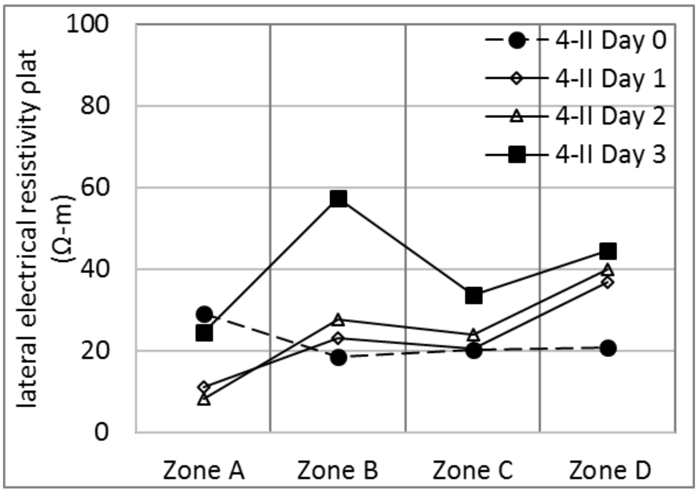
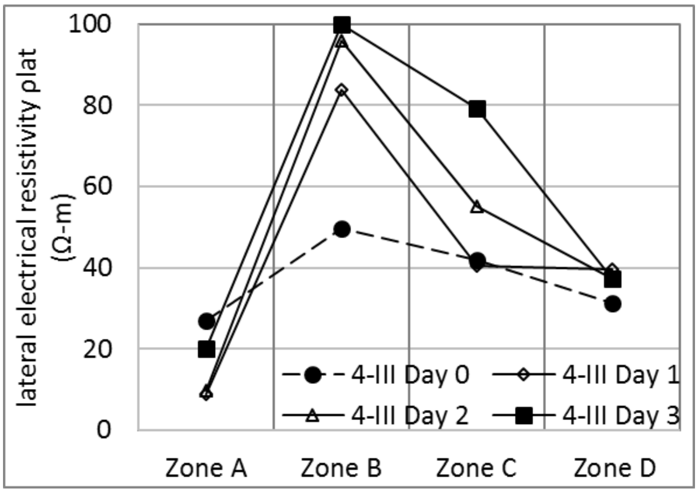


Fig. 3 (a) Lateral Resistivity values for the Leachate



(b)



(c)

Fig. 3 (b) & (c) Lateral Resistivity values for the Leachate

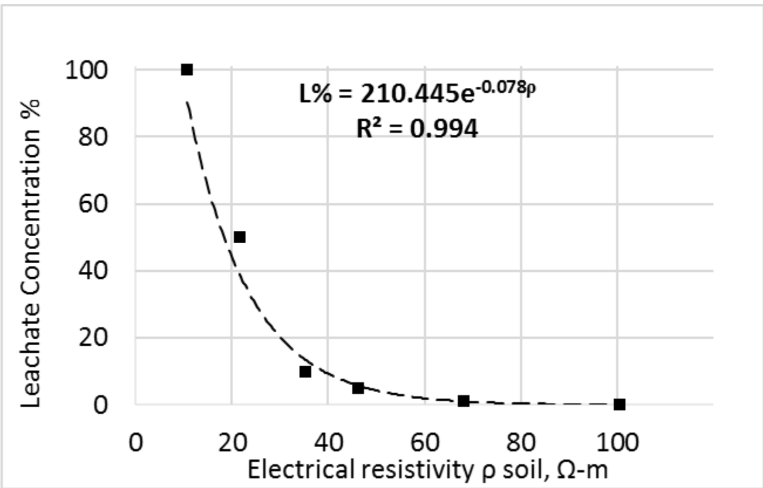
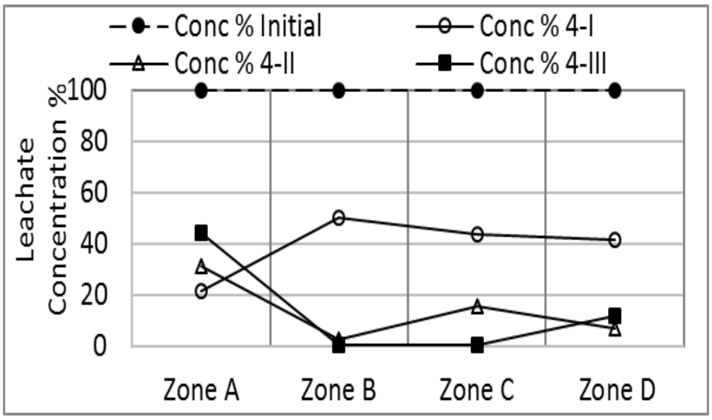


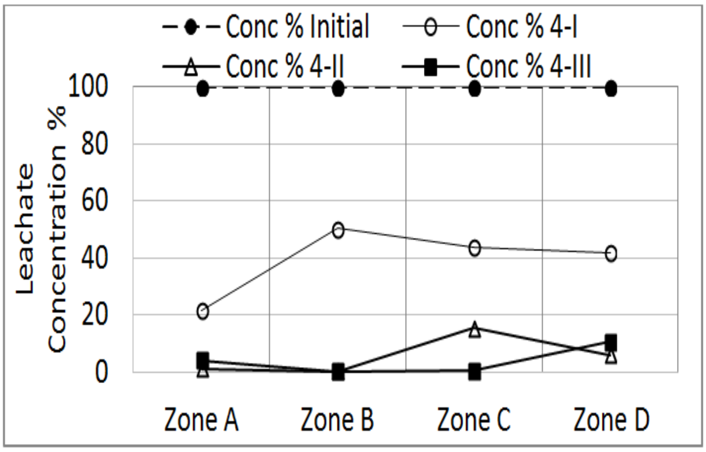
Fig. 4 Calibration curve for electrical resistivity against the leachate concentration (pH 7-8.5).

Initially, the concentration was found using the calibration curve for pH 7-8.5 without considering the pH effects (See Figure 5.a). Different calibration curves were used to find the concentration of leachate using the resistivity of soil (see Figure 5.b). Without the pH consideration, Zone A had shown lesser decontamination which contradicted with the data from other properties. After the pH consideration, the leachate concentration dropped to a range of other zones. At the end of the test with the pH consideration, very less contaminant concentration was found in all zones which may be correct. This result was further checked by using the data from the electrical conductivity of the pore fluid extracted from the soil.

To conclude, due to the complex composition of the leachate (Table 1), the degree of contamination determined using soil resistivity values was checked by using the electrical conductivity (EC) value of the pore fluid from the soil. Based on the color and other properties, the resistivity values and EC values of the pore fluid were considered in the case of leachate and was analyzed simultaneously. The chemical analysis gave a reliable amount of metals and organic contents present in the soil.



(a)



(b)

Fig. 5 Leachate concentration during the EKT test:
(a) without considering pH; (b) considering pH.

4. CONCLUSIONS

EKT thus can be considered as an efficient technique for the removal the leachate, however, attention should be given to the factors such as the formation of strong acids/bases, evolution of gases and increase in temperature. Real-time monitoring of the decrease in the leachate concentration using the electrical resistivity values can be a helpful tool during the EKT as it allows to check and change the working parameters of the on-going test. It can be used as a decision-making tool, for instance, to stop the test when the desired minimum and safe level of contamination is achieved due to EKT.

The consistency of monitoring the saturation or decontamination of the soil by measuring its electrical resistivity can be further enhanced by considering the evolution of pH and conductivity of the pore fluid.

ACKNOWLEDGEMENTS
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Understanding the (Bio)geochemistry of an Arsenic-Contaminated Aquifer for Sustainable Remediation

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ABSTRACT

Arsenic (As) prevalence in Indian groundwaters is well known. India's heavy dependence on groundwater requires a sustainable approach to get rid of this toxic and carcinogenic metalloid. In this study, linkages between physiochemical and biological factors affecting arsenic were investigated to target long-lasting solutions to the arsenic pollution problem. Certain locations near Kanpur, U.P., were identified with arsenic concentrations greater than the permissible drinking water limit of 10 µg L^{-1}. Groundwater was sampled multiple times in a year and analyzed to understand the geochemistry governing the aquifer. Efforts were also made to investigate the microbial population to understand the interaction of arsenic and native biogenic population. Based on these analyses, an immediate household-scale treatment solution was targeted to provide immediate relief to the affected community. A low-cost (Jalkalp) filter was procured from the Sehgal Foundation to evaluate its As-remediation potential and provide potable water at household levels. This filter contained rusted-iron nails for the removal of arsenic from contaminated water. The Jalkalp filter was validated by spiking arsenic solution (50-500 µg L^{-1}) in uncontaminated groundwater, and by directly passing As-contaminated groundwater (~200 µg L^{-1}) sampled from the contaminated site. The As-removal efficiency was found to be more than 97 % and was able to consistently bring dissolved arsenic levels below the permissible level. The filter was also able to pass other water quality tests related to most drinking water parameters. This study highlights the importance of combining long-term biogeochemical investigations and short-term treatment options while targeting sustainable site remediation.

Keywords: Inorganic arsenic; geochemical analysis; low-cost filter; biogenic sources

1. INTRODUCTION

Arsenic (As) contamination in subsurface water has severely affected many countries (Bhowmick et al., 2013; Chakraborti et al., 2018). Arsenic is a geogenic metalloid contaminant that affects aquifers worldwide. Sustained ingestion of As-contaminated water (>10 µg L^{-1}, WHO permissible limit) causes several chronic health problems, including cancers in humans (Ratnaike, 2003). Some of the health effects associated with arsenic are cancer (skin, lung, kidney), neurological disorder, reproductive effects, and hypertension (IARC, 2012). The National Rural Drinking Water Program report (2016-17) suggested that tube wells in 6800 villages in 96 districts have As concentrations >10 µg/L, adversely affecting more than 43000 people. In an aqueous environment, arsenic mainly exists in +III (AsO_3^{3-}; arsenites) and +V (AsO_4^{3-}; arsenate) (Bissen and Frimmel, 2003), where the former considered more toxic than the latter. Since As source in groundwater is primarily geogenic, it mobilizes due to site-specific geochemistry (Corkhill and Vaughan, 2009; Nickson et al., 1998; Nickson et al., 2000). The three most accepted As-release mechanisms in groundwater are (i) reductive dissolution of arsenate-bearing iron oxides (Nickson et al., 2000); (ii) oxidation of As-containing minerals (Corkhill and Vaughan, 2009); and (iii) competitive replacement by co-ions(Acharyya et al., 2000).

To remediate As-contaminated water, pump-and-treat methods were devised, which mainly employ sorption and precipitation based techniques using different chemicals (Singh et al., 2015). Primarily, oxides of iron, aluminum, and manganese were used as sorbents to remove arsenic efficiently (Goldberg, 2002). However, these conventional techniques suffer from certain disadvantages—low selectivity, disposal of As-containing sludge, long-term stability of immobilized arsenic on sorbents and in precipitated forms, secondary contamination caused by use of different chemicals for immobilizing chemicals, and high capital investment (Johnston et al., 2010; Khoei et al., 2018). Several studies showed that iron is an excellent adsorbent for arsenic removal, but the limitation is the high cost of treatment, which makes it out of reach of the majority of the rural population. Arsenic sand filter technology, also named as Kanchan Arsenic Filter (KAF), removes arsenic by adsorption of arsenic on iron nails placed in the filter (Ngai et al., 2007). The reason behind the use of zero-valent iron is that oxidation of iron is a very spontaneous reaction which results in the formation of Fe^{2+} and Fe^{3+} (Manning et al., 2002). However, the efficiency of KAF for arsenic lies in the 85-95 % range (Ngai et al., 2006). Previous studies suggested that iron and arsenic cannot pass through sand media over a period of time (Ngai et al., 2007). Also, arsenic removal efficiency drops down if the operating flow of the filter is higher than 35 L h^{-1} because of reduction in contact time. Arsenic bio-sand filter is easy to operate and is robust. It also costs very low and is primarily meant for people with low annual income. Another advantage of this bio-sand filter is that it can be constructed using local resources, and it also has safe methods for As-rich sludge disposal (Banerji and Chaudhari, 2017). This type of filter does not need any kind of chemical and power input (Ngai et al., 2007).

The objective of this study is to present a sustainable solution to remove arsenic using low-cost-based technique for household use by understanding the geochemistry of the contaminated site. Efforts were made to improve the arsenic removal efficiency in the bio-sand filter using iron nails under different conditions. Also, a preliminary investigation was made to understand the missing link between physiochemical and biological factors which could lead the long-lasting solutions to arsenic contamination in the future.

2. MATERIALS AND METHODS

2.1 Materials

All chemicals used in this study were of ACS or higher grade. Stock solutions of 1,000 mg L^{-1} of As(V) and As(III) were prepared by dissolving sodium arsenate ($Na_2HAsO_4 \cdot 7H_2O$; purity > 98 %) and $NaAsO_2$ in ultrapure water. (Milli-Q, resistivity > 18.2 MΩ-cm). The solutions were stored in a 250 mL HDPE bottle. For ICP-MS analysis certified stock standard was used, and for other wet-chemical analyses standards were prepared using high-purity salts. Samples were filtered using a 0.22 µm syringe filter.

2.2 Experimental methods

2.2.1 Sample collection. As-contaminated groundwater samples were collected from previously identified locations (manuscript in review) near Kanpur, Uttar Pradesh, India situated in the Indo-Gangetic plains. Two such locations were designated as BK2 and BK14. Also, As-uncontaminated groundwater was collected from IITK tap water. For each sample, pH, temperature (°C), conductivity (µS cm^{-1}), and redox potential (E_H; V) were measured using a portable multiparameter meter (Orion star A329; Thermo Fischer Scientific) and suitable electrodes. Three sets of water samples were collected from the mentioned aquifers. Two sets were filtered using 0.2 µm Nylon syringe filters (Cole-Parmer). One of these sets was immediately acidified using 1% (v/v) with a trace-metal grade of HNO_3 for dissolved total arsenic measurement using inductively coupled plasma mass spectrometry (ICP-MS). The other set of filtered samples was left unacidified for measurement of dissolved As(V) and As(III) using ion chromatography coupled with ICP-MS (IC-ICP-MS).

2.2.2 Arsenic removal in Jalkalp filter. Both As-spiked uncontaminated (IITK groundwater) and As-contaminated groundwater (BK-2 and BK-14) were introduced into Jalkalp filter to investigate its arsenic-removal efficiency. Arsenic was spiked in the form of only As(V), or only As(III), or As(V) and As(III) (1:1 molar ratio) such that the total arsenic concentrations (50-500 µg L^{-1}) remained the same. These experiments were performed under three different heads—0, 3, and 6 cm (Fig.1). Further, the Jalkalp filter was also validated with real As-contaminated groundwater. Around 40 L of As-contaminated samples were collected from location BK-2 and BK-14 and passed in the Jalkalp filter under the constant head of 0 cm.

Samples from filter outlet were collected after every 10 min until 3 h and were filtered using a 0.22 µm syringe filter. An aliquot of this filtered sample was transferred to other collection tubes and was immediately acidified for total arsenic, and other trace metal analysis using ICP-MS. The other part of the unfiltered sample was left unacidified for arsenic speciation study using IC-ICP-MS, and cation and anion measurement using IC.

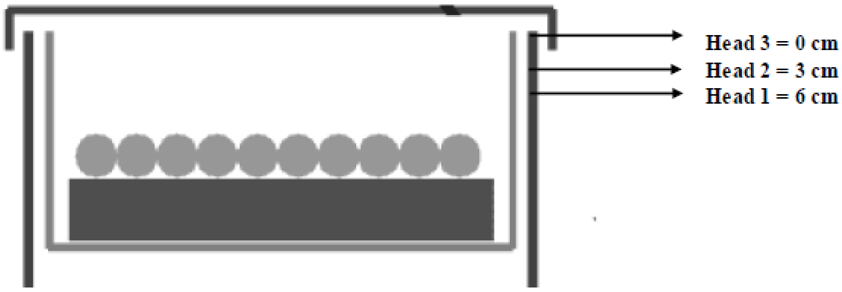

Fig. 6 Schematics of diffuser box of filter under different heads.
Filled circles represent rusted-iron nails used for arsenic removal

2.2.3 Water quality parameters, and preliminary microbial characterization. To test whether Jalkalp filter is good for drinking purposes or not, several water quality parameters were tested for samples collected before and after filtration from Jalkalp filter. Water quality parameters were tested only for field samples collected from two As-contaminated locations (BK-2 and BK-14). Parameters such as pH, turbidity, alkalinity, solids determination, hardness, chemical oxygen demand (COD), biochemical oxygen demand (BOD), anions such as F^-, Cl^-, SO_4^{2-}, NO_3^-, heavy metals, and coliforms. These tests were performed based on IS:10500 (2012) second revision.

Efforts were also made to identify certain microbes that could be impacting water quality, especially arsenic concentrations in the groundwater. For microbial work, groundwater was specifically sampled and was stored without acidification and filtration. About 100 µL of water sample was spread in the Luria-Bertani medium and was incubated for 24 h at 37 °C. An anti-fungal agent, cycloheximide (10 mg mL^{-1}), was used. Gram-positive and Gram-negative bacteria were separated based on differential agar-Eosin methylene blue (EMB).

2.2.4 Analytical methodology. Measurement of total arsenic was performed on inductively coupled plasma mass spectroscopy (ICP-MS; iCAP QC; Thermo Scientific). Samples were filtered, acidified using 1% HNO_3, and diluted before analysis. Samples containing both arsenic species from arsenic experiments were collected, filtered (from 0.22 μm syringe filter) and analyzed on the IC-ICP-MS instrument (Thermo Scientific iCAP Q with the Thermo Scientific Dionex ICS-5000 IC System). Standards were prepared using certified stock solutions. Ion chromatography (IC) was used to analyze various cations and anions in different types of samples.

3. RESULTS AND DISCUSSION

3.1 Physiochemical parameters of sampled groundwater

The total arsenic concentrations in contaminated groundwater were 142 and 132 μg L^{-1} sampled from locations BK-2 and BK-14, respectively. Measured redox potential values (E_H), 114.9 mV for BK-2, 49.7 mV for BK-14, suggested oxidizing conditions prevailed in the aquifers. The arsenic speciation study indicated that location BK-2 was As(III) dominated [As(III) =87, As(V) =20 μg L^{-1}], whereas BK-14 was As(V) dominated [As(III) = 1, As(V) =143 μg L^{-1}]. Some other geochemical parameters are listed in Table.1.

3.2 Arsenic removal in Jalkalp filters

3.2.1 Uncontaminated groundwater spiked with arsenic. For validating Jalkalp filter, different concentrations (50-500 μg L^{-1}) of As(V) and As(III) were spiked in As-uncontaminated groundwater under different heads (0, 3, and 6 cm). For all the different conditions—dissolved As spiked at different heads, Jalkalp filter was able to remove both As(V) and As(III) within 20 min of filtration. Figure 2 shows the arsenic removal from As-spiked uncontaminated IITK groundwater at head = 0 cm. The arsenic removal efficiencies at various dissolved arsenic concentrations were in the range 95-99 % which validated the ability of Jalkalp filter to remove arsenic up to 500 μg L^{-1} at the highest flow rate of 27 L h^{-1}.

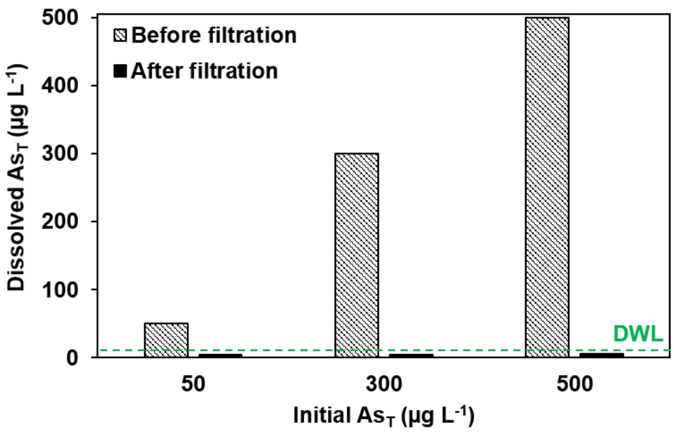

Fig. 7 Arsenic removal using Jalkalp filter by spiking arsenic in uncontaminated groundwater

3.2.2 Arsenic-contaminated groundwater. Jalkalp filter was also validated for real As-contaminated aquifer BK-2 and BK-14 (Fig. **8**). The initial arsenic level was 142 μg L^{-1} and 132 μg $L^{-1}$for BK-2 and BK-14, respectively. For both water samples, arsenic removal efficiencies were found to be above 99%, whereas reported As efficiency by Kanchan Arsenic Filter (KAF) was 85-90% (Ngai et al., 2006). It is a known fact that phosphate interferes with arsenate removal due to structural similarity, yet Jalkalp filter was able to remove arsenic in sample BK-14, even though the sample contained a high concentration of phosphate (2.7 mg L^{-1}). Further, sample BK-2 contained a dissolved iron concentration of 9 mg L^{-1}, which was reduced to below permissible limit (108 μg L^{-1}) by the filter. In comparison, KAF removed iron concentration between 10-20 mg L^{-1} (Ngai and Walewijk, 2003).

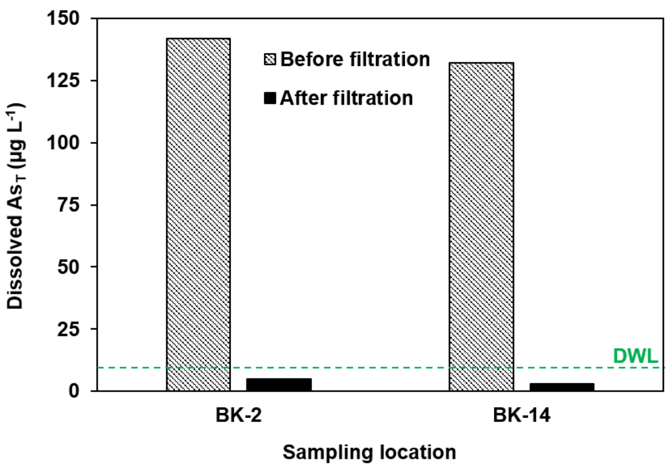

Fig. 8 Arsenic removal using Jalkalp filter from real As-contaminated groundwater Data correspond to head = 0 cm. BK-2 and BK-14 were the two samples from As-contaminated aquifer

3.2.3 Water quality parameters and microbial characterization. The water quality parameters were tested on two samples, BK-2 and BK-14, before and after filtration through Jalkalp filter sampled from As-contaminated locations (Table 3). From all water quality tests performed, it was clear that the filtered water was under the permissible limit for all parameters tested, except alkalinity and hardness.

Several bacterial colonies were identified after incubation at 37 °C. These bacteria could be pathogens, which could adversely affect the health of living beings. Preliminary microbial characterization suggested that As-resistant isolates from affected aquifers were gram-negative bacteria, which could be responsible for arsenic mobilization and redox transformations in the groundwater. However, a detailed microbial study is warranted to investigate the link between abiotic and biogenic sources for controlling arsenic concentration in this groundwater.

Table 3 Selected water quality parameters for As-contaminated groundwater before and after filtration

Parameters*	Permissible limit	Maximum limit	Before filtration		After filtration	
			BK-2	BK-14	BK-2	BK-14
pH	6.5	8.5	7.04	6.96	7.38	7.44
Total coliform (CFU 100 mL^{-1})	0	0	400	595	0	0
TDS; (mg L^{-1})	500	2000	1956	1498	1417	1787
Hardness	200	600	325	1400	52	520
Alkalinity (mg L^{-1} as $CaCO_3$)	200	600	1240	1000	900	1100
SO_4^{2-}(mg L^{-1})	200	400	71	156	75	126
Cl^-(mg L^{-1})	250	1000	592	353	457	337
Total Fe (mg L^{-1})	1	No relaxation	0.09	0.06	0.05	0.06
COD (mg L^{-1}; as O_2)	0	0	64	32	0	0
BOD (mg L^{-1}; as O_2)	0	0	9	5	0	0

**Other water quality parameters are not listed as they were below the detection limit*

4. CONCLUSIONS

Jalkalp filter can efficiently remove total dissolved arsenic (50-500 µg L^{-1}) below permissible limit from As-affected aquifers, even in the presence of a high amount of dissolved phosphates. This filter has the capacity to treat 60,000 L of 100 µg L^{-1} As-contaminated water, the average concentration found in As-affected aquifers near Kanpur, U.P., and has an estimated life of 1.6 years. Considering the effectiveness of Jalkalp filter in removing total, fecal coliforms, and other water quality parameters along with total arsenic, this low-cost filter is a sustainable way to be used at a household level, especially for the families in the low-income groups. Understanding the link between abiotic and biogenic sources would be important to probe As-redox transformation and factors controlling As concentration, so as to develop a suitable arsenic in-situ remediation technique.

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Subsurface Soil Contamination and Remediation Strategy for Industrial Area of Bangalore

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ABSTRACT

Rapid industrialization coupled with appropriate technological interventions in the last decade has elevated the economic growth of the country. The consequence of which is observed in terms of increased levels of contaminants in the air, water and soil environment. According to the CPCB report on the Comprehensive Environmental Pollution Index CEPI (2010), out of 88 identified industrial clusters, 43 are critically polluted (CEPI score >70). The Peenya Industrial area, Bangalore, Kolar Industrial Area, Bidar, and Raichur Industrial Area are identified as severely polluted where the CEPI score ranges between 60 -70. In 2016 these 88 industrial clusters increased to 100. Peenya is declared as a critically polluted area by CPCB in 2019 based on the CEPI score which was increased from 65.11 to 78.12. This paper presents existing heavy metal contamination levels in Peenya Industrial Area and transport of the same is simulated to study the vulnerability of the existing borewells to these contaminants to arrive the suitable remediation strategies.

Keywords: Comprehensive Environmental Pollution Index; heavy metals; remediation.

1. INTRODUCTION

The extensive use of natural resources for human well-being has led to many environmental-related issues. Unplanned growth and planning of industrial areas have created huge havoc in urban and semi-urban areas by polluting the surrounding environment through improper disposal of industrial effluent and hazardous waste. The central pollution control board report reveals that 64% of 88 industrial clusters showed severe to critical levels of pollution for the land environment (soil + groundwater) in the Comprehensive Environmental Pollution Index score (CPCB, 2009). With the support of world bank, the report from MoEFCC on the inventory of probably contaminated sites of India, showed nearly 35% of identified sites are polluted with chromium and lead in industrial areas (MoEFCC, 2015). Recently the Peenya industrial cluster is identified as a critically polluted area with the CEPI 78.12 (NGT, 2019). The sub-index value for air, surface water, and groundwater in CEPI are 41, 66 and 70 respectively. The major contribution to the CEPI score is from groundwater where BOD, TKN, and total chromium have been considered as major pollutants. The groundwater showed a very high concentration of heavy metals like hexavalent chromium, copper, lead, nickel, zinc, etc. To tackle this systematically, there is an urgent need for both the policymakers and researchers to act coherently to ensure a pollution-free environment. This paper discusses the existing conditions, soil contamination levels and recommendations for further remediation approaches.

2. METHODOLOGY

Peenya, Bengaluru, one of the largest industrial hubs of Asia with an area of 40 sq. km. houses many small, medium and large-scale industries by employing 5 lakhs plus people and with an annual turnover of Rs. 15,000 Crores. (Fig 1) This industrial cluster comes under the jurisdiction of BBMP and located at 13º 1’42" N and 77º 30’45" E of North-western suburbs of Bengaluru city. The average annual rainfall for Bangalore was observed as 923 mm. Red sandy soil has covered the industrial cluster with 1 to 2 meters from the natural ground level. The industrial area is witnessed with residential and other commercial activities without any buffer zone.

The major industrial processes which are responsible for pollution are electroplating, textile dyeing, lead processing, spray painting, powder coating, and pharmaceutical formulations, etc.

Fig. 1 Peenya Industrial Area

In the first stage, the existing data on pollution levels of groundwater and soil samples (12 locations) were collected from the Karnataka state pollution control board (KSPCB and NGRI, 2018). The CCME (Canadian Council of Ministers of the Environment) Canadian environmental quality guidelines were used as soil screening levels to compare with the existing contaminant levels. (MoEFCC, 2015). Based on the pollution levels sampling of soil was done and analyzed in the laboratory for different heavy metals. Totally 21 sampling locations were identified and, in this paper, only 4 site locations results are presented. The soil samples were collected in self-locking covers at the depth of 0-30 cm. The soil samples were analyzed for heavy metals as per EPA 3050B using concentrated nitric acid, hydrogen peroxide, and hydrochloric acid. The organic matter is analyzed using loss on the ignition method at 550^0C. The moisture content, specific gravity, and pH are analyzed as per IS 2720.

3. RESULTS AND DISCUSSION

As per the data provided by KSPCB, groundwater borewell showed an increasing trend in the concentration of total chromium (Fig 2) for the years 2015 and 2016. The latest water sample analysis reported the maximum concentration of total chromium and hexavalent chromium recorded as 15 mg/L and 14.3 mg/L respectively against drinking water IS 10500 standards of 0.05 mg/L. The elevated concentration of contaminants can be attributed to two reasons. The results were:

- The contaminated soil is leaching heavy metals to infiltrated rainwater.
- The industries are continuing the disposal of untreated industrial effluent on soil (illegally).

KSPCB soil reports showed an elevated concentration of total chromium, copper, lead, zinc, and nickel. The soil analysis reports of 12 sites showed a maximum total chromium concentration as 574 mg/kg and followed by copper as 576 mg/kg. These soil samples were collected at 3 different depths. The graphical representation for total chromium, copper and nickel concentration are shown in Fig 3,4 and 5. Nearly 50% of the sites have a higher concentration of nickel at the depth 30 – 90 cm depth and 33% of sites at the depth 90 – 150cm along with surface soil contamination.

The laboratory analysis of soil samples is shown in Table 1. From Table 1 it can be observed that all 4 sites have a higher concentration of total chromium and nickel in soil samples. Particularly the site no.7 showed comparatively higher concentration of total chromium, copper, nickel, and zinc. The current analysis clearly shows the surface soil contamination and this needs to be further explored to analyze the migration of heavy metals at a deeper depth. The current lab analysis showed an increase in the concentration of heavy metals compared to previous data.

Table 1 Characterisation of Soil samples

Site Location	1a	1b	4	7	CCME soil quality guidelines for Industrial Zone
Moisture content (%)	13.84	13.17	13.19	14.38	
Specific gravity	2.46	2.32	2.41	2.51	
Organic matter (%)	3.12	3.62	4.79	3.83	
Total Chromium, mg/Kg	148.50	160.50	198.25	491.50	87
Copper, mg/Kg	45.75	72	79.50	126.50	91
Lead, mg/Kg	25.50	15.25	27.50	102.75	600
Nickel, mg/Kg	81.25	66	93	191.0	50
Zinc, mg/Kg	56.25	64	169.50	367.50	360

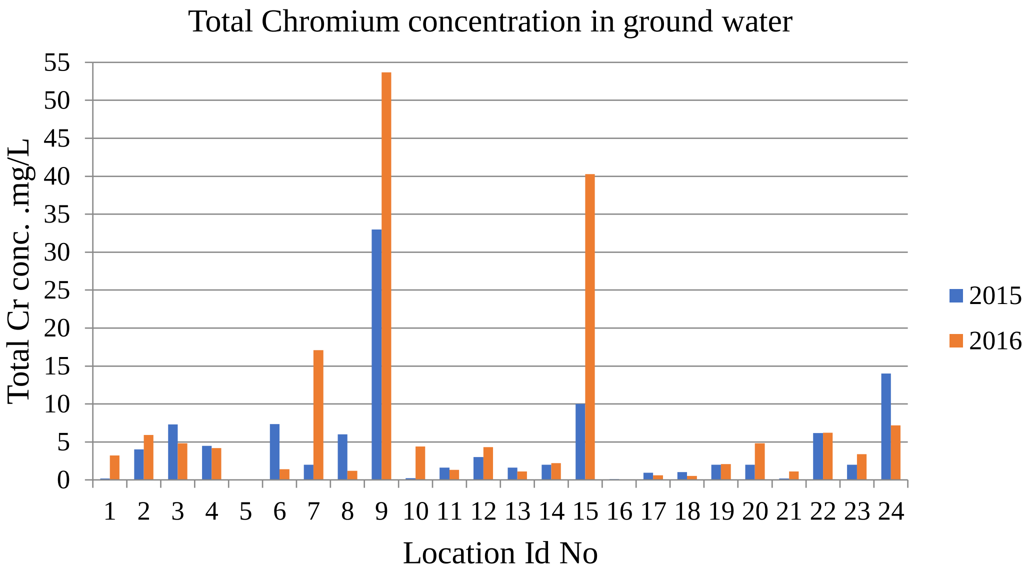

Fig. 2 The concentration of Total Chromium in groundwater (KSPCB)

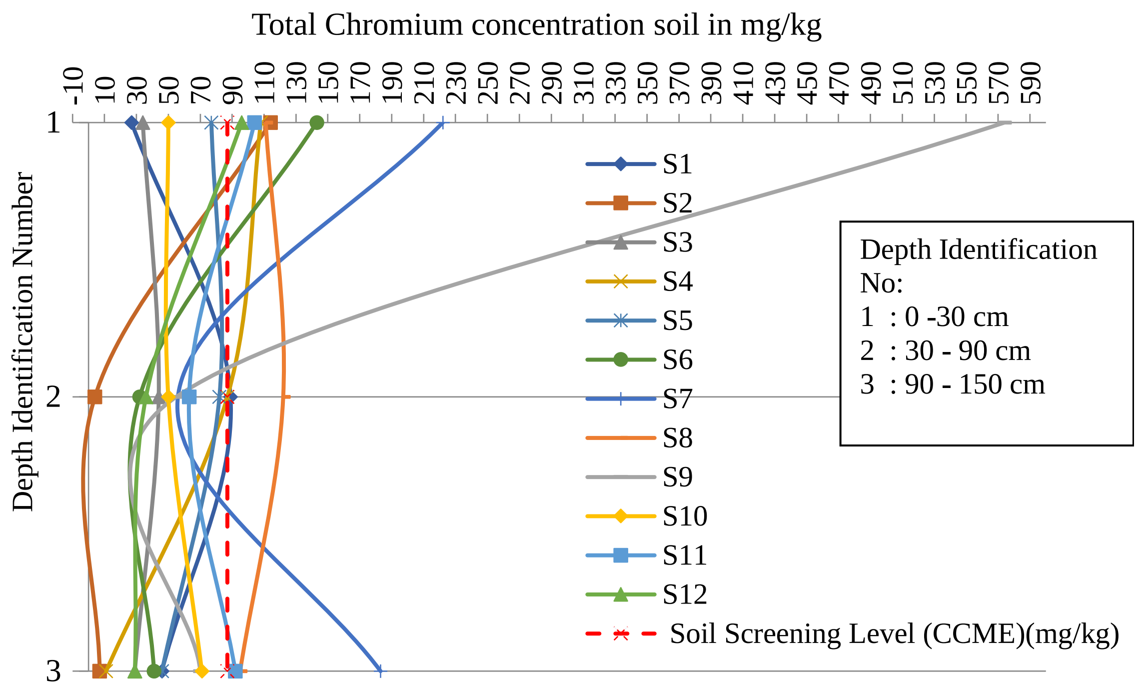

Fig. 3 The concentration of Total Chromium in soil (KSPCB)

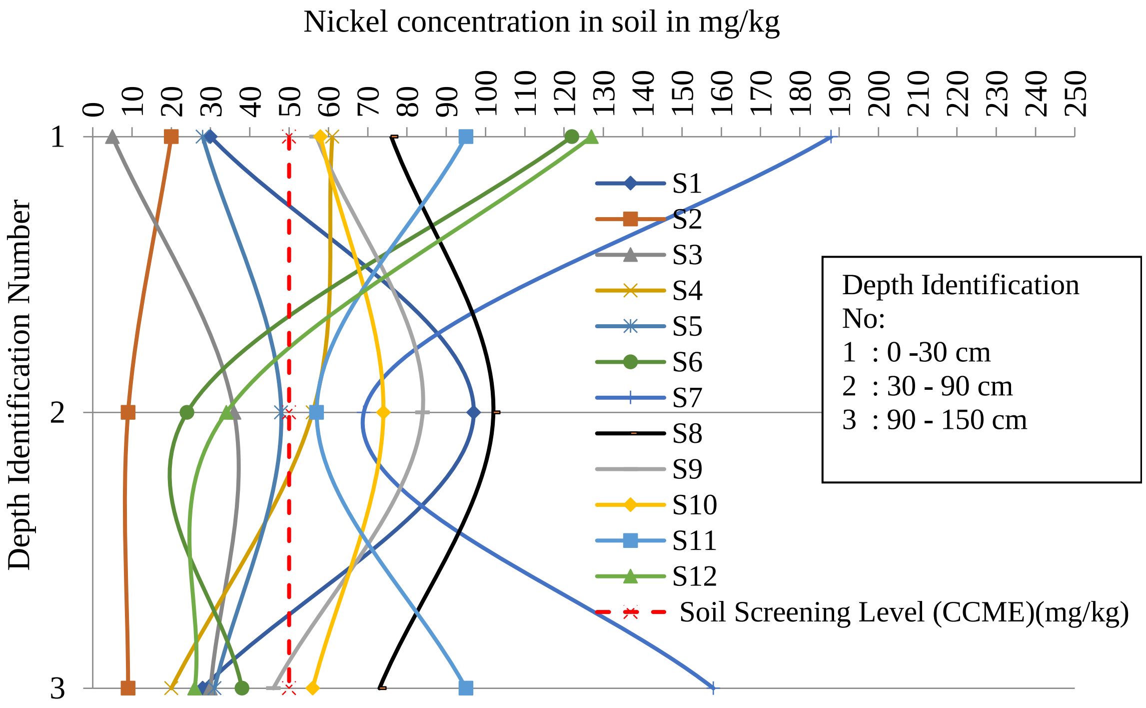

Fig. 4 The concentration of Nickel in soil (KSPCB)

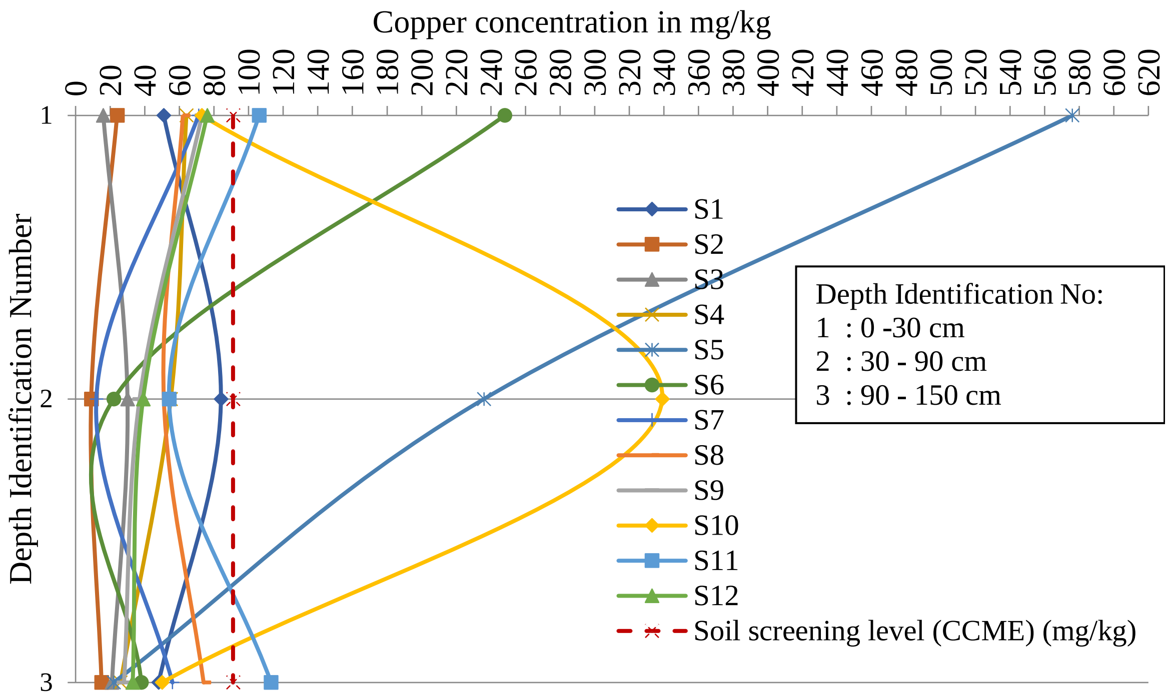

Fig. 5 The concentration of Copper in soil (KSPCB)

3.1 Numerical simulation of Nickel using Hydrus 1D

A preliminary analysis of the migration of nickel in the subsurface is performed using Hydrus 1D software (Fig 6) for site no 7. The input parameters for simulation are shown in Table 2. The transport domain of 10m is considered and assumed uniform soil profile throughout the domain. The nonlinear adsorption model is considered and the distribution coefficient is determined in the laboratory through batch studies as per ASTM D4646.

Table 2 Input parameters used for simulation

Parameter	Value
Transport Domain depth	10 m
Period of simulation	10 years
K_d	6.45 cm^3/g
β	0.95
Bulk density	1.5 g/cm^3
θ_r	0.065
θs	0.41
Upper boundary condition	Atmospheric BC with surface runoff
Lower boundary condition	Free drainage
Initial condition	0-30 cm: 0.282 mg/cm^3 30 – 90 cm: 0.103 mg/cm^3 90cm – 150 cm: 0.237 mg/cm^3

From Fig 6, it is observed that the nickel concentration of about 10 mg/L can be found in infiltrated water at 2 m depth within a year and it reaches 5 mg/L at 3m depth. The shallow water table wells may be vulnerable to nickel pollution because of leaching from the soil. However, this simulation is not comprehensive and further modeling and experimental studies are needed to understand the migration of the nickel.

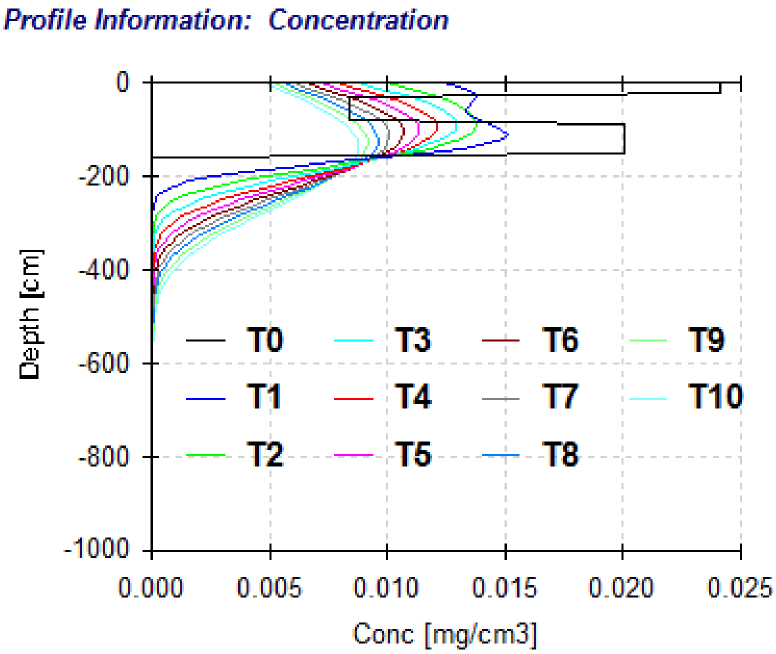

Fig. 6 Concentration profile of Nickel

4. REMEDIATION APPROACHES AND CONCLUDING REMARKS

From the laboratory and numerical analysis, the remediation of the groundwater and surface water through a direct approach is recommended. Controlling heavy metals leaching to groundwater through indirect means by isolation/immobilization is necessary. As existing and laboratory studies a higher concentration of chromium, copper, and nickel compared to CCME guidelines the following steps need to be adopted before remediation approaches.

- Additional soil sampling points at different locations and depth needs to be considered to demarcate the spatial extent of soil pollution. Further investigation on different soil fractions like exchangeable, carbonate bound, organic matter, iron, manganese oxide bound and residual content of heavy metals need to be analyzed to adopt suitable remediation methods.
- As groundwater and the soil environment are interlinked, the contaminated soil will act as a source for further contamination of surface and groundwater sources. Hence, it is required to isolate or immobilize the soil environment pollutants on priority and followed by the treatment of groundwater/surface water.
- Groundwater contaminated with heavy metals like total chromium, hexavalent chromium, lead, etc needs to be closed to prevent further consumption. The spatial extent of contamination needs to be assessed and the same can be remediated directly through a permeable reactive barrier using suitable reactive materials. This can be achieved using laboratory and pilot-scale studies.
- Few unauthorized small-scale industries have disposed of the industrial effluent by constructing pits. Clear demarcation and immediate action are necessary to remediate/isolate such contaminated soil.
- Many electroplating industries were closed due to non-compliance with KSPCB norms. But the same land is occupied by other industrial vendors after concreting the entire polluted area. It is required to check the subsurface soil contamination levels at these sites to avoid further contamination of water resources.

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Assessment of Moisture Migration from an Open Wastewater Drain using ERT

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ABSTRACT

Geophysical techniques are the noninvasive methods of investigation for preliminary subsurface exploration using techniques like Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR), Seismic Refraction, Seismic Reflection, etc. In the present study, two-dimensional geoelectrical investigation, ERT, is carried out to assess the extent of water emanated from a wastewater drain in the campus area of IIT Delhi, India. ERT survey found to be a very time-efficient method for approximate assessment of the subsurface moisture transport near any source of contamination. Resistivity surveys are conducted on both the upstream and downstream sides of the drain, where the only downstream side is lined. Resistivity profiles were spread across and on either side of the drain using Wenner-Schlumberger array configuration. Data acquisition was carried out using a Syscal junior pro resistivity measuring unit with multi-electrodes. Array configuration was created in Electre Pro, and the observed data were processed and inverted in Prosys II and RES2DINV software, respectively. Analysis of the result suggested that there is an adequate amount of moisture flow on both sides of the drain, more at the upstream side, in lateral and vertical directions, which are suspected to be contaminated water due to very low resistivity values in that region. Further investigation can be done using other geophysical techniques or by borehole observation method for more detailed information regarding contamination of the subsurface soil near the wastewater drain.

Keywords: Geophysical Techniques; ERT; Moisture Migration

1. INTRODUCTION

Geophysical methods provide the noninvasive means of subsurface exploration and are ideal when a large area needs to be investigated economically and quickly. Some of the commonly employed geophysical methods are Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR), Seismic Reflection, and Refraction. Since these methods are rapid and easy to perform, they can be used for preliminary site investigation. These methods are helpful in mapping depth to bedrock, depth to the water table, contaminated/ saturation zone in soil, leachate flow, etc. by observing anomalies or sudden changes in the data. All geophysical techniques measure the physical properties (resistivity, conductivity, magnetic permittivity, etc.) of subsurface material (Barker 1990, Porsani et al. 2004, Thomson 2007, etc.).

A drain system passes through the IIT Delhi campus, collects and transports wastewater. Some portions of this drain are lined, and some are unlined. There is a high possibility of migration of wastewater from the drain which may cause contamination in the adjacent area. This contamination, if present, may cause subsurface pollution. Thus, there is a need to study the zone of saturation around this wastewater drain that is possibly contaminated. This study aims to map the possible migration of wastewater around the drain using a 2D electrical resistivity method. The geoelectrical technique is one of the most applied geophysical methods in environmental studies (Soupios et al. 2006, Saha et al. 2019). ERT has recently become the most frequently used geoelectrical application for these purposes due to its relative simplicity and time effectivity. Electrical resistivity is an intrinsic property of the material. Soil is a matrix of solid, liquid and gases hence electrical resistivity of soil also depends on the liquid present in it. Soil solid is highly resistive material but any presence of moisture decreases its electrical resistivity drastically. Based on this principle, in this study, an attempt is made to observe the zone of moisture migration near an open drain which may also be a possible source of contamination.

2. DESCRIPTION OF STUDY AREA

The study includes the prediction of the zone of saturation around the wastewater drain in the IIT Delhi campus. Three sites were chosen at a stretch of about 200-300 m, one at upstream and two at the downstream side of drain such that ERT studies can be carried out at both lined and unlined portions of the drain. The locations selected are shown in Figure 1, and their respective descriptions are given in Table 1. The site consists of uniform soil type, up to the depth of exploration which was confirmed by 6-7 m deep boreholes. ERT mapping is done on either side of the drain, at upstream (Location 1: unlined). At downstream (Location 2; lined, and Location 3; unlined), it was performed only on one side because of obstruction at the other side of the drain. At these three locations, a total of four resistivity profiles were selected, as depicted in Figure 2. The photo of test locations is shown in Figure 3.

Fig. 1 Test Locations

Table 1 ERT Test Details

Drain Side	Location	Profile	Spread Length (m)	No. of Electrodes Used	Electrode Spacing (m)
Upstream	1	A	34	18	2
		B	34	18	2
Downstream	2	C	36	36	1
	3	D	36	36	1

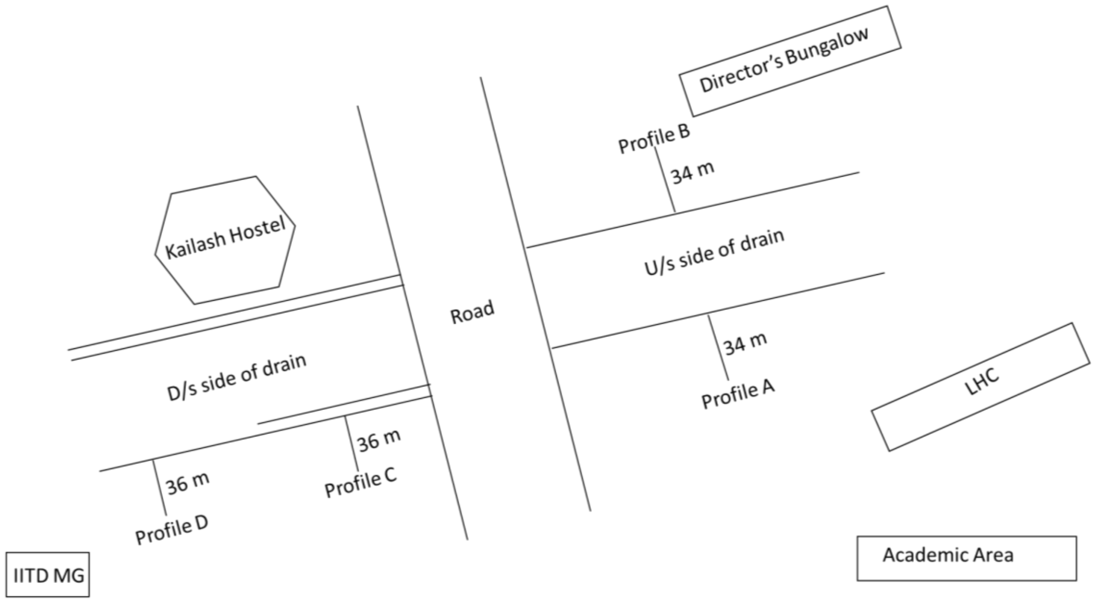

Fig. 2 Schematic Diagram of ERT Locations

Profile-A

Profile-B

Profile-C

Profile-D

Fig. 3 Ground Profiles of ERT

3. METHODOLOGY AND BACKGROUND

ERT is a non-destructive technique, in which a current is ejected into the ground, and the potential difference is measured to find the resistivity of the medium (Lazzari et al. 2006, Sass et al. 2008). A minimum of four electrodes are required; two electrodes for conducting current and the remaining two measures the potential difference generated, as shown in Figure 4. Electronic Conduction and Electrolytic Conduction are the two main methods by which electric current flows in the ground at shallow depth. Out of these two methods, electrolytic conduction is more suitable for engineering and environmental applications (Loke 2002). The resistivity, ρ (ohm m) is given by:

$$\rho = R \times k$$

R is resistance in ohm, and k (in m) is a geometric factor, which depends on the configuration of electrodes. In the field, apparent resistivity is obtained instead of true resistivity because of the inhomogeneity of the subsurface. This resistivity so obtained is inverted using software, and true resistivity is determined (Loke 2002, Reynolds 2011).

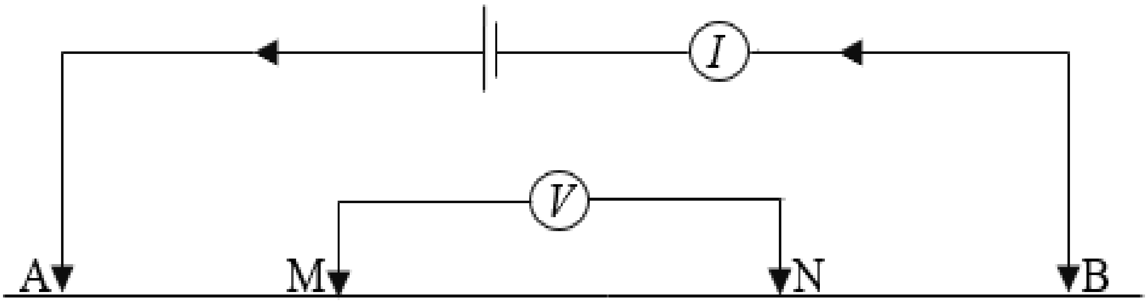

Fig. 4 Generalized Electrode Configuration in Resistivity Surveys

As stated earlier, resistivity depends on electrode configuration, and there are so many different array configurations available, which provides flexibility in resistivity computation in different conditions. Wenner, Schlumberger, and Dipole-Dipole are the most commonly employed array types for geoelectrical explorations. Wenner and Schlumberger are most effective for predicting lateral and vertical changes, respectively, at shallow depths. They also have better sensitivity to orientation and lateral inhomogeneities, whereas Dipole-Dipole array is usually employed for deeper sounding depths (Drahor et al. 2006, Reynolds 2011).

The selection of array types also depends on the configurations available in the software. Electre Pro software provides the flexibility of using combined Wenner-Schlumberger array configuration, which is used in this study. This array combination offers advantages of both the arrangements and hence better lateral and vertical variability can be obtained for shallow depths. In the present study, Syscal Junior/ R1 Plus (IRIS Instruments, France) resistivity measuring unit configured for the multi-electrode and multi-channel system is used for data acquisition. Different resistivity profiles (A, B, C, and D) selected are shown in Figure 2 and 3, and their location, profile length, number of electrodes and spacing used is presented in Table 1. The observed apparent resistivity data is processed and inverted using Prosys II and RES2DINV software, respectively.

4. RESULTS AND DISCUSSION

Two-dimensional geoelectrical subsurface exploration is done at three locations (four profiles). The resistivity profiles obtained are shown in Figures 5 to 8. Figures 5 and 6 are the upstream profiles on either side of the drain at Location 1 and Figures 7 and 8 are the downstream profiles at Locations 2 and 3, respectively.

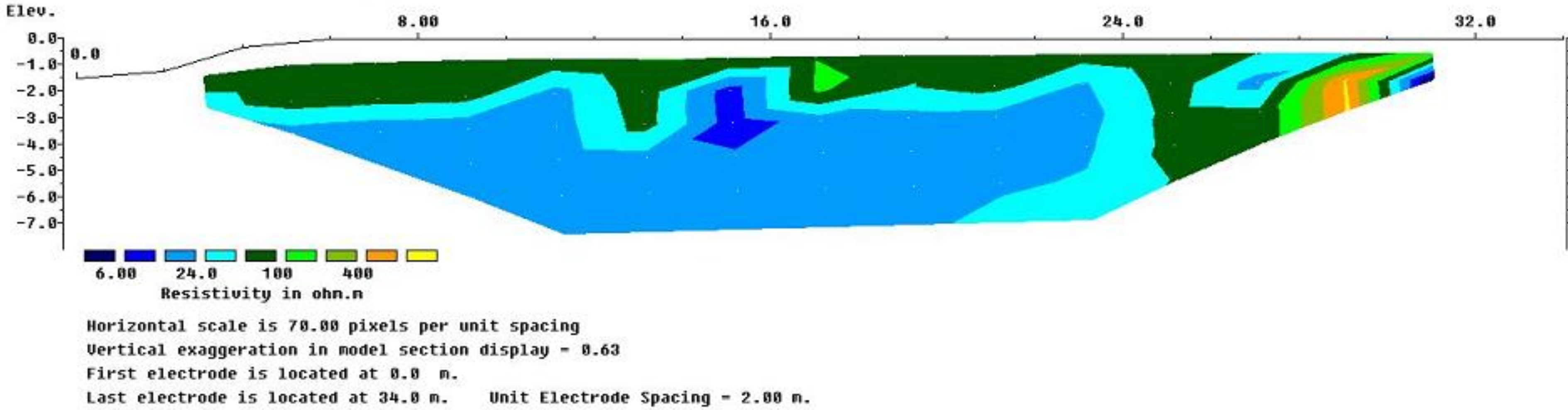

Fig. 5 Inverted Resistivity Section of the Profile-A

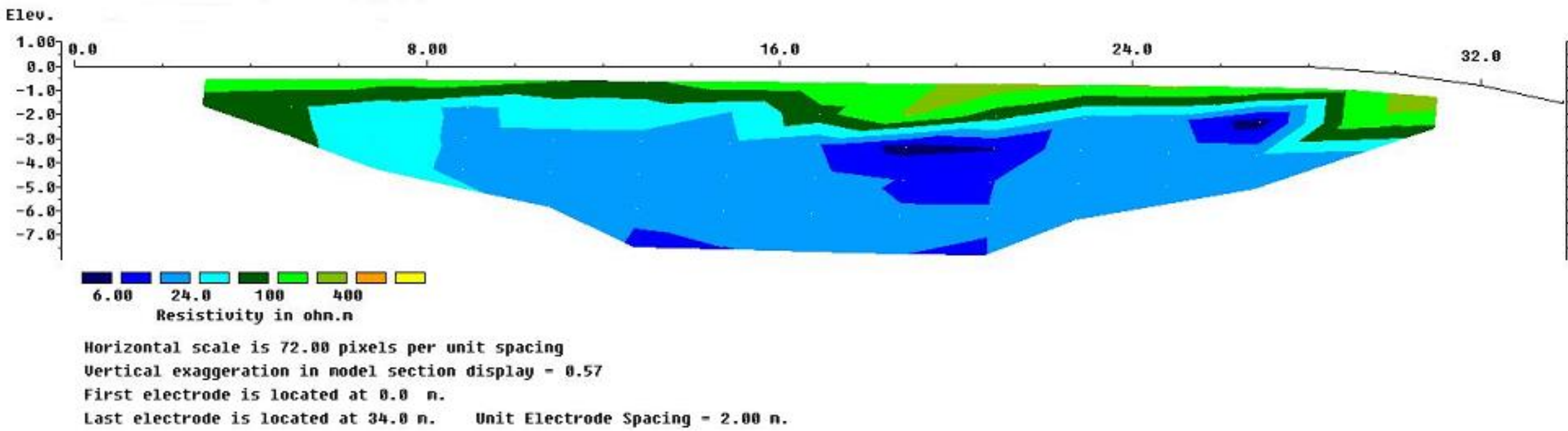

Fig. 6 Inverted Resistivity Section of the Profile-B

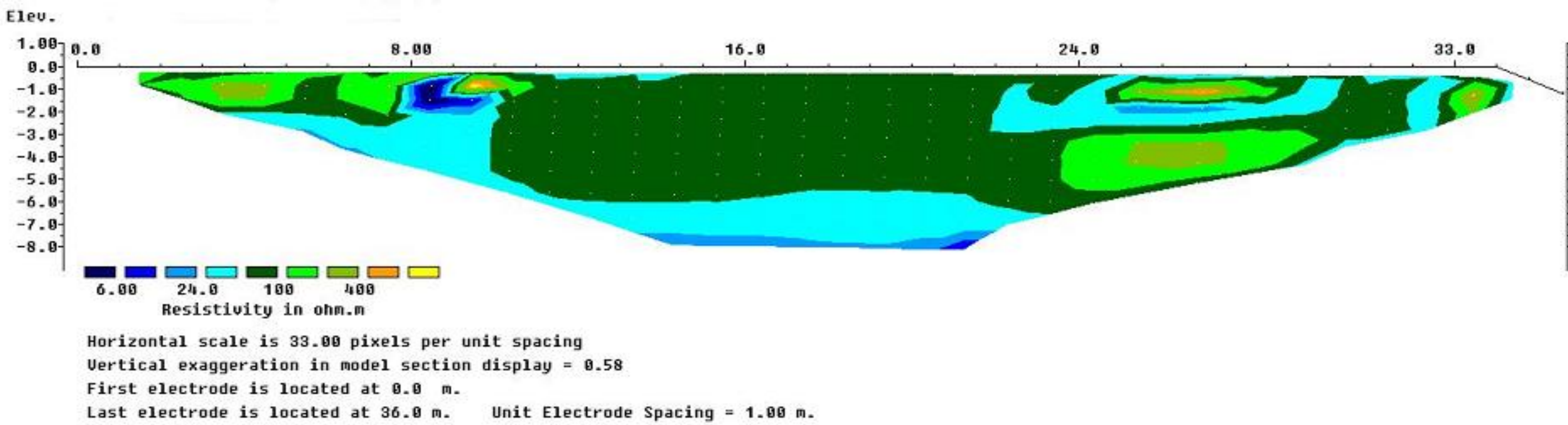

Fig. 7 Inverted Resistivity Section of the Profile-C

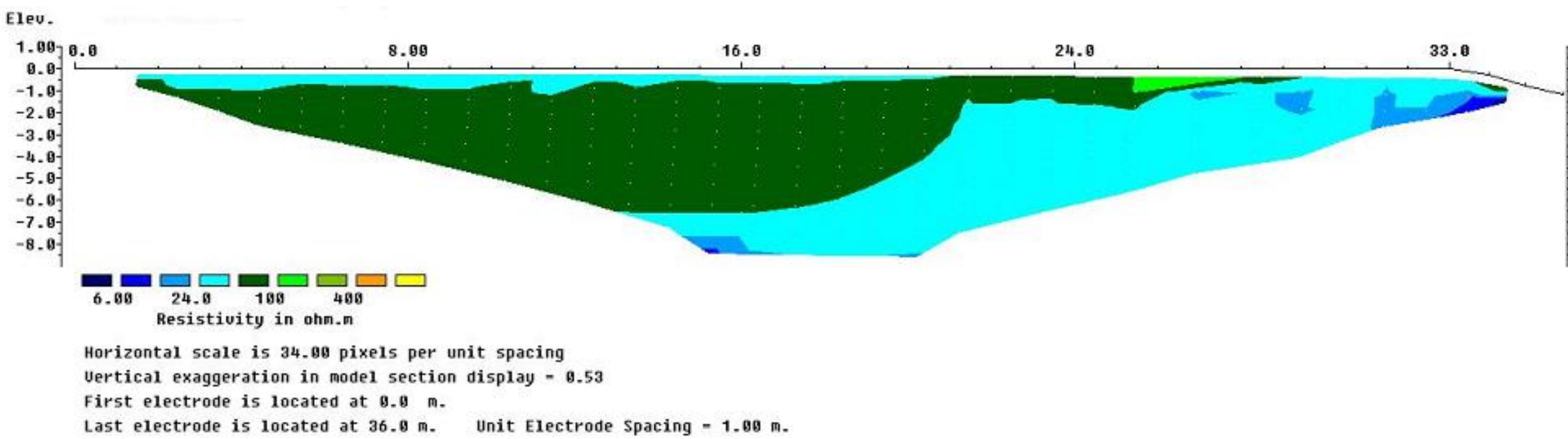

Fig. 8 Inverted Resistivity Section of the Profile-D

From Figures 5 to 8, it can be seen that there is a low resistive zone near the open drain which is pronounced in the unlined portion. In the upstream side, the low resistivity zone extends more in the lateral direction, and its effect is visible from a depth of 2-2.5 m which was confirmed from both the profiles (A and B) at Location-1 (Figures 5 and 6). It is suspected that this low resistive zone is because of the migration of moisture from the drain on either side which is a possible zone of contamination (Saha et al. 2019). The upper 1.5-2 m layer appears to be dry and its resistivity values correspond to that of sandy silt to silty sand (Reynolds 2011), which is usually found in this region. The high resistive zone in Figure 5, at a distance of 28-32 m, is possibly due to the footpath passing through that area. Unexpected low resistive zone towards the other side of the drain in Profile-A is suspected because of the presence of metallic sheets (as seen in Figure 3, Profile-A) present for the barricading which might have influenced the electric field.

In the downstream side, Profile-C and Profile-D are along the lined and unlined portions of the drain, respectively. Profile-C being lined has very low or no influence of moisture migration from the drain whereas a significant moisture migration is observed along the drain in Profile-D as shown in Figures 7 and 8, respectively. At both these locations, boreholes were made up to the depth of 6-7 m and no water table was observed. This further correlates to moisture migration from the drain to adjacent ground. In both the profiles, high resistivity values are obtained under a footpath which was passing through the test locations as indicated in Figure 3. In Profile-C, at 8 m from the starting point, a low resistive zone is observed which is perhaps due to leakage of a pipe lying above it.

It is also suspected that low resistive zones in the profiles (A, B, and D) corresponding to the unlined portion along the drain represent the possible chances of contamination since the drain carries wastewater.

5. SUMMARY AND CONCLUSIONS

Electrical resistivity is an intrinsic property of the material. Soil is a matrix of solid, liquid and gases; hence electrical resistivity of soil also depends on the liquid present in it. Soil solid is highly resistive material but any presence of moisture decreases its electrical resistivity drastically. Based on this principle, in this study, an attempt is made to observe the zone of moisture migration near an open drain. From the electrical resistivity contours, the following conclusions can be drawn:

- ERT can be used to predict the extent of the saturated/contaminated zone.
- The electrical resistivity of the soil near the unlined open drain is less as compared to that of soil near the lined drain, which is also expected as the lining will not allow moisture migration.
- At locations 2 and 3, borehole up to a depth of 6-7 m indicates a uniform type of soil, which in turn suggests the same electrical resistivity, but a low resistive zone is observed near the drain. So, it can be inferred that this low resistive zone indicates moisture migration.
- Since this low resistive zone is due to the wastewater from the drain, there are high possibilities of this area to be contaminated, which needs to be further studied.
- This is a qualitative analysis only; quantitative analysis can be done in the future to see the resistivity variation with the amount of moisture.

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Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites

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ABSTRACT
Geophysics applies the principles of physics to the study of the Earth. Non-destructive nature, quick application and a large amount of data generation, mostly continuous as against discrete point data obtained from invasive methods, has made it popular over the years in various industries. Most petroleum and mining exploration depend heavily on geophysics. The use of geophysical techniques is rapidly increasing in near-surface applications as well.

Comprehensive investigations for contaminated sites and groundwater also need a large amount of high-quality data in the shortest possible time and a cost-effective manner. Generation of a site conceptual model required information on geology, presence of faults/ fractures/ shear zones, contaminant presence/ location, spatial and temporal information on contaminants, buried drums/ infrastructure, etc. It is also desired to have this information in a continuous manner all over the study area. Unless such information is made available, it becomes extremely difficult to develop a contaminant management/ remediation strategy.

The use of geophysical methods in the study of contaminated sites has gained wide acceptance in the last decade as a cost-effective means of performing site characterization and ongoing monitoring. The methods include airborne, surface and borehole geophysical tools, having their respective strength and limitations. No single tool is appropriate for every geological condition and tool/ technique selection based on problem definition and geology of the area is one of the most critical aspects of the geophysical campaign. The paper briefly discussed various geophysical tools/techniques to help to design and evaluate a geophysical program at contaminated sites

Keywords: Geophysics for Contamination; Contamination Site Investigation

1. INTRODUCTION

Geophysical methods derive their major strength from their non-destructive nature, quick application and capability to generate a large volume of data on subsurface in a cost-effective manner, giving them an edge over the use of only monitoring wells. It makes these methods extremely suitable for the study of contaminated sites where high-quality data is the foundation on which the contaminant management/ remediation strategy is built. The methods can be used for:

- Geologic characterization, including assessing types and thicknesses of strata and the topography of the bedrock surface below unconsolidated material, and generating fracture mapping and paleochannels.
- Aquifer characterization, including depth to the water table, water quality, hydraulic conductivity, and fractures.
- Contaminant plume identification, both vertical and horizontal distribution including monitoring changes over time.

- Locating buried wastes and other anthropogenic features through the identification of buried metal drums, subsurface trenches, and other features (e.g., cables, pipelines).

The methods can further be sub-divided into airborne, surface and borehole geophysical methods.

2. AIRBORNE GEOPHYSICAL METHODS FOR CONTAMINATED SITES

Hydrogeologists have used the term remote sensing loosely to apply to all airborne sensing methods (Ellyett and Pratt, 1975). Exploration geophysicists usually use the term airborne geophysics to refer to magnetic, gravimetric, and electromagnetic measurements taken from a helicopter or airplane aircraft and they restrict the term remote sensing to observations of electromagnetic radiation from satellites and high-altitude aircraft (Regan, 1980). Airborne sensing and methods are more commonly used in regional investigations where large areas must be evaluated, rather than for site-specific studies. The discussion here is kept limited to airborne geophysical methods only.

Airborne Time Domain Electromagnetic Method (TDEM) uses an electromagnetic wave transmitter and receiver that responds to changes in the ground electrical conductivity. It Detects variations in soil and reek types; variations in ground-water salinity; location of shallow subsurface aquifers and deeper brine contaminated aquifers.

Airborne Magnetic Method measures the earth's total magnetic field. It is primarily used in petroleum and mineral exploration to assist with geological mapping and structural interpretations. Also used to locate abandoned wells with metallic casings.

3. SURFACE GEOPHYSICAL METHODS FOR CONTAMINATED SITES

Electrical and electromagnetic methods are the most commonly used surface geophysical methods in the study of groundwater and contaminated sites. Various surface geophysical methods with their brief principle and application are as under:

Electromagnetic Method uses a transmitter coil to generate currents that induce a secondary magnetic field in the earth that are measured by a receiver coil. The method can be used to map a wide variety of subsurface features including natural hydrogeologic conditions, delineation of contaminant plumes, rate of plume movement, buried wastes, and other artificial features (e.g., buried drums, pipelines). Depth of penetration is typically up to 60 meters but depths to 200+ meters are possible.

Electrical Resistivity Method measures the resistivity of subsurface materials by injecting an electrical current into the ground by a pair of surface electrodes and measuring the resulting potential field (voltage) between a second pair of electrodes. The method is used widely to study contaminated sites. 2D and 3D imaging capabilities have made this method extremely attractive for contaminant site investigations.

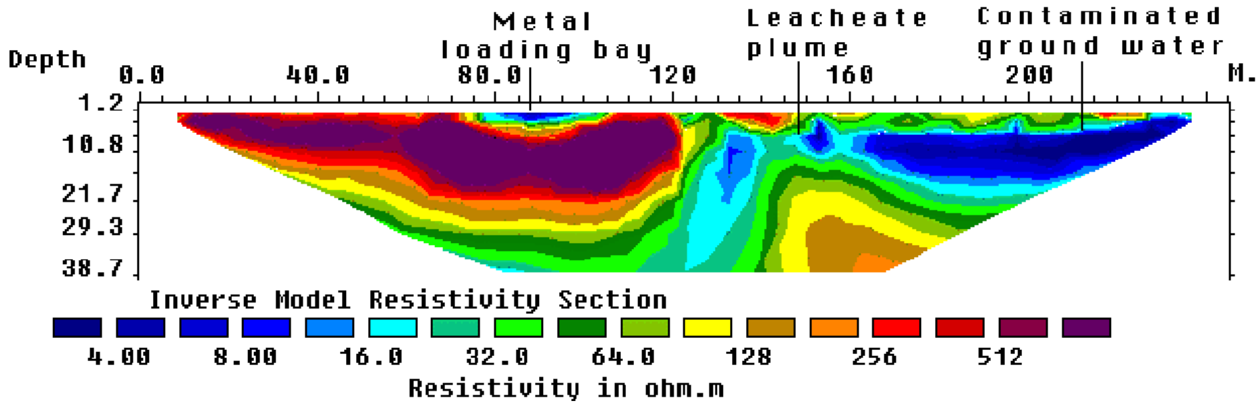

Fig. 1 The resistivity section from a survey over a derelict industrial site

Seismic Methods (Refraction/Reflection) uses a seismic source (commonly a sledgehammer), an array of geophones to measure the travel time of the refracted/reflected seismic waves and a seismograph that integrates the data from the geophones. The method can be used to define the thickness and depth to bedrock or water table, the thickness of soil and rock layers, and their composition and physical properties; it may detect anomalous subsurface features such as pits and trenches.

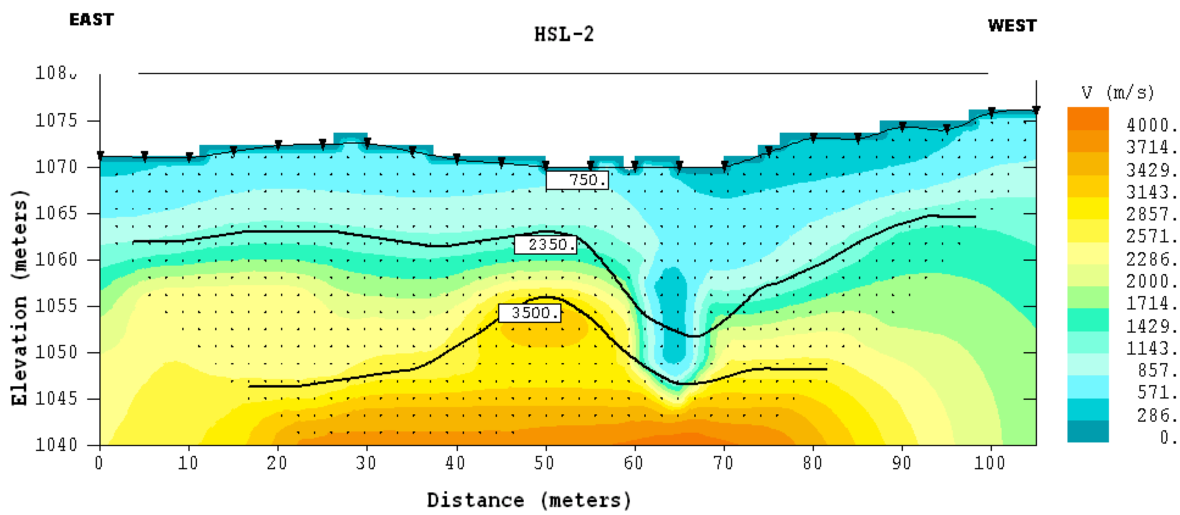

Fig. 2 The Seismic Refraction section detecting a shear zone

Magnetic Methods use a magnetometer to measure the intensity of the earth's magnetic field. The presence of ferrous metals can be detected by the variations they create in the local magnetic field. This method is used to locate buried metal drums that may be sources of soil and groundwater contamination.

Ground-penetrating radar (GPR) uses a transmitter coil to emit high-frequency radio waves that are reflected off subsurface changes in electrical properties (typically density and water content variations) and detected by a receiving antenna. GPR can map soil layers, depth of bedrock buried stream channels, rock fractures, cavities in natural settings, buried waste materials. The maximum depth of penetration under favorable conditions is around 25 meters. 100s of meters penetration may be possible in highly resistive materials (salt or ice).

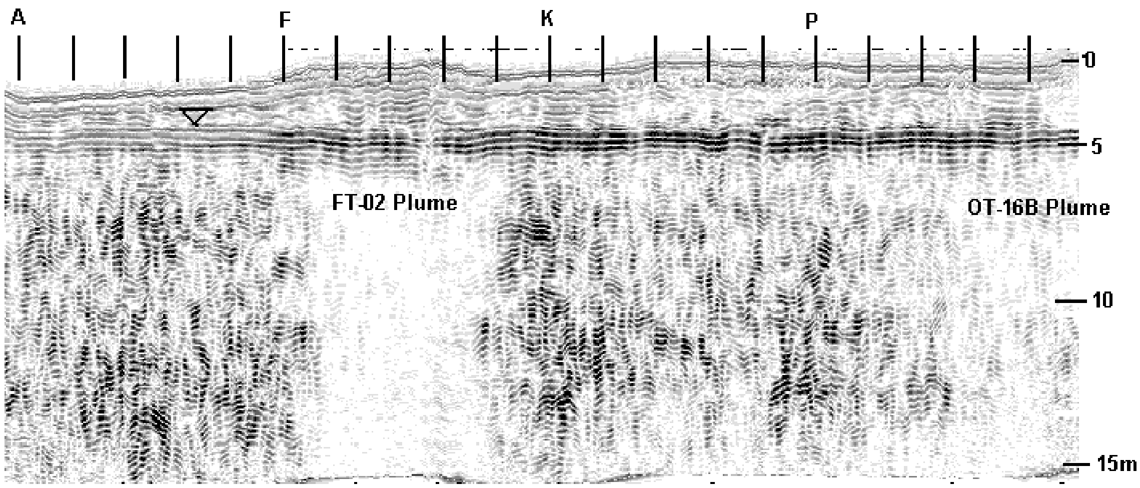

Fig. 3 Ground penetrating radar profile showing the strong amplitude shadow caused by the proximal end of the neighboring FT-02 plume, and the somewhat weaker shadow at the right end caused by the OT-16b plume. Source: EPA-542-R-00-003

Gravity Survey uses one or more of several types of instruments that measure the intensity of the earth's gravitational field. It can be used to estimate the depth of unconsolidated material over bedrock and boundaries of landfills, which have a different density than natural soil material. Microgravity surveys may be able to detect subsurface cavities and subsidence voids.

4. BOREHOLE GEOPHYSICAL METHODS FOR CONTAMINATED SITES

Borehole geophysical methods provide excellent vertical resolution and information obtained from drill holes can be greatly enhanced by using these tools.

Electrical logging measures the flow of electric current in and adjacent to a well, using the same principles as various surface methods. Fluid conductivity measurements are used to measure variations in salinity and locate saltwater leaks in artesian wells. Spontaneous potential logs, one of the most commonly used electrical logs, simply records the changes in current flow that result from changes in lithology. Single-point resistance and normal focused and lateral resistivity logs all measure resistivity using the same principles as surface resistivity measurements. Resistivity logging methods have numerous variants depending on electrode configurations and spacings. Normal resistivity logs are widely used to measure variations in water quality.

Induction logs operate on the same principles as surface EM methods that measure conductivity. Since direct contact with a conductive medium is not required, induction logs are especially useful for logging the dry portion of boreholes where the water table is far below the surface (see, e.g., Turner and Black, 1989). Also, induction logs are unaffected by the presence of plastic (e.g., polyvinyl chloride) well casings, making them particularly useful for locating electrically conductive contaminant plumes in existing wells.

There are various other logging tools like caliper for diameter, neutron for porosity, natural gamma for clay content, gamma-gamma for density, etc.

Cross-hole seismic tomography is another strong borehole geophysical method providing a high-resolution image of geology between two boreholes.

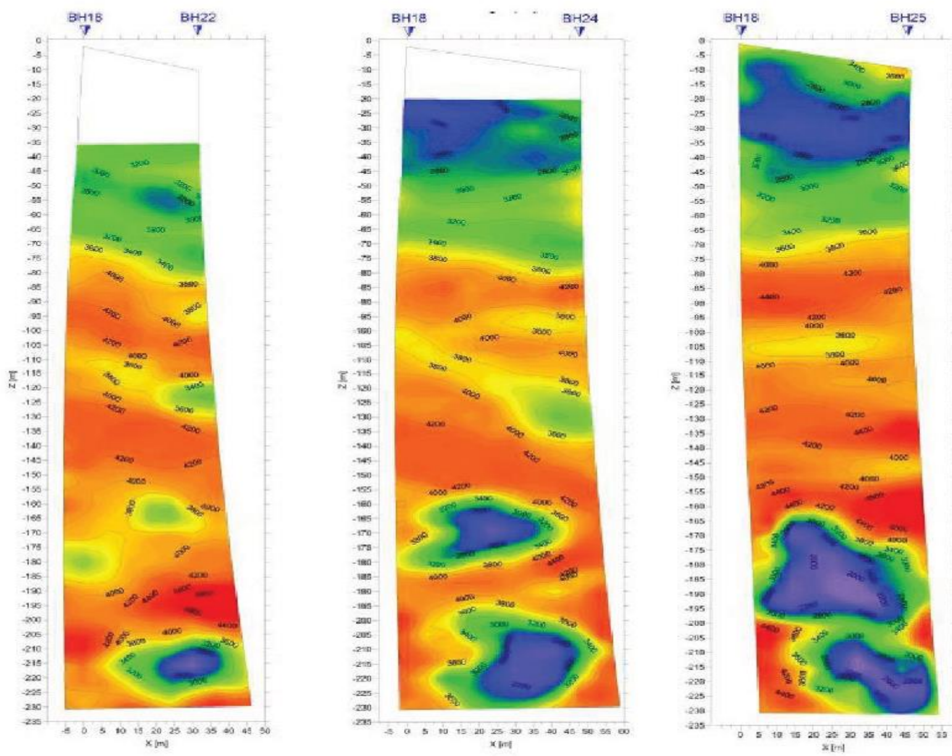

Fig. 4 Detection of cavities between boreholes using seismic tomography

5. CONCLUSIONS

Geophysical Techniques provide a quick assessment of subsurface conditions in a non-destructive manner. These methods provide detailed and continuous information as against drilling and hence are critical for contaminated site investigations. The detailed methodology should be worked out based on details of problems and objectives.

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PARSAN's Report on Seismic Tomography at Bhutan

Electrokinetic Remediation of Soil Contaminated with Chromium (VI) and 2,4- Dichlorophenoxyacetic Acid (2,4-D) – An Experimental Approach

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ABSTRACT

Electrokinetic (EK) remediation is an extensively applied method nowadays for the treatment of contaminated soil. In this present study, the efficacy of the EK technique was examined for the decontamination of soil polluted with chromium (VI) and 2,4-dichlorophenoxyacetic acid (2,4-D) herbicide. Three different sets of experiments were conducted comprising of (i) distilled water as both anolyte and catholyte (DW-EK), (ii) 0.1 M citric acid as catholyte and distilled water as anolyte (CAEK), and (iii) phosphate buffer as anolyte and distilled water as catholyte (DP-EK) for Chromium (VI) extraction from soil. However, two different electrode configurations, comprising of single anode-cathode (SAC) of parallel positioning and alternate anode-cathode (AAC) located as a fence, were tried in the EK process to extract the 2,4-D from the soil. The voltage gradient was maintained at 1.3 VDC per cm for Cr(VI) and 1.0 VDC per cm for 2,4-D using a DC power source.

The current intensity, solution pH, and contaminant concentrations in electrolyte cells were periodically observed, and finally, an in-depth post-mortem analysis in soils was performed. The introduction of different catholyte conditioners in the experiments boosted chromium removal efficiencies. While purely distilled water resulted in Cr(VI) removal of 56% and 86.4% at the anode and cathode section respectively, Citric acid addition improved it to 86.96% and 95.52%, and Phosphate buffer enhanced it even further up to 97.60% and 97.87%. Increased mobility, the solubility of chromium ions, and resistivity against the formation of a neutral zone in the soil resulted in higher efficiency in chromium removal. The presence of citric acid and phosphate buffer played a significant role in the ionization process by varying current density from 0.208 to 1.082 $mA.cm^{-2}$. Due to the control of catholyte within acidic range, the pH level within the soil remained within 2.35-2.68 compared to 7.2-8.92 in DW-EK experiments, which indicated better ionic movement within the soil and intensified the removal of Cr (VI). In the case of 2,4-D extraction, the electro-kinetic remediation technique was applied for a limited time of 15 days. The contaminant removal efficiency was achieved by nearly 80 % for single anode-cathode (SAC) arrangement and 78.19% for alternate anode-cathode (AAC) arrangement. The economic viability of the EK treatment was also calculated through power consumption (kWh/m^3) during the experiment. Energy consumption of 83 kWh/m^3 was estimated for SAC and 174 kWh/m^3 for the AAC arrangement of electrodes in the EK cell. EK treatment is thus cost-effective, flexible, sustainable, robust techniques for remediation of polluted soil. The promising results in the present

study will immensely help the environmental engineers and contractors to overcome the limitations of in-situ soil decontamination and agricultural land restoration for future cultivation purposes.

Keywords: Soil contamination; Chromium (VI); 2,4-D herbicide; Electrokinetic remediation; Electrode configurations; Removal efficiency

1. INTRODUCTION

Nowadays, to cope up with the huge need of mankind, different fertilizers, as well as herbicides, are used to enhance production in the field. But after a certain period, the soil gets overdosed by these chemical pollutants causing salination and organic contamination of the lithosphere. Many pollutants especially hydrophobic organic compounds (HOC) have longer retention time and can penetrate the interface in different environmental media due to their low solubility, high lipophilicity, semi-volatility, and low degradability, thus they can cover a large area and remain for quite a long time in the environmental media. Soils are also contaminated with heavy metals such as chromium, nickel, and cadmium as a result of improper waste disposal practices in the past. Amongst these heavy metals, Chromium, to be more accurate, Chromium (VI) is a carcinogenic element. Soils that are not affected by contamination or pollution by natural or anthropogenic sources will contain a small amount of chromium. The content will increase depending on the nature of the source. Generally, higher chromium content in soil resulted from improper discharge of effluents or wastewater from metal smelting, electroplating, tanning, metallurgy, and mining. Thus, the remediation of contaminated soils has currently become a research hotspot in environmental science as well as one of the most challenging research fields. Over the decades, the 2, 4-Dichlorophenoxy acetic acid (2,4-D) has become a popular choice of herbicides among the farmers in India (Kumar and Singh, 2010). However, the excessive application of herbicides to protect crop health is causing severe lithospheric pollution due to sub-surface migration of organic contaminants and subsequently mixing with the aquifers (Souza et. al. 2016). Electrokinetic (EK) remediation of contaminated soil has emerged as an efficient in-situ technology due to its easy installation in the fields, low-cost and lesser time-consuming applications (Risco. et al. 2015). Most of the studies carried out earlier using EK technologies were mainly concentrated on the removal of soluble metal ions (Malarbì et al. 2015.). However, very little research works reported in the state of the art on in-situ removal of herbicides from the agricultural fields (Rodrigo et al. 2014). The objective of the present study is to investigate the efficacy of the in-situ electro-kinetic treatment technology to remediate the 2, 4-D herbicide as well as Cr(VI) polluted soil. The cost-benefit analysis was also conducted to evaluate the applicability of the method in a real-life scenario.

2. MATERIALS & METHODS

2.1 Materials

The soil samples were collected in a container and then sealed to preserve the filled moisture content in the soil. The soil sample was then oven-dried for 24 hours and physical properties were determined. The physicochemical properties of the soil were evaluated as per guidelines depicted in the Bureau of Indian Standards (BIS: 2720). The adsorption capacity of the soil was also determined by the batch adsorption test. The synthetic solution of the solute was prepared using analytical grade Chromium (VI) and 2,4-dichlorophenoxyacetic acid (2,4-D) solution. Distilled water was used throughout the experiment and solution preparation.

2.2 Electrokinetic Experiment

The electro-kinetic test was conducted using SAC (Single anode-cathode) setup, in a cell consisting of three compartments viz. anode compartment, a middlebox, and a cathode compartment. The cell was made of a perspex sheet and opened at the top. The cell was 48 cm long, 20 cm wide and 15 cm high as shown in Fig.1. The middle compartment (Length 16.1 cm) was filled with compacted soil specimens. Two graphite electrodes were placed in the cathode and anode chambers and connected to DC power supply equipment. Inert electrodes were used in the present study to prevent the release of ions to the soil through the decomposition of electrodes. A constant voltage of 30 V was maintained throughout the experiment using a DC power source.

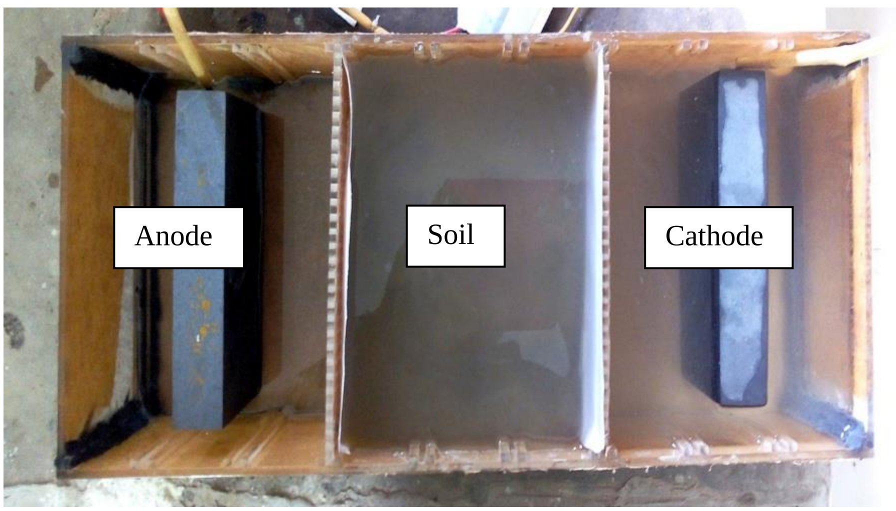

Fig. 1 Electro-kinetic test (SAC arrangement) with soil in between two electrodes compartment

Another separate electro-kinetic setup was constructed using AAC (Alternate anode-cathode) arrangement where an electro-kinetic set-up consists of an electro-kinetic reactor, a DC power source, and electrolyte solution tanks. The compacted soil volume in the tank was kept as 36,000 cm^3 (LWH: 60x60x10 cm^3) which is shown in Fig 2. The electrodes used for both anodes and cathodes were graphite rods of diameter and length as 1 and 30 cm, respectively, positioned in semipermeable electrolyte wells. A constant voltage gradient of 1 V/cm was maintained throughout the experiment. A layer of sand (1 cm height) was placed on the surface of the soil as a capillary barrier to minimize herbicide volatilization as well as evaporation loss of electrolyte solutions.

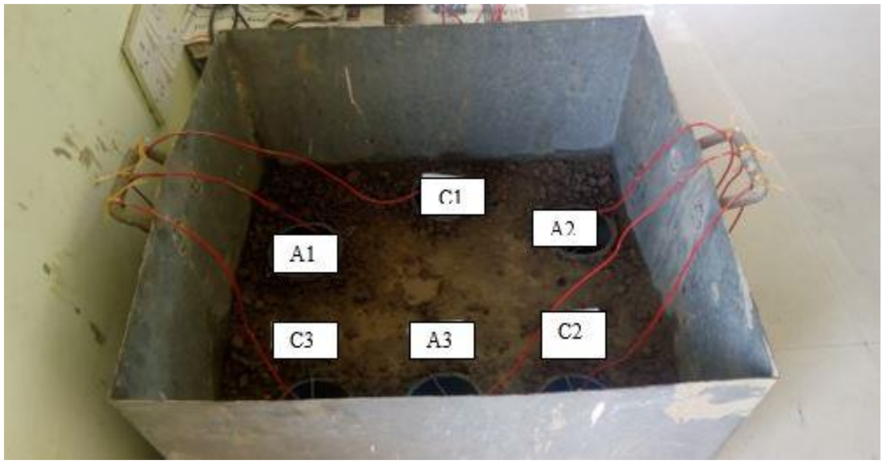

Fig. 2 Electro-kinetic test set-up in AAC electrode arrangement

2.3 Analysis Procedure

The electrical current at different locations was recorded. The chemical concentration of the contaminant and pH of the electric-osmotic volume collected from the cathode & anode collector was measured on a daily basis.

The soil sample was divided into three zones after completion of the test, lengthwise for SAC and depth-wise for AAC. The L-S extraction process was used to find out the pollutant concentration at different sections along with the length/depth. An amount of 50 gm dry soil extracted from each zone was added to 250 ml of distilled water and agitated magnetically for 20 minutes. The agitated sample was taken in an Eppendorf tube of 50 mm^3 capacity and stirred vigorously in centrifuge rotor REMI R-8C at 4000 rpm. The aqueous phase was taken from the tube for the determination of solute concentration with the help of a Spectrophotometer model of Shimadzu UV-500 and 1 cm^3 quartz cells (cuvette).

3. RESULTS & DISCUSSIONS

3.1 Basic Soil Properties

The physio-chemical properties of the collected soil sample are shown in Table 1. The result showed that the percentage of fine (silt and clay) content in the soil was 82%. The soil is classified as lean clay with medium plasticity (CI) according to the Indian Standard Classification System (IS: 1498-1970).

3.2 Current Intensity

Fig 3a represents the variation of current intensity vs time at a constant voltage gradient of 1 V/cm for the first experiment (SAC) for the 2,4-D solute. At the beginning of the experiment electric current was varied from 0.02 to 0.05 A. At 144 hours, electric current was at its highest value 0.14 A, then decreasing and finally stabilized at 0.2A at 288 hours. The current value varies with the resistance to the flow of ions which depends on soil moisture, ionic concentration of solute, temperature, etc. Increasing and decreasing slopes in the graphs show the continuations of ionization while the constant slope depicts the completion of ionization.

Table 1 Physico-Chemical properties of soil sample

Soil properties		Values	Standards
Soil color		Brown	---
	Sand	18 (%)	
Grain size distribution	Silt	47 (%)	IS 2720-4(1985)
	Clay	35 (%)	
Natural Water Content		35.6 %	IS 2720-2(1973)
Bulk density (kN/m^3)		14.9	IS 2720-29 (1975)
OMC (%)		23.4	IS 2720-7 (1983)
Max dry density (kN/m^3)		15.5	
Specific gravity		2.6	IS 2720-3(1) (1980)
Liquid limit (%)		47	IS 2720-5 (1985)
Plastic limit (%)		19.33	IS 2720-5 (1985)

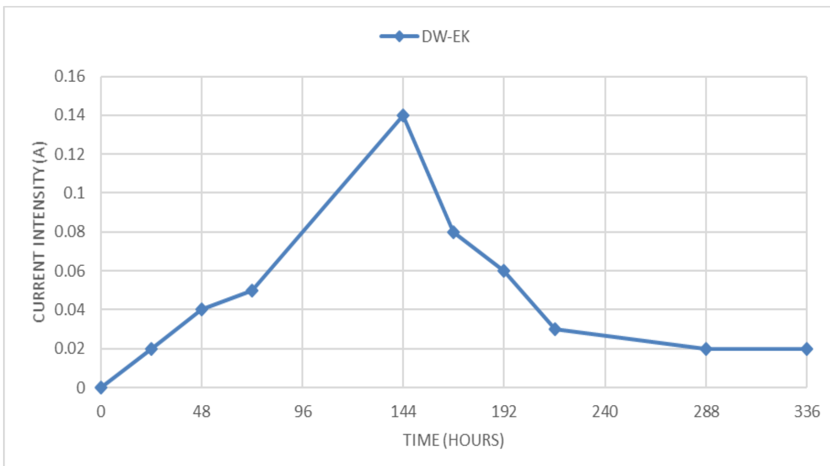

Fig. 3a Variation of current intensity as a function of time (SAC experiment for 2,4-D solute)

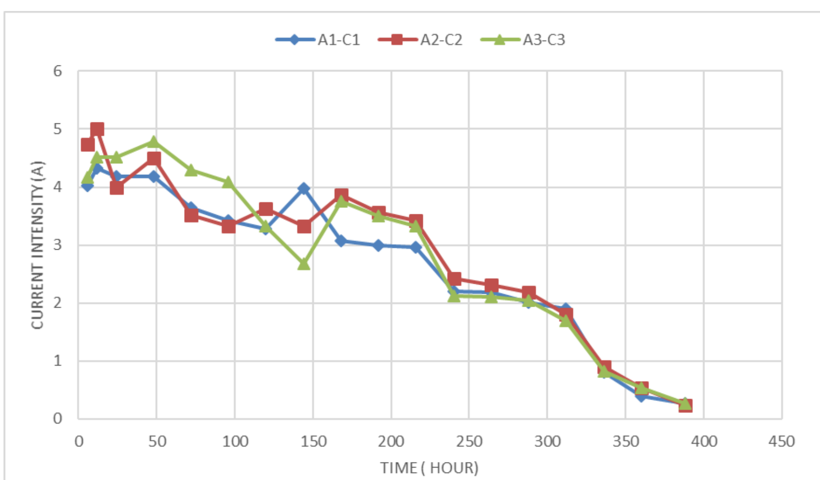

Fig. 3b Variation of current intensity as a function of time (AAC experiment for 2,4-D solute)

Fig. 3b represents the variation of current intensity against time for the second experiment (AAC). It can be observed that during the initial phase, the current intensity produced by the applied voltage gradient of 30 V/cm was within the range of 0.8-1.2 A with small fluctuations. The current increased to 4.0-4.9A and the voltage decreased to 5-10 V. As the limit of the ammeter is 5 A in the present experiment and current cannot be increased beyond that. So, the water of catholyte and anolyte are changed before the current intensity reaches the ammeter's peak value (12 hours). After 15 days the current intensity becomes constant. This phenomenon describes that ionization has been completed.

3.3 pH profile

In the first set of experiments, where only distilled water was used as both electrolytes, pH in anolyte solution decreased with the progress of the experiment and finally attained a value of 1.88. This implies that the region near anode well becomes acidic and it shows that the maximum amount of herbicide is present in an anolyte solution after 14 days. This graph also describes that the pH in the catholyte solution continuously increased from 11.98 to 12.4. the pH of deionized water was 7. In the rest two sets of experiments, the pH of anolyte is controlled at 10 and the change in pH in catholyte is duly noted at different time intervals.

Fig. 4 shows the variation in pH in the electrolyte solutions for the AAC experiment. The acute variation of pH in the wells reflects the formation of the well-known acidic and basic fronts. The polarization of fronts was performed by interchanging the anodes with cathodes, in order to achieve higher removal efficiency.

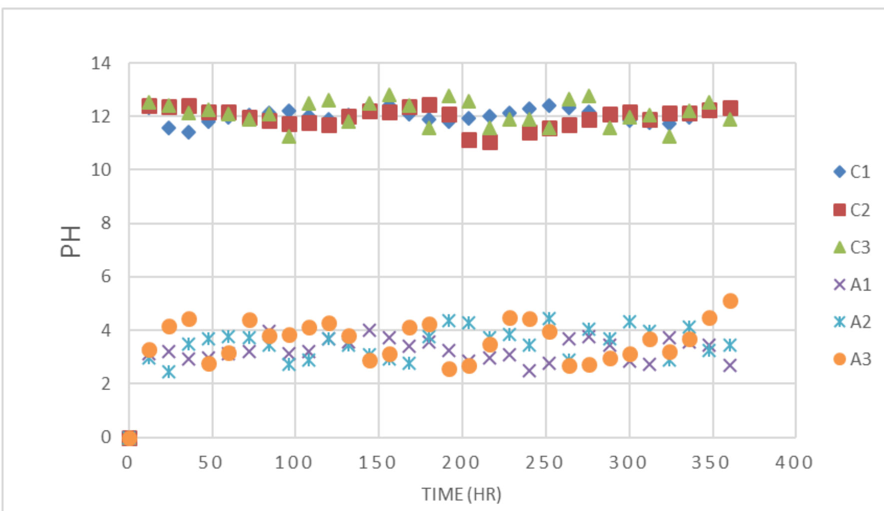

Fig. 4 Variations of pH in an electrolyte solution with time (AAC experiment)

3.4 Concentration of Chromium (VI) and 2,4-D in the soil after the test

In the first experiment (SAC), both the Chromium (VI) and 2,4-D were washed out of the soil by the water flux flowing from anode towards cathode due to the electro-osmotic flux. Also, the chemicals which were present in high concentration could be transported towards the anode by electromigration. Due to the combined effect of the two processes, the higher removal efficiency of both Chromium (VI) and 2,4-D herbicide from the soil occurred.

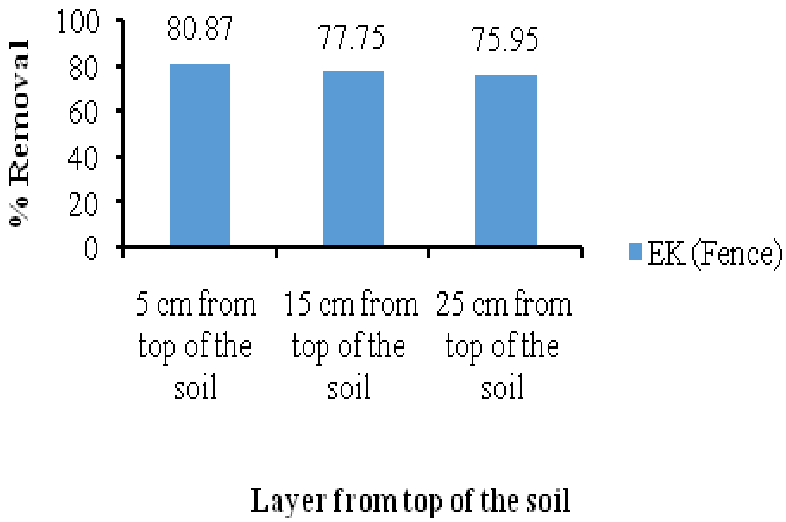

Fig. 5 Variations of % removal of 2,4-D for AAC electrode configuration in EK cell

The experiment using the SAC arrangement for 15 days, the decontaminating efficiency of Cr (VI) was nearly 97%. The decontaminating efficiency of 2,4-D was nearly 80%. Also, the removal efficiency using the AAC arrangement was 78.19% (Fig. 5).

The performance of 2,4-D removal from soil using the SAC arrangement of electrodes was found to be marginally better than the AAC arrangement in EK cell, however, the AAC arrangement of electrodes configuration is easily applicable as large blocks of graphite used in SAC are difficult to implant on the field.

3.5 Energy consumption in EK treatment

Power consumption depends mainly upon the current density when the voltage is constant. Energy consumption was calculated with respect to time for both experiments using the following equation no. 1:

$$E_c = \frac{V}{1000AL}\int_0^t I dt \qquad (1)$$

where, E_c = energy consumption per unit volume of soil (kWh/m^3),
V = applied electric potential in Volt,
I = current density flowing through the soil specimen (Amp),
A = cross-sectional area of the soil specimen (m^2),
L = length of the specimen (m)
t = elapsed time in hours

The energy consumption for the SAC arrangement was 83kWh/m^3 and for AAC was 174 kWh/m^3, respectively. This estimation clearly shows that the chromium (VI) and herbicide decontamination from the soil using the EK process is a rapid and cost-effective in-situ technique.

4. CONCLUSIONS

In the present work, the electro-kinetic remediation technique was applied for 15 days to remove Cr (VI) and 2,4-D from the soil. The contaminant removal efficiency was achieved by nearly 97% and 80% for single anode-cathode (SAC) arrangement for Cr (VI) and 2,4-D and 78.19% for alternate anode-cathode (AAC) arrangement in a limited time of 15 days.

The economic viability of the EK treatment was also calculated through power consumption (kWh/m^3) during the experiment. Energy consumption of 83 kWh/m^3 was estimated for SAC and 174 kWh/m^3 for the AAC arrangement of electrodes in the EK cell.

EK treatment is thus cost-effective, flexible, sustainable, robust techniques for remediation of polluted soil. The promising results in the present study will immensely help the environmental engineers and contractors to overcome the limitations of in-situ soil decontamination and agricultural land restoration for future cultivation purposes.

ACKNOWLEDGMENT

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Assessment of Heavy Metal Contamination in the Vicinity of the Jamunia Open Cast Mine - Jharia, India.

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ABSTRACT

The heavy metal contamination and seasonal variation of the metals in soil, and water in the vicinity of Jamunia Open Cast Project in Matigara, Jharia Coalfields, BCCL (JOCP) were studied. Elevated levels of potentially toxic metals like copper (Cu), chromium (Cr), cadmium (Cd), iron (Fe) and lead (Pb) were found during the pre-monsoon period as compared to the post-monsoon season in both overburden and agricultural soil. According to pollution matrices Cd, Pb and Cr have more contamination factors (5.01, 2.3 and 1.01) as compared with others. As indicated by the pollution load index the overburden soil is found to be polluted with the value of 2.05 during pre-monsoon season. The ecological risk indices agricultural soil is under low risk and overburden soil is at moderate risk category with a value of 70.37 and 168.46. These metals are continuously dispersed downstream and downslope from the tailings by clastic movement through wind and water. Thus, contaminating the location around the mining area and both groundwater as well as surface water. The significant levels of the elements in waters and soil were found up to 3-5 km downstream from the mining site. Enriched concentrations of heavy metals were also found in agricultural land, groundwater and the nearest river. In a study of seasonal variation on the heavy metals in those respective areas, relatively high concentrations of heavy metals were found during pre-monsoon season as compared to post-monsoon. As per the result Cd, Pb concentration for mine pit lake 0.019, 0.032, for groundwater 0.022, 0.028 and for surface water 0.018, 0.024 which is slightly higher than the permissible limits as per the BIS10500 guidelines during pre-monsoon season. Toxic heavy metal concentration during the post-monsoon season in water bodies is found within permissible limits.

Keywords: Heavy metals; coal mine; soil contamination.

1. INTRODUCTION

Coal is the principal source of energy in India which contributes 57.3% of total supplied energy (CEA 2018) using approximately 8% of the total coal in the world (Yao et al. 2015). The coal mining industry can be an economic asset for a nation. However, if preventive measures not taken carefully it may lead to substantial environmental damage such as water and soil pollution, land degradation, topographical change, and ecological deterioration. Acid mine drainage is another major environmental problem that is related to coal mining resulting in acidification of soil and receiving water bodies. Due to the acidification, there is an increase in the dissolution of toxic metals from open mine pits, water-permeable tailings, waste rock piles, etc. Resulting in highly impacted water and soil ecosystems (Gaikwad and Gupta 2007). As a result of mining activity huge overburden known as mine spoil with very poor soil health in terms of nutritionally, physically and microbiologically impoverished habitat. These overburdens are highly prone to erosion due to various environmental factors that could cause contamination of adjoining agricultural lands and water bodies with harmful substances that leach out through rainwater. Several studies have been reported about the properties of mine soils and their impacts on surrounding sites and the environment including surface mining in several countries. The mine soil typically consists of different chemical properties, high (35 to ≥ 70%) rock fragment and low clay content (Daniels et al. 2004). The mine soil properties such as surface pH, color and texture, etc. are generally inherited from parent overburden type (Indorante et al. 1992).

The heavy metal pollution of mining and urban soils has been investigated in many areas, which indicates that large amounts of anthropogenic activities are explored day by day. Mining related pollution creates a serious health implication and affects the crops in the surrounding areas. The composition of the mine waste dumps varied from site to site and it depends on the peculiarity of the neighborhoods. The major environmental threats including the release of a huge amount of heavy metal, extreme acidity, surface crusting, low nutrient conditions and collision of soil properties have been reported by many authors (Ledin and Pedersen 1996, Adewole and Adesina 2011). Most of the metals (like Zn, Fe, Ni, Cu, Fe, and Mn) are essential for the growth of organisms in a low concentration and it occupies a special position in soil chemistry (Sheoran et al. 2010). The high concentration of these heavy metals with their continuous exposure for a longer period causes severe health impact on humans (Prasad 1995, Loska et al. 2003, Roba et al. 2005). The diseases like a tumor, gastrointestinal, muscular, neurological and genetic malfunctions and congestion of nasal mucous membranes, etc. are caused by a high concentration of heavy metals (Tsuji and Karagatzides 2001). Assessing the problems caused by metal-containing mine soils are highly significant to analyze any adverse environmental effects. However, the present study investigates the potentially toxic metal concentration and its contamination in and around the coal mine area.

2. SITE DESCRIPTION

Jamunia Open Cast Project in Matigara (JCOP), Jharia Coalfields, BCCL (23.74°N, 86.41°E) were selected as a sampling point. Jharia Coal Field produces bituminous coal. Runoff from the overburden dump and underground mine water discharge is channeled into Jamunia river which later meets Damodar river. The study area was chosen as it is situated near the Jamunia river and the distance between Jamunia dam and the JOCP is around 1 km. The mining area has an overburden (OB) dump (40-50 m height) and a mine pit lake which appears to be the probable cause of heavy metal contamination in soil and water bodies, i.e. groundwater and surface water. The study is done in order to determine contamination in soil and water in and around JOCP due to the creation of overburden dump and mine pit lake of the mine.

3. MATERIALS AND METHODS

A total of eight soil samples were collected from the OB dumpsite and agricultural field (4 from each location). The zipper bag was used to keep the collected samples and brought to the laboratory for the analysis. At first, the samples were air-dried at room temperature and then ground in mortar and pestle in order to obtain a homogenized mixture. Later the samples were then sieved through 0.15 mm stainless steel sieve (100mesh) (Lu et al. 2012, Liu et al. 2013, Huang et al. 2017). The sieved samples were then oven-dried at 80°C until the constant weight was achieved.

For acid digestion, the samples were carefully weighed about 0.2 gm and were mixed with aqua regia (1 ml HNO_3, 3 ml HCl). The sample was then digested in microwave digester for acid digestion. The machine was operated for 1 hr. For the first 20 mins, the temperature was gradually increased up-to 190 °C and for the next 20 mins, the temperature was maintained at 190 °C. Then the solution was set to cool for the next 20 mins. After the solution was cooled, the setup was taken out of the microwave digester. Using Whatman 42 filter paper the samples were then filtered. The filtered sample was kept at 4 °C for further analysis in the atomic absorption spectrometer (AAS) for heavy metal concentration.

The water samples from different locations required different sampling procedures. For the collection of samples from the mine pit lake and surface water (Jamunia river), the samples were directly collected in 1L plastic bottles and a few drops of Nitric Acid (6 M HNO_3) were added after taking the pH of the sample for the preservation of the water samples. Whereas, for collecting an underground water sample, the hand pump had to be operated for 5 minutes before collecting the sample. It is done to avoid the contamination from the hand pump that could alter the results of the study. A total of 12 water samples were collected. Out of which, 4 samples were taken from the mine pit lake, 4 samples were taken from the surface water, i.e. Jamunia river and 4 samples were taken from the underground water table, i.e. through hand pumps.

For acid digestion of water samples, 500 ml of the water samples were taken and it is heated at 100 °C. The heating is continued until the water reduced to approximately 100ml. The samples are then cooled and collected in plastic bottles and stored at 4°C until the heavy metal concentration is measured through AAS.

3.1 Pollution matrices

The effect of coal mining activities on soil of adjacent areas was evaluated using different pollution matrices such as contamination factor (C_f), degree of contamination (C_d), pollution load index (PLI), ecological risk factor (E_{rf}), ecological risk index (E_{ri}). The threshold limits of the pollution matrices are presented in Table 1.

3.2 Contamination factor

The contamination factor estimates the impact of pollution caused by the specific toxic metals in soil. It is calculated using equation (1).

$$C_f = \frac{C_{PTE}}{C_{BC}} \tag{1}$$

C_{PTE}= Measured concentration of potentially toxic elemental
C_{BC}= Background concentration;
According to Turekian and Wedepohl 1961, the background concentrations of potentially toxic elements in the soil are Cu-45, Cd- 0.3, Fe- 47200, Cr- 90, Pb-20.

3.3 Degree of contamination

C_d is the measurement of the degree of overall contamination in the surface layer in a specific sampling area. It is defined as the sum of the overall contamination factor for all the pollutant elements. (Hakanson et al. 1980) and calculated using the equation (2)

$$C_d = \sum_{i=1}^{n} C_f i \tag{2}$$

3.4 Modified degree of contamination

${}^{m}C_d$ was given by Abrahim by modifying the generalized form of Hakanson et al., 1980 equation for the degree of contamination. It is the sum of all the contamination of specific site divided by the total number of analyzed elements and given by equation (3)

$$^{m}C_{d} = \frac{\sum_{i=1}^{n} C_{f} i}{n} \quad (3)$$

Table 1 Description of Contamination factor, degree of contamination, modified degree of contamination, ecological risk factor, ecological risk index and their threshold value.

Pollution Index	Threshold values	Pollution Index	Threshold values
Contamination factor (C_f)	$C_f<1$ Low contamination $1\leq C_f<3$ Moderate contamination $3\leq C_f<6$ Considerable contamination $6\leq C_f$ Very high contamination	Degree of Contamination (C_d)	$C_d<8$ Low degree of contamination $8\leq C_d<16$ Moderate degrees of contamination $16\leq C_d<32$ Considerable degrees of contamination $C_d\geq 32$ Very high degree of contamination
Modified degree of Contamination ($^{m}C_d$)	$^{m}C_d<1.5$ Very low degree of contamination $1.5\leq {}^{m}C_d<2$ Low degree of contamination $2\leq {}^{m}C_d<4$ Moderate degrees of contamination $4\leq {}^{m}C_d<8$ High degree of contamination $8\leq {}^{m}C_d<16$ Very high degrees of contamination $16\leq {}^{m}C_d<32$ Extremely high degrees of contamination $^{m}C_d\geq 32$ Ultra-high degree of contamination	Ecological Risk Factor (E_{rf})	$E_{rf}<40$ (Low ecological risk) $40\leq E_{rf}<80$ (Moderate potential ecological risk) $80\leq E_{rf}<160$ (Considerable potential ecological risk) $160\leq E_{rf}<320$ (High potential ecological risk) $E_{rf}>320$ (Very high potential ecological risk)
Ecological risk index (E_{ri})	$150<E_{ri}$ (Low ecological risk index) $150\leq E_{ri}<300$ (Moderate ecological risk index) $300\leq E_{ri}<600$ (Considerable ecological risk index) $E_{ri}>600$ (Very high ecological risk index)		

3.5 Pollution load Index

The concept of PLI was given by Tomlinson et al. (1980). It evaluates the number of times by which the metal concentration in the soil exceeds the background concentration. It is the geometric mean of all the contamination factors of the toxic element present in the particular study area. The equation (4) has been used to calculate the PLI.

$$PLI = \sqrt[n]{C_f 1 \times C_f 2 \times C_f 3 \times \text{.........} \times C_f n} \quad (4)$$

3.6 Potential ecological risk factor

The Potential ecological risk factor illustrates the potential risk towards the ecology of an individual toxic element. It is calculated by equation (5)

$$E_{rf} = T_f \times C_f \qquad (5)$$

Where T_f= Response factor of individual potentially toxic element
Standard T_f value as given by Turekian and Wedepohl (1961); Cu- 5, Cd- 30, Cr- 2, Pb- 5.

3.7 Potential Ecological Risk Index (E_{ri})

Potential Ecological Risk Index is the sum of all the individual Potential ecological risk factors of all the toxic elements present in the study domain. It is calculated using equation (6).

$$E_{ri} = \sum_{i=1}^{n} E_{rf\ i} \qquad (6)$$

Where E_{rf} is the individual value of ecological risk factor and n= number to potentially toxic element presents in the study area.

4. RESULTS AND DISCUSSION

The concentration of different metals in OB dump, agricultural land, mine pit lake, surface water, and groundwater are presented in Tables 2 and 5. The elevated levels of metals were found during the pre-monsoon season as compared to post-monsoon in all cases. In the present study the measured total concentration of Cu, Cd, Cr, Pb and Fe of OB mine soil were found to be 43.15, 1.50, 91.5, 66.5 mg $kg^{-1}$and 42.71g kg^{-1} whereas for agricultural soil it was 27.75, 0.57,29.25, 36.5 mg $kg^{-1}$and 42.71 g kg^{-1}during the pre-monsoon season. While the concentration of Cu, Cd, Cr, Pb and Fe during post-monsoon were found to be 25, 0.32, 41, 16.21mg kg^{-1} and 31.29 g kg^{-1} for agricultural land and for OB dump site it was 37.5, 1.03, 49.75 and 20.11mg kg^{-1} and 31.29 g kg^{-1}. The concentration of metals during the pre-monsoon period is high as compared to post-monsoon. The higher deposition of iron in the soil might be due to the minerals associated with the geological formations (Singh et al. 2012) and also long-term use of the production machine.

Table 2 Heavy metal concentration in soil.

	Overburden soil		Agricultural soil	
Metals	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Cu (mg kg^{-1})	43.15	37.5	27.75	25.01
Cd (mg kg^{-1})	1.50	1.03	0.57	0.32
Fe (g kg^{-1})	42.71	39.29	33.91	31.29
Cr (mg kg^{-1})	91.5	49.75	29.25	41.11
Pb (mg kg^{-1})	46.5	20.11	36.50	16.21
pH	5.93	6.12	7.61	7.36

According to Rout et al. (2014) high heavy metal deposition in the mining area is the result of mine spoil and dust along with the coal that is produced during the process of coal mining. Due to the weathering of the coal mine spoil, a large number of tiny particles laden with heavy metals are released in the surrounding areas within the short course of time (Masto et al. 2011). The seasonal variations in heavy metals content depend on various factors like soil chemical and physical and chemical properties, biological as well as metal deposition rates, etc. (Pandey et al. 2014). During the pre-monsoon period the pollutant gets deposited at a higher rate and due to the relatively high pH and low soil porosity, the vertical movement of any pollutant gets confined and thus more heavy metal deposition. Whereas the post-monsoon period the pollutants get leached out due to the rainfall.

Table 3 Contamination factor, degree of contamination, modified degree of contamination and pollution load index value of OB and agricultural soil

	Agricultural soil		Overburden soil	
Variables	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Metals	C_f	C_f	C_f	C_f
Cu	0.62	0.56	0.96	0.84
Cd	1.91	1.06	5.01	3.43
Fe	0.72	0.67	0.90	0.84
Cr	0.33	0.46	1.01	0.56
Pb	1.82	0.81	2.32	1.01
PFI				
^{d}C	5.50	3.58	12.05	6.92
$^{m}C_d$	1.10	0.71	2.45	1.38
PLI	0.02	0.12	2.05	0.26

Table 4 Ecological risk factor and ecological risk value of OB and agricultural soil.

	Agricultural soil		Overburden soil	
Variables	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Metals	E_{rf}	E_{rf}	E_{rf}	E_{ri}
Cu	3.08	2.78	4.79	4.17
Cd	57.50	32.00	150.00	32.00
Cr	0.65	0.91	2.04	1.10
Pb	9.13	4.06	11.63	5.02
E_{ri}	70.36	39.75	168.46	113.29

The C_f, C_d, $^{m}C_d$, PLI, $E_{rf,}$ and E_{ri} for OB dump and agricultural site are presented in Tables 3 and 4. The contamination factor ware found to be maximum for Cd followed by Pb and Cr. The remaining metals were low contaminated as their C_f values were <1. Whereas the degree of contamination is low for agricultural and for OB dumpsite is was found to be a moderate degree of contamination. Modified degree of contamination factor indicates a moderate degree of contamination except for agricultural site which is nil to very less degree of contamination. The PLI values show that soil of the agriculture area is unpolluted as compared to OB dump soil whose PLI value is found to be 2.45 and 2.14 for pre-monsoon and post-monsoon season. The considerable potential ecological risk was noticed for cadmium in both post and pre-monsoon season for OB dumpsite and moderate for the agricultural site during the pre-monsoon period. However, the low potential ecological risk was in the agricultural site during post-monsoon. Remaining metals i.e. Cu, Cr, Pb for all sites were a low potential ecological risk for both seasons. E_{ri} suggests a low ecological risk for the agricultural site during the post-monsoon period and moderate for pre-monsoon. Moderate ecological risk index is found for OB dump location during the pre-monsoon period and low for post-monsoon.

Table 5 Heavy metal concentration in water.

	Mine pit lake		Grown water		Surface water	
Metals (mg/l)	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Cu	0.015	0.007	0.012	0.011	0.083	0.075
Cd	0.019	BDL	0.022	BDL	0.018	BDL
Fe	1.120	0.089	0.109	0.022	0.235	0.120
Cr	0.017	0.008	0.068	0.007	0.000	0.010
Pb	0.032	BDL	0.028	BDL	0.0245	BDL
pH	6.31	6.89	6.52	6.97	7.26	7.57

According to different studies, heavy metals are mainly associated with mine OB, coal and sediments of mining areas that are released into water bodies including drain water (Lors et al. 2004; Borma et al. 2003). As is seen in Table 5 the heavy metal concentration in the mine pit lake is more as compared to ground and surface water. Since the major sources of heavy metal for these two water bodies (groundwater and surface water) is the leachates and the run-off from the coal mines. The results of the pre-monsoon sampling depict that the concentration of Cd, Cr, Fe, and Pb exceeds the permissible limit given by BIS 10500. Only Cu and Cr are within the permissible limit. However, it is not true for the post-monsoon as the concentration is well below the standard limit as prescribed by BIS 10500 for drinking water. Chromium found in the surface water of the Jamunia river is relatively high when compared to the other heavy metals present but still lies well within the permissible limits. After rainfall, the water level rises in the water bodies, hence diluting the concentration of the heavy metals in the water bodies. It is found that the heavy metal concentration is higher during the pre-monsoon period as compared to post-monsoon. This kind of pattern generally indicates the accumulation of metal during the low flow condition. Also, according to Abdel-Satar, 2001 it might be due to the high evaporation rate of surface water followed by elevated temperature.

5. CONCLUSIONS

The present study suggests that the primary source of toxic metals in an around coal mining area is the open cast mining activities. It has not only affected the adjoining area but the groundwater has also been affected with some toxic metal. But when it comes to post-monsoon season most of the toxic metals are found within permissible limits as per the BIS 10500 guidelines. As per the heavy metal pollution in soil, contamination factor, suggested that contamination is considerable in agricultural soil whereas it is moderate for overburden soil. According to PLI overburden soil is polluted and agricultural soil is at a moderate ecological risk index. In order to control these discharges of potentially toxic metals government should take some legislative measures, regular monitoring and strict actions towards industries. Proper strategies should be adapted in order to maintain the soil and water pollution which further prevents the health of the local residents in the vicinity of the coal mining area.

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Shallow Depth Environmental Soil, Groundwater and Gas Vapor Sampling Techniques

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ABSTRACT

The Ministry of Environment, Forest and Climate Change (MoEF&CC) has prepared a report on 320 probably contaminated sites in India. It has been observed that a lot of the sites are concentrated towards Delhi, Haryana, Uttar Pradesh and Punjab. Out of these probably contaminated sites, there are many sites at which no investigation has been carried out. These sites with alleged but not scientifically proven presence of constituents of contaminants or substances pose a significant risk to human health or the environment. Hence, there is a need to educate practitioners, academicians, researchers about the latest techniques available for environmental sampling of soil/ groundwater/ gas vapor at probably contaminated sites. In this paper, various tools and techniques for environmental soil/ groundwater/ gas vapor sampling as well as various field screening techniques available for contaminated sites have been discussed. Also, procedure and planning of an environmental site investigation program have been explained briefly.

Keywords: Shallow depth environmental soil sampling; Environmental Protection Agency; Field screening; Sampling plan; Contaminated sites

1. INTRODUCTION

The paper briefly describes planning of an environmental soil sampling program, reviews a number of methods available for environmental soil/ groundwater/ gas vapor sampling and field screening techniques, their advantages and disadvantages, and offers insights into state-of-the-art techniques based on authors' experience.

The environmental soil sampling is often carried out to verify whether a site is contaminated or not and to also check whether the level of contamination is within a tolerable limit. A well-planned investigation could easily pin-point the "hot-spots" (areas having high level of contamination), characterize the nature and extent of contamination and delineate the flow of contamination across the area under consideration. This would further help in separating clean areas from the contaminated ones and planning of mitigation of the sites and appropriate response in case of an emergency. However, a lousy approach can give clean chit to a probably contaminated site.

A number of techniques are available for environmental soil/ gas/ groundwater sampling e.g. stainless-steel augers and samplers for soil, peristaltic pumps for groundwater and gas vapor probes for gas sampling. However, issues arise when suitable accessories/ equipment/ tools are not selected based on the site conditions.

2. HOW TO PLAN AN ENVIRONMENTAL SOIL SAMPLING PROGRAM?

It is important to keep a few things ready before going to a probably contaminated site for sampling. The first step is to collect all the relevant background information, such as, site history (location, soil type, climate), site use (products manufactured, raw material used, fertilizers used in case of agriculture land), site contamination (possible emission, wastewater, solid waste being generated based on site use) and past studies (if any).

The second step is the selection of sampling areas and depth on the sites. This can be done with the help of field screening techniques using some portable equipment like photo-ionization detector (PID) or handheld X-ray fluorescence (XRF) gun. Based on the results, sites with high concentration of contaminants can be pinpointed and sampling locations can be decided. Geophysical equipment like ground penetrating radar (GPR) should be used to locate non-metallic buried pipelines, tanks, or other irregularities in the ground and magnetometer should be used to detect metal pipes/ utilities and live electrical cables. Based on the results, such locations can be avoided to prevent accidents during sampling. Electrical resistivity profiling (ERP) can detect moisture in sub-soil. ERP can be carried out in order to identify the depth up to which the effluent has been infiltrated and therefore, the depth of investigation/ soil sampling can be fixed. This would help in reducing extra time and cost to drill surplus boreholes (IAEA, 2004)). Some of the advantages and disadvantages of the above-mentioned techniques have been reported in Table 1.

A suitable sampling plan for e.g. judgmental sampling, random sampling, stratified random sampling, systematic grid sampling, systematic random sampling, search sampling or transect sampling may then be adopted as per the specifications of EPA (2002).

During the sampling at field following things should be taken care of; determination of physical characterization (colour, temperature etc.) and climatic conditions, number of samples (use equations as per EPA,1992 to calculate the number of samples required to hit hot spots of known size and dimensions), extent of sampling (Depth-samples should be collected at the surface (0–3 in.), extended surface (0-6 in.) and/or at one-foot depth intervals; Area- collect soil over a surface area of one square foot per sample), remove extraneous material, sample sieving (for XRF, a 0.841 mm screen size is recommended; sieving is not recommended where volatile compounds are of concern), sample homogenization (blend the soil sample using stainless steel spoon or scoop to provide uniform distribution of contaminants; do not homogenize samples for volatile compound analysis), sample splitting (mechanically split the sample using a riffle sample splitter) and sample preparation (pack all the samples in a plastic or steel liner with end caps; use swatches to seal and wrap samples). Table 2 presents the checklist for the materials to be taken to the site along with the sampling tools.

The packed samples are then sent to the appropriate labs for further detailed chemical/ environmental testing.

A number of exploration kits are available for environmental soil/ gas/ groundwater sampling e.g. environmental soil sampling kit, petrol powered continuous soil coring kit, hollow stem auger kit, flighted auger kit and gas vapor probe (GVP) kit. These techniques have been explained in detail in the following sections.

Table 1 Review of Field Screening Techniques

Equipment	Application	Advantages	Disadvantages
PID (EPA, 1988)	Detects total concentration of VOCs and some non-volatile organics and inorganics.	Immediate results; easy to use; detects to ppm level	Results affected by high ambient humidity and electrical sources such as radios; in soils does not respond to methane
XRF (EPA, 1988)	Detects heavy metals in soils.	Rapid sample analysis, may be used in situ; may be used with a generic or site-specific calibration model; detects to ppm level	Requires trained operator; Potential matrix interferences; detection limit may exceed action level; detection limit should be calculated on a site-specific basis
GPR (Benson, et. al. 1988; NJDEP, 1988)	Detects reflection anomalies caused by lithology changes buried objects; varying depths of investigation, 15 to 30 feet, are possible.	Capable of high resolution; generates continuous measurement profile; can survey large area quickly; site specific; best results are achieved in dry, sandy soils	Clay-rich and water saturated soils produce poor reflections and limit depth of penetration; data interpretation requires a trained geophysicist
Magnetometer (Benson, et. al. 1988; NJDEP, 1988)	Detects presence and areal extent of ferromagnetic material in subsurface soils, including buried metal containers. Single 55-gallon drums can be identified at depths up to 10 feet and large massed of drums up to 30 feet or more.	Quick and easy to operate; good initial survey instrument; data interpretation may require geophysicist	Readings are often affected by nearby man-made steel structures (including above-ground fences, buildings, and vehicles)
ERP (Samouëlian et al., 2005)	Detects electrical resistivity variations in subsurface materials (e.g. lithology, pore fluids, buried pipelines and drums).	Non-destructive lateral and vertical mapping technique; temporal monitoring of soil water distribution; flexibility in the volume of soil to be investigated; data acquisition facilities; Large sensitivity of the measurement; Numerical modelling advancement	Spurious results due to poor contact between the soil and the electrodes; needs calibration for in-situ properties; cannot reveal smaller heterogeneities; a basic knowledge of the medium under study is must; data interpretation requires a trained geophysicist

Table 2. Checklist of the materials required at the site

Materials
Stainless steel knife, screw driver, Teflon tapes, measuring tape, thermometer, Munsell soil colour chart, stainless steel/ plastic liner, Tedlar bags, swatches, waterproof marker-pen, sampling kits/ tools, bucket, plastic sheets, working gloves, masks, sanitizer, sticks/ canes for laying out grid, strings, field notebook, pliers etc.

3.0 Experience with various shallow depth environmental sampling kits

3.1 Soil sampling using environmental soil sampling Kit

The kit includes regular, sand and mud augers, split soil core sampler for disturbed representative sample, soil core sampler for undisturbed samples, 4.6 kg slide hammer for driving, plastic liners with plastic end caps and swatches for packing and transportation of samples. The augers, extension roads and the samplers are made of stainless steel and hence can be easily be decontaminated to avoid cross-contamination. The kit can be used to carry out shallow depth investigations up to 3m.

There are five types of auger commonly used in shallow depth sampling, i.e., regular soil auger, clay/ mud auger, sand auger, open face auger and planer auger (see Fig.1). The regular soil auger can be used in all the field conditions except for clay/mud and sands. The bits of the regular soil auger are open to allow entry of small soil clumps and relatively small rocks and particles. The clay/mud auger has a laser-cut, open cylinder design for easy removal of heavy, wet, or clay soils. Two openings in the cylinder wall facilitate emptying. The bits are spaced a bit wider than the regular soil auger for the effortless entry of sticky soils. In sand auger, a closed bit design with a restricted opening prevents the loss of sampled material during retrieval. Inner edges of the sand auger bits touch at their mid-point to make the sand auger much more efficient in loose, unconsolidated soil conditions. The open-face auger has a unique design that allows for quicker penetration into combination soils (mud and clay to dense soils). The cutting head helps the auger push itself into the ground with little effort and yields quicker soil penetration. The open-face design also allows for a quick visual profile of the soil sample and for easy soil extraction. The planer auger is fitted with a cutting blade at the bottom of the auger cylinder. The flat, slotted design of the planer auger's head allows for the auger to remove loose material from the bottom of a borehole. Hence, it is generally used to remove loose soil and other materials from the bottom of an already augered borehole.

Fig. 1 Various types of stainless-steel augers

There are three type of stainless-steel samplers available with the kit (see Fig. 2). The type I soil core sampler (2” x 6”) has a vertically split cylinder, cutting shoe and cap. It can be used without a liner to collect relatively undisturbed soil cores for immediate field examination and testing or can be used with a liner for collection of relatively undisturbed, sealed soil core samples that are suitable for EPA Level III or Level IV soil analysis. The core splits lengthwise to allow easy access to sample to inspect moisture content, soil consistency, and VOC using a PID on the site. The type II samplers (2” x 6”) are used when an undisturbed sample is desired with no intent of on field investigation. The type III sampler has stainless steel sample rings which are ideal for laboratory studies and for undisturbed core samples. In comparison to type I and type II sampler, it has a much shorter 5/16” gap which provides a more representative core and reduces compaction as the soil enters the sampler. It has a built-in waste barrel which provides a 2” relief and hence eliminate compaction due to overdriving.

(a) Type I: split (lengthwise) soil core sampler- cutting shoe, split core and cap

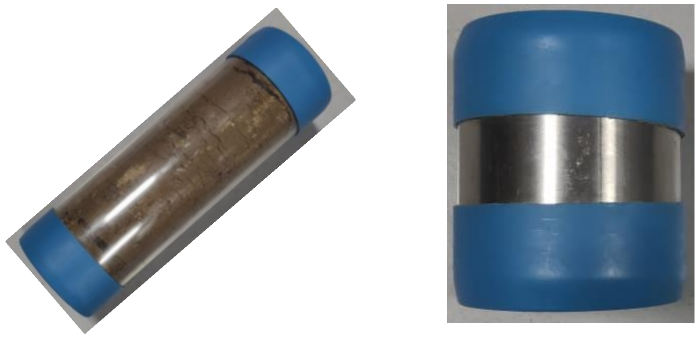
(b) Type II: soil core sampler – core and cap

(c) Type III: split (widthwise) core sampler – cup, cap and inner rings

Fig. 2 Various types of stainless-steel samplers

Boreholes should be drilled using a suitable auger attached to an extension rod (1.2 m length) as per the field conditions. More extension rods can be added to reach the desired depth of sampling. Samples are then retrieved at different intervals as specified in the soil sampling program. Maximum possible depth of exploration with this type of kit is up to 3m. After reaching the sampling depth, a suitable core sampler is attached to the extension rod with slide hammer (see Fig, 3) attached to the other end. Teflon tape is recommended over the threads to protect them from wearing/ loosening. Assembly should be tightened using wrenches and loosened using a slip wrench in combination with wrenches. Mark a point 6” above the ground on the extension rod and drive using the slide hammer. When sampler is driven to a depth of 6” below the sampling depth, shear of the sample from the ground by rotating it in clockwise direction. A sample retrieved from a site is shown in Fig.4. Sometimes while sampling in stiff soil sites sample will not come out by manual pulling, then, it can be pulled by reverse hammering. While sampling in loose cohesionless/ wet soils use of core catchers (see Fig. 5(d)) is recommended to avoid any slippage of samples from the liner while pulling.

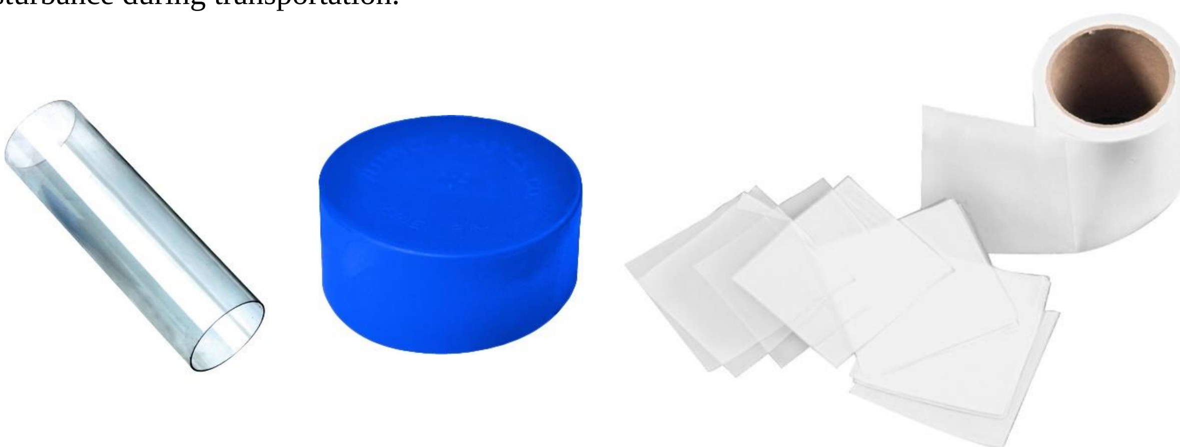
Fig.3. Slide Hammer



(a) Plastic liner (b) Steel liner

Fig. 4 Soil sample collected in plastic and steel liner

Use of plastic liner is recommended. Plastic liner should be inserted inside the core sampler before sampling. The sample when retrieved should be seal immediately using swatches and end caps (see Fig. 5) for safe transportation to lab for further analysis. The liner containing sample should be cut upto the recovered length of sample using a suitable cutting tool to avoid any disturbance during transportation.



(a) Plastic liner (b) End cap (c) Swatches

(d) Core catcher

Fig. 5 Sample packing for transportation to lab

3.2 Soil sampling using petrol powered continuous soil coring kit

The kit includes a petrol-powered hammer, 1.2m slotted sampler tube, 0.6m extensions, plastic liner (38mm x 1.2m and 38mm x 0.6m) and plastic end caps. The petrol powered REDI Boss Hammer (see Fig. 6) can obtain continuous soil core samples upto a depth of 2.4m. Practitioners can use various combinations of the 0.6 m extension rods and 1.2 m slotted sampler tube to retrieve continuous core samples at the desired depths. The slotted sampler tube also gives a quick visual profile of the soil sampled. Ear plugs are recommended while sampling continuous cores using the petrol powered REDI boss hammer.

Fig. 6. Petrol powered REDI Boss Hammer

The extension rods with liner inside are connected with a drive tip at one end and a liner retainer at the other end. Then liner retainer is then fixed with a drive head and the hole assembly (see Fig.7) is pushed down using the hammer. Before pushing, a well lubricated sleeve is to be inserted in the hammer to ensure proper seating. After pushing the tubes/ extensions containing liners to the desired depth, they can be pulled back using a foot jack & shackle system (see Fig. 8).

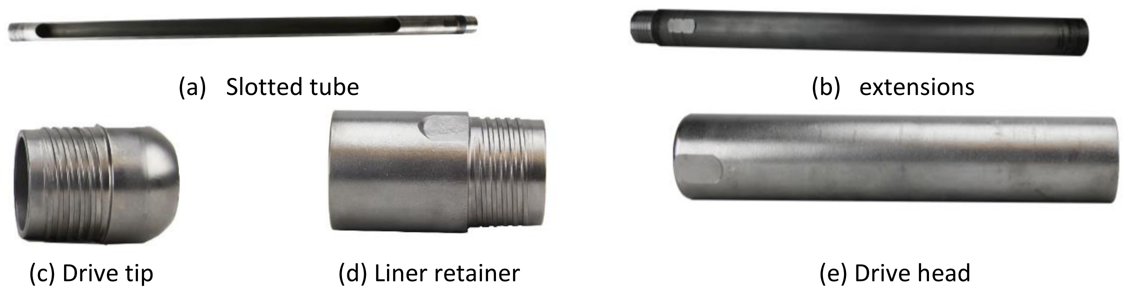


Fig.7 Sampling assembly

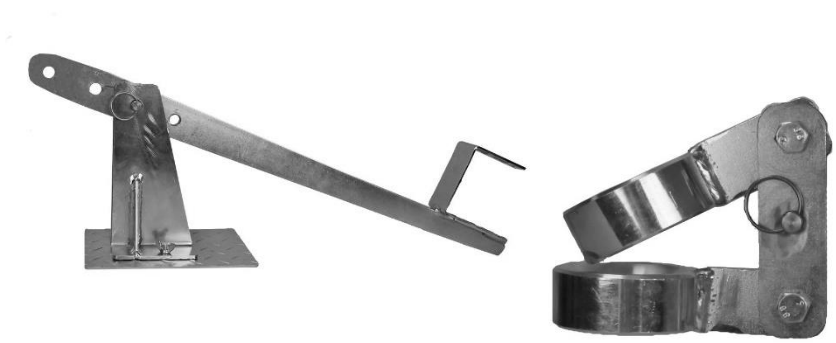


Fig. 8. Foot and shackle system

After retrieving the sample, the extensions/ slotted sampling tube should be cleaned using a brush attached to a cleaning rod (see Fig. 9). Before sending samples to lab ensure safe transportation as discussed in section 3.1.

Fig. 9 Cleaning tool

3.3 Groundwater sampling using Hollow stem auger kit

The kit includes flighted lead hollow stem auger (see Fig. 10), hard surfaced tip, flighted extension, inner rod, tip & plug cap with two extensions (see Fig.11), and slotted soil sampling probe (see

Fig.12). The hollow stem auger with an ID 1 1/8" cuts a 3" diameter hole, making them suitable for soil, soil gas and groundwater sampling through a cased hole up to a depth of 3m. A combination electric rotary hammer drill is used to power the augers for extending the boreholes. A special soil probe, 7/8" OD by 24" long with slide hammer can be used for the collection of a soil sample through the auger. The gas vapor probes may be used through these augers telescopically (explained in section 3.4).

Fig.10. Hollow stem auger with hard surface tip & cap

Fig.11. Inner rods, tip and plug cap

Fig.12. Special soil probe and retrieved sample

Before connecting the rotary hammer drill to the hollow stem auger, it is recommended to lubricate all joints with vegetable oil to prevent locking of the assembly.

Groundwater can be sampled with hollow stem auger kit by lowering telescopically a suitable Teflon tube connected to a tubing weight at one end and peristaltic pump at the other end (see Fig.13). The peristaltic pump can be used for pumping liquids (pressure and vacuum both) at depths up to 8 meters. They operate by mechanical peristalsis, so the sample only comes in contact with the tubing only. This allows for consistent sample integrity as well as easy cleaning and replacement. Sampling tubes should be inserted from left side of the pump head. Based on the field conditions, speed can be increased (range of speed is 30 to 300 rpm for a standard pump). The delivery rate of the standard pump is 1.67 ml per revolution or up to 1 litre/ minute. Reverse pumping should be done immediately to back-flush the water from the tubes, if any unwanted material is being pulled up. Suitable bottles should be used to collect groundwater at the other end of the tubes.

After sampling groundwater/ soil, the hollow stem auger can be pulled out of the ground by reverse augering using a pipe wrench.

(a) Peristaltic pump (b) Tubing

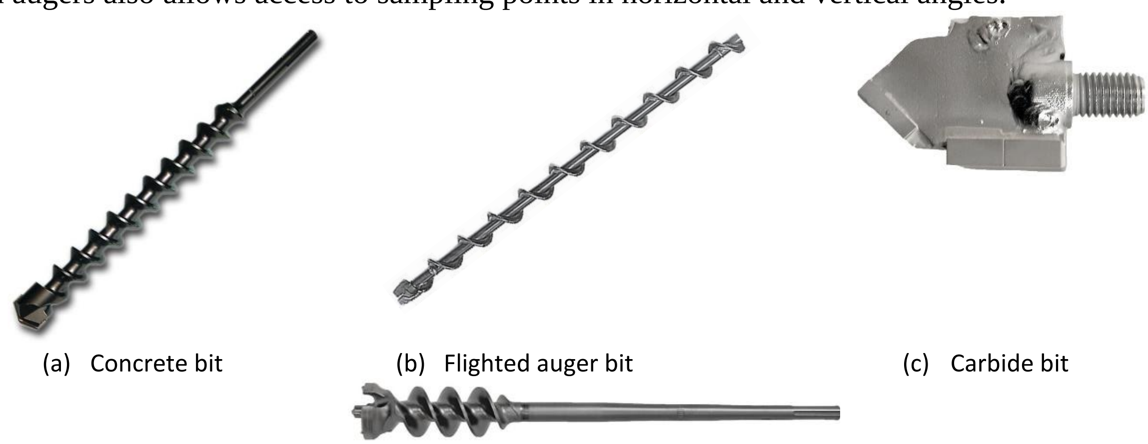
Fig.13. Peristaltic pump for groundwater sampling

3.4 Gas vapor sampling using GVP kits

The GVP kit includes GVP extensions, retractable tips, tile probe base with tile probe extensions, wild bore bit, larger concrete bit, carbide tip, slide hammer and tefluoropolymer tubing and a hand pump.

The boreholes can be extended using hollow stem auger/ flighted auger or a hand auger based on the field condition. There are different types of bits/ augers available (see Fig.14), concrete bit to allow clearance for flighted augers, lead flighted auger bit with a hard-surfaced tip for regular soil conditions, carbide tip for heavily compacted soil and wild bore bit to drill through asphalt roads.

Pre-drill your boreholes with the flighted augers prior to insertion of your GVP extensions and sampling tips to increase the lifespan of your stainless-steel sampling points. Pre-drilling with flighted augers also allows access to sampling points in horizontal and vertical angles.



(a) Concrete bit (b) Flighted auger bit (c) Carbide bit

(d) Wild bore bit

Fig. 14. Various types of bits/ augers heads

There are two types of GVP tips, regular tip with umbrella and retractable tip (see Fig.15). The GVP tips can be used as a surveying tool or as a monitoring point. The regular GVP tip can be installed as a permanent sampling point or for soil gas monitoring or can also be used for used for detecting hydrocarbon spills, underground storage tank and pipe leaks, landfill contamination and hazardous waste sites. The unique design and umbrella ensure an easy passage for gas entering the collection system. The umbrella assists in keeping the tip vapor inlets free of soil. Screen should be used particularly in fine-grained soils. The GVP retractable tip is generally used as a survey tool for collection of discrete soil vapor samples below the ground surface, usually at discrete depths.

The sampling point is pre-drilled using a solid tile rod with probes to a depth of about 3/4th of the desired sampling depth. The GVP tips should be connected to the suitable sampling tubes (fluoropolymer), telescopically inserted through the hollow GVP extensions and slotted drive head (see Fig. 16). The slot in the drive head helps in easy movement of the sampling tube. The whole assembly is then driven to the desired sampling depth using a slide hammer or electric rotary hammer. The sampler is opened by retracting the gas vapor probe extension string an inch or so. When open, the sampling ports protected by a mesh screen are exposed, hence after the gas collection, the sampler may be closed by pushing down on the drive string. The gas can be sampled using a vacuum pump station connected to tedlar bag/ or directly in a tedlar bag using an automatic vacuum air sampling chamber. The whole assembly then can be pulled out using a big foot removal jack. Decontamination of the GVP tips before the next use is highly recommended.

The above discussed kits with suitable accessories can be efficiently used for environmental soil/ Groundwater/ gas sampling. Site conditions and sampling kits/ tools required for soil/ groundwater/ gas vapor sampling have been discussed in Table 3.

(a) Retractable GVP tip

(b) Regular GVP tip

Fig.15 GVP tips

Fig. 16. GVP Assembly

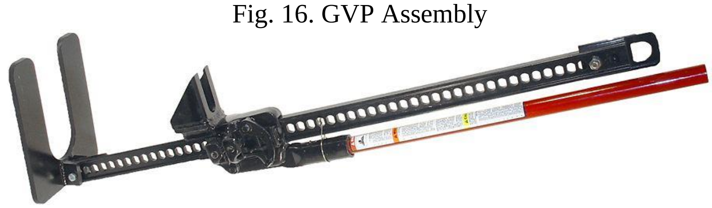


Fig. 17. Big Foot Removal Jack

Table 3. Site conditions and sampling kits/ tools required for soil/ groundwater/ gas vapor sampling

Environmental Shallow Depth Sampling						
	Soil Sampling		**Groundwater Sampling**		**Gas Vapor Sampling**	
	Cohesive soils/ Stiff cohesionless soils with no water table	Loose cohesionless soils with or without water table	Cohesive soils	Loose cohesionless soils	Cohesive soils	Loose cohesionless soils
Type of Sampling Kit/ Tools	* Environmental Soil Sampling Kit * Petrol Powered Continuous Soil Coring Kit * Flighted Auger Kit	Hollow stem auger kit	Suitable auger with peristaltic pump	Hollow stem auger kit with peristaltic pump	Gas Vapor Probe Kit and an automatic vacuum air sampling chamber for filling Tedlar bags	Gas Vapor Probe Kit in combination with Hollow stem auger kit and an automatic vacuum air sampling chamber for filling Tedlar bags
Accessories/ materials Required	Stainless Steel/ plastic liners with end caps, swatches, stainless steel knife, hacksaw with stainless steel blade, screwdriver, permanent marker etc.		Plastic bottles, permanent markers, pliers for cutting tubes, vegetable oil etc.		Tedlar bags, automatic vacuum air sampling box	
Precautions/ Safety measures	• Use of any type of lubricants at the joints is strictly prohibited. • Use of gloves, masks and safety shoes is recommended.		• In case of hollow stem auger, joints can be lubricated using vegetable oil. • Use of gloves, masks and safety shoes is recommended.		• Use of any type of lubricants at the joints is strictly prohibited. • Use of gloves, masks and safety shoes is recommended.	

4. CONCLUSIONS

The conclusions derived from the study are as follows:

1. A well-planned investigation could easily pin-point the "hot-spots" (areas having high level of contamination), characterize the nature and extent of contamination and delineate the flow of contamination across the area under consideration. However, a lousy approach can give clean chit to a probably contaminated site.
2. Field screening should be carried out using some portable equipment like photo-ionization detector (PID) or handheld X-ray fluorescence (XRF) gun. Based on the results, sites with high concentration of contaminants can be pinpointed and sampling locations can be decided.
3. Soils sampling kits explained in the paper can be used for environmental soil, ground water and gas vapor sampling. However, these kits can be used for sampling at shallow depths upto 3m only.
4. Precautionary and safety measures must be followed while sampling in field.

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Direct Push Technique for Collecting Continuous Core Soil Samples for Environmental Studies in Delhi Silt

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ABSTRACT
The collection of soil samples without cross-contamination is one of the primary requirements in any environmental site characterization study. There are several ways to collect soil samples from an area under interest, but one should ensure that there is no cross-contamination either while collecting samples or from equipment handling. This paper presents a methodology using direct push sampling for the collection of continuous core soil samples without cross-contamination.

Keywords: Direct Push Sampling; Continuous Core Sampling; Dual Tube Sampling

1. INTRODUCTION
This paper highlights the methodology and advances of collecting soil samples without cross-contamination using direct push technique. Using this technique, samples were collected near sports ground at the Indian Institute of Technology, Delhi. The tool used in this technique is called DT 325 which is manufactured by Geoprobe. The DT stands for Dual Tube and 325 stands for 3.25 inches outer diameter of the outer casing rod. The direct push method is shown to have advantages in terms of operational speed and better quality of collected specimens (McCall et al. 2002).

DT 325 is advantageous as it offers a way of collecting samples that are untouched and without cross-contamination from external sources. The outer casing is driven with inner rods. Inner rods have PVC liner enclosed within. A core catcher is attached at the bottom of the liner to ensure that the samples are not lost during extraction. This paper will include a demonstration of field works carried out at IIT, Delhi using DT 325.

2. EQUIPMENT DETAILS AND ADVANTAGES
The name of the equipment used for applying the required push and percussion hammering force is called Geoprobe 7822DT as presented in Fig. 1. This rig can be used for high-resolution site characterization (HRSC) using tools like Optical Imaging Hydraulic Profiler (OIHP), electric cone penetration testing using piezocone (eCPT), gas sampling and groundwater sampling. This paper focusses on DT 325 tools to collect continuous soil core samples without cross-contamination using Geoprobe 7822DT.

DT 325 is a direct push system for the collection of continuous core samples from the required depth with the use of sealed casing. The 1.25 inches outer diameter lightweight center rods having an enclosed PVC liner are inserted to the bottom of outer casing having 3.25 inches outer diameter. The samples which are collected in the PVC liner can have volume up to 2,600 ml.

The liner is 2.1 inches outer diameter thin-walled PVC liner which is placed within a steel sheath to contain and retrieve the core samples. A core catcher is a dome-shaped device attached at the driving end of the liner which prevents loss of collected soil during retrieval of the soil core.

A cutting shoe is threaded onto the leading end of the rod string which shears a 1.75- or 1.85-inches outer diameter soil core which is then further collected in the liner. The main advantage of using dual tubes is that there is no side slough to deteriorate the ingenuity of the sample. Also, the outer casing seals the probe hole making sampling in perched water table simpler. The effect of cross-contamination is also eliminated in this method.

Fig. 1 Geoprobe 7822DT rig

3. METHODOLOGY

The name dual-tube stems from the fact that two sets of rods are used in this process. One set of rods called outer casing having 3.25 inches outer diameter is driven into the ground which receives the driving force from the hammer and it also provides a sealed casing through which soil samples can be recovered. The second set of rods having outer diameter 1.25 inches are placed inside the outer casing with a sample liner attached to the leading end of the rod string. For retracting the full liner, the only inner set of rods needs to be retracted.

3.1 Cleaning

The equipment associated with DT 325 was thoroughly cleaned before its use according to the project requirement. Routine inspection of parts for wear and tear was done and a new liner was used each time for each core.

3.2 Field Activity

The first activity with the use of 7822DT is to level the rig at the required point of investigation. The setting up process is presented in Fig. 2. After the rig is positioned at the required location, we proceed with the assembly of DT 325 tools at the site for the collection of samples.

DT 325 is designed for continuous soil sampling. The sampling may start from ground level or from any pre-determined depth. Once the sampling commences, consecutive soil cores are removed as the outer casing is advanced to greater depths.

The sample sheath is used to protect the liner from getting damaged while advancing the DT 325 too string. Sample sheath also bears the weight of the inner rods. The PVC liner and retainer ring are attached as shown in Fig. 3. Then the PVC liner along with the retainer ring is pushed into the sampling sheath (Fig. 4) and is tightened using threads (Fig. 5). The core catcher is attached to the downhole end of PVL liner as presented in Fig. 6b.

Fig. 2 Setting up Geoprobe 7822DT rig at the field location

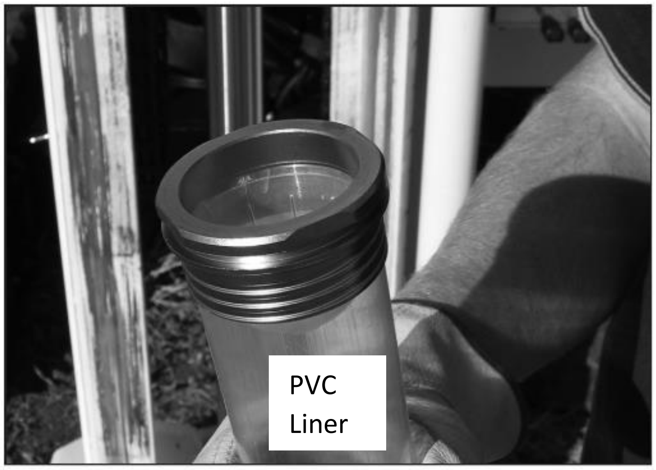

Fig. 3 Assembling of PVC liner and retainer ring

Fig. 4 PVC liner and retainer are placed on sample sheath

Fig. 5 Tightening of retainer ring with PVC liner on to the sample sheath

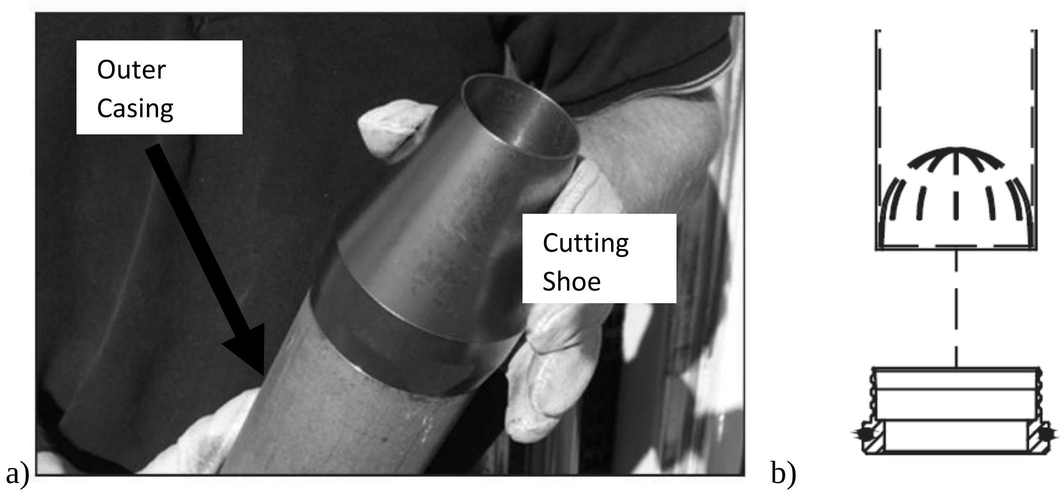

Fig. 6 a) Cutting shoe tightened at the downhole end of outer casing and b) Core catcher and retainer ring schematic on the downhole side of PVC liner

Sampling began at the ground surface and field process showing direct push technique is presented in Fig. 7. The collected samples with liners are presented in Fig. 8. After retrieval of the first liner and soil core, a new liner was inserted to the bottom of the outer casing on the end of the inner rod. It shall be noted that the push is given using a static push and also with active hammer percussion.

Fig. 7 Direct pushing of DT325 tool to required depth

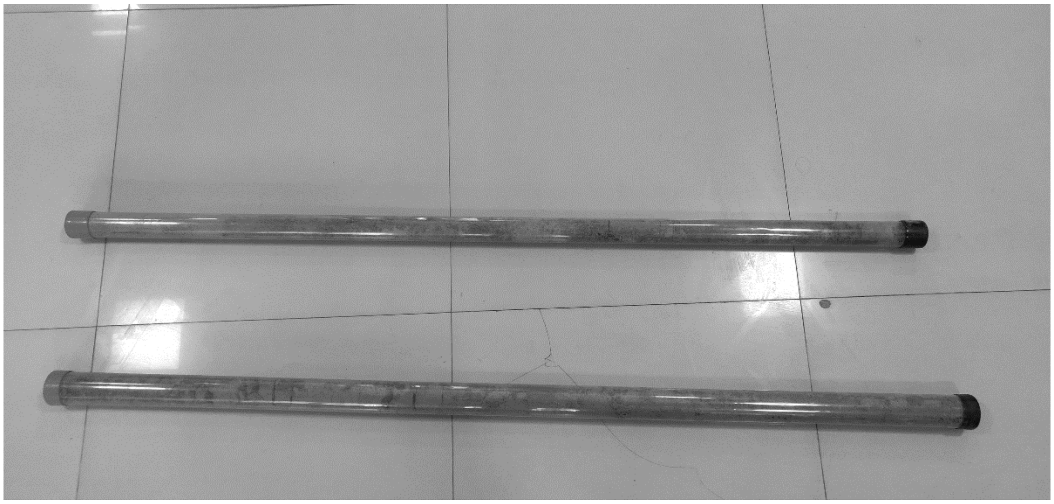

Fig. 8 Collected continuous soil core samples without cross-contamination with end caps

4. DISCUSSION

In general, this technique gives an effective method to retrieve continuous core soil samples at contaminated sites and is relatively easier to use. The obtained samples are nor cross-contaminated and can be directly transported to the laboratory for further investigations.

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A Field Study to Identify Underground Utility using Ground Penetrating Radar

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ABSTRACT
Presence of underground utilities can significantly obstruct the sampling operations; hence site investigations followed by detecting these utilities are in trend to minimize the loss at the site. Ground Penetrating Radar (also known as GPR), is an instrument that uses radar pulses to image the subsurface, is used in various fields like archaeology, earth science, structural geology, pavements, landfills, remediation sites etc. This paper presents the survey of a field at IIT Delhi campus with an antenna of 400 MHz frequency. The results obtained from the field are in the form of time and number of scans. Post-processing of the herein work is performed using REFLEX-W software which produces result showing the depth of the utilities and images of them both in 2-Dimensional and 3-Dimensional coordinate. Observation of hyperbolic returns with brighter appearance signifies the presence of utilities, although GPR cannot encounter material properties.

Keywords: Antenna; Ground Penetrating Radar; Frequency; Underground utilities; REFLEX-W

1. INTRODUCTION

Complexity in collecting soil samples for site investigation may arise for hidden underground utilities, which may get damaged during sampling. Hence smart technologies are implemented to detect these utilities through electromagnetic wave propagation. There are several methods to detect these utilities such as Metal Detectors, Electronic Marker Systems (EMS), Electromagnetic Terrain Conductivity, Acoustic Emission, Resistivity, Ground Penetrating Radar (GPR), Micro-gravitational Techniques, and Seismic Reflection and Refraction methods (Jeong et al., 2003). Ground penetrating radar (GPR) offers a rapid and effective way to locate these utilities by making the use of electromagnetic pulse. Several researchers successfully established to detect plastic and clay conduit pipe in agricultural lands (Allred et al., 2004; Szuch et al., 2006), as such to assess the potential of presence of water/in around buried underground conduits (Hunaidi et al., 2010) using ground penetrating radar.

Monitoring through GPR via microwave tomographic inversion (Crocco et al., 2009; Cataldo et al., 2014) can be useful for the detection and evaluation of leaking pipes. However, it all depends on subsurface conditions, presence of water or salt. The depth and nature of the target for different soil condition are needed to be studied. In addition, operating GPR requires expertise in data interpretation, which traditionally lies in human visual recognition or specific patterns that may reflect in the form of 2-D hyperbolic returns signifying buried conduits (Olhoeft, 2000).

The main objective of the present study is to collect the raw GPR data from the field and post-processing of the data using REFLEX-W software to investigate subsurface utilities.

2. WORKING PRINCIPLE OF GPR

A GPR is comprised of components like a controller, antennae (250 MHz, 400 MHz or 1 GHz), and a GPS unit. The controller used in the study has eight channels and each channel is capable of carrying antennas of six different central frequencies i.e. 6 GHz, 4 GHz, 1.5 GHz, 1 GHz, 400 MHz or 250 MHz. The antenna contains one transmitter as well as one receiver. The transmitter emits electromagnetic energy pulses at a specific frequency range (typically between 16 MHz to 2000 MHz) depending on the type of antenna being used. The receiver receives reflected electromagnetic pulses and produce a hyperbola when there is a change in the dielectric permittivity of the material below the surface (Conyers, 2013). The energy pulses are reflected back to the antenna from the subsurface utility, which could be buried pipes, soil strata etc.

The travel time of pulses from the transmitter to the receiver is recorded by the GPR equipment which can be imported into REFLEX-W software which digitizes the reflections and allows the user to determine the depth of the reflection. The accuracy of the digitized reflections and intensity of signal penetration below the surface depends on the frequency of the pulses that are assigned to specific antenna models. Antennas, operating at lower frequencies (200 MHz to 400 MHz) may penetrate deeper into subsurface (typically 4 m to 9 m) due to higher amplitude. Higher operating frequencies (1000 and 2000 MHz) may penetrate lower into subsurface typically (1 m to 1.5 m); however, they provide sharper images in comparison to the higher frequency. The 400 MHz antenna and complete assembly of GPR system used in the present study are shown in Fig. 1(a) and 1(b) respectively.

(a) (b)

Fig. 1 Ground-penetrating radar (GPR): (a) Antenna (400 MHz), (b) Complete GPR assembly

2.1 GPR Data Collection Systems

GPR data collection system comprises of a ground-coupled unit with antennas, mounted on a cart with single or multiple wheels depending on the size of antennas to be connected which must have constant contact with the ground surface which is to be scanned. The antenna with a frequency of 400 GHz is assembled in one unit in the hand cart with four wheels, and an encoder is attached to one of the wheels. Data collection is normally performed at a scan frequency of 100 Hz. The cart has provision to be either pushed or pulled with arrangements to connect extra receivers of different frequency to get average velocities of different layers accurately.

2.2 GPR Data Processing

The reflections and refractions of the electromagnetic waves depend on several factors such as soil type, presence of moisture and salt etc. Clayey soil obstructs the signal whereas granular, sands, glacial tills and sandy soils respond very well (Saaranketo, 1999). The presence of nearby buildings, cellphone towers, overhead wires, transmission lines and such things can cause interference, which in turn, can cause significant error in the form of 'noise' to the collected data, making it difficult for interpretation.

The post-processing of the collected data is accomplished by software REFLEX-W. The recorded data is processed in a series of steps to obtain noise-free data. Initially, data is obtained in the format of time, which is being applied to distance conversion to represent the depth of penetration of radar signals. Secondly, the most crucial step is to apply 'background removal', which makes data free from the interference by any air interface between antennas and the ground surface. The third step involves applying 'gain' to counter-balance the energy loss as the waves penetrate deeper and return. The researchers can also go through different kinds of filter to get a data modified within either half and double the frequency of antennas. By fitting hyperbola method, the researcher can be able to find velocity and permittivity of material accurately. The REFLEX-W 2-D interpretation presents only 2-D view of scans which can be further stacked together to get 3-D analysis of data which slices them in horizontal planes. Fig. 2 shows the flow-chart for GPR data processing, i.e. from raw data collection to 3-D interpretation.

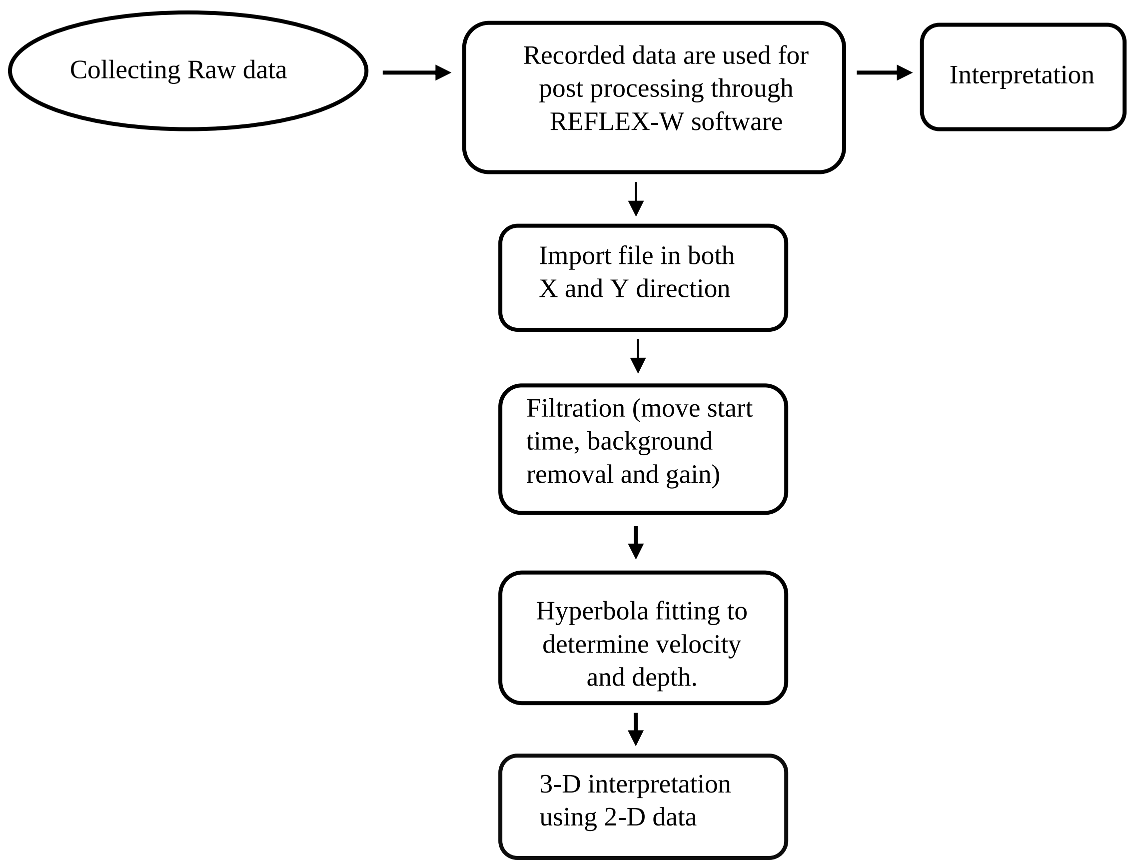


Fig 2. Flow-chart for GPR data processing

3. FIELD STUDY

The GPR field survey was carried out using GPS in a small plot of area 12 m × 34 m at IIT Delhi campus to detect the underground utilities. A grid was made at 2 m interval with reference-point at 6 m from starting in the field. Cart mounted GPR survey was carried out using 400 GHz antenna. The antenna was set to collect data at timesweep of 40 nanoseconds, or up to a depth of approximately 4 m below ground surface with scan frequency 100 Hz and 256 samples per line.
Consecutive longitudinal and traverse passes were performed as Channel 1. Data were collected in the form of time required for the electromagnetic waves to reflect from the anomaly and reach the antenna and number of scans per lane. Bright reflections and hyperbolic returns were obtained in GPR data. The 400 MHz antenna has capabilities to represent penetration depth of 4 m. Fig. 3 shows the data being collected by GPS unit which portrays the plan view of survey area to evaluate the coordinates in both X and Y direction. This would ultimately help to retrieve at the exact location of the area.

Fig. 3: Plan view of the survey area (source: Google Earth)

4. DATA INTERPRETATION

The Fig. 4 shows a sample image of raw data obtained using 400GHz antenna. The raw data is required to be made ‘noise-free’ which is being followed by 2-D interpretation. The raw data shows the presence of anomalies which can be differentiated from other objects clearly in form of hyperbolic returnsin. Boulders and hard surface such as concrete base could also give bright and higher contrast indications, but underground conduits can be confirmed by the linear repetition of data in both ‘X’ and ‘Y’ direction. The typical processed GPR data for 400 MHz antennae using 2-D data-analysis is shown in Fig. 5. The utility has been marked resulting from 2-D analysis based on the hyperbolic fitting method representing conduits as most of the electromagnetic waves get reflected from the top surface of the underground conduit forming hyberbolic returns in data.

The 2-D processed data were then stacked together to get a horizontal planar view in 3-D interpretation. The processed data turns simpler to determine the actual depth of underground utility by slicing in the horizontal plane at regular timeslice in terms of depth. The typical processed GPR data in 3-D interpretation in both X and Y direction are shown in Fig. 6 and Fig. 7 respectively. The processes data shown here represents at a timeslice of 46 cm depth, i.e. presence of underground utility at 0.46 m from the ground surface. Thus, by adjusting the timeslice at frequent intervals, several such anomalies can be detected.

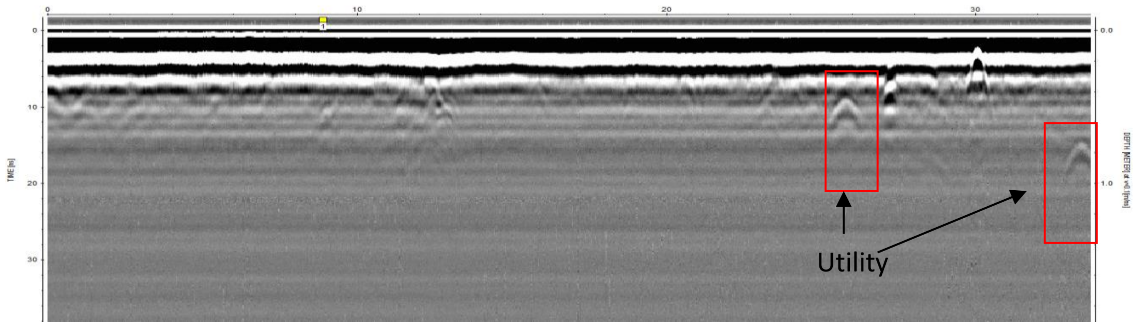


Fig. 4 Raw GPR data for 400 MHz antenna

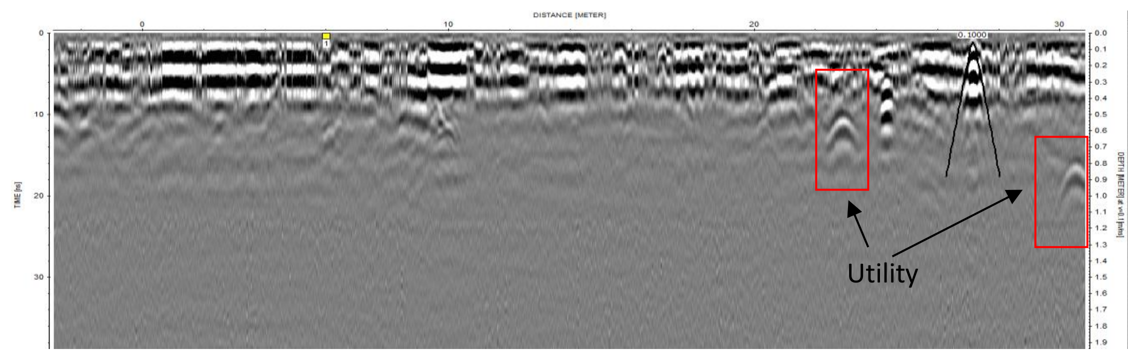
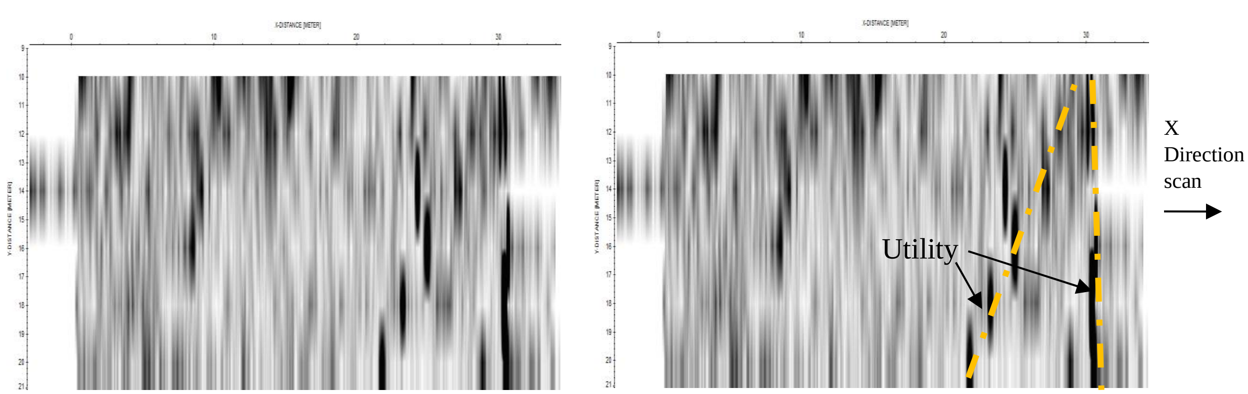
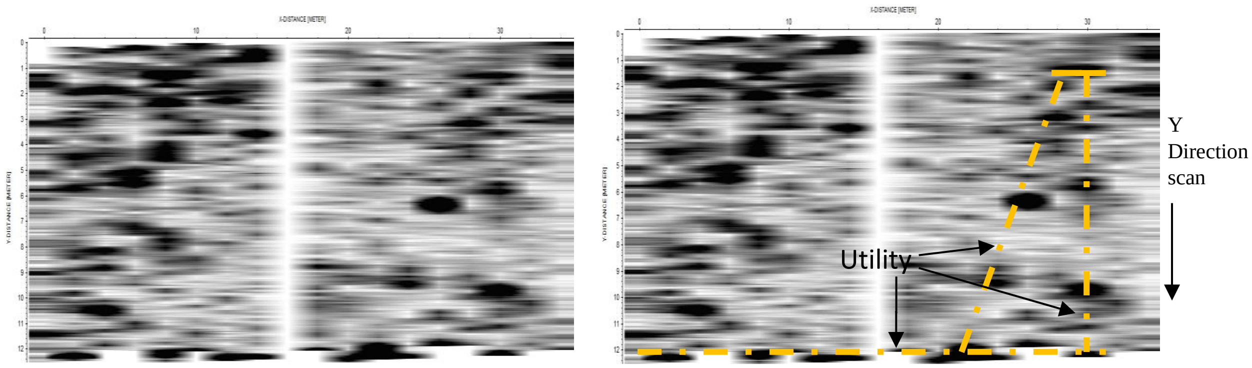


Fig. 5 Processed GPR data for 400 MHz antennae using 2-D data-analysis



(a) (b)

Fig. 6 Processed GPR data for 400 MHz antenna using 3-D data interpretation in X-direction: (a) Original data; (b) Data with utility marked



(a) (b)

Fig. 7 Processed GPR data for 400 MHz antenna using 3D data interpretation in Y-direction: (a) original data, and (b) data with utility marked

From the ground-truthing done initially before the survey and by observing hyperbola returns at the same slice in 2-D analysis and 3-D interpretation in both directions, location of utilities at approximate depth can be realized. Based on processed GPR data, the underground utilities were detected and marked for convenience to avoid such areas from being damaged during sampling operations. Fig. 8 shows the plan view of survey area at IIT Delhi campus indicating the underground utilities.

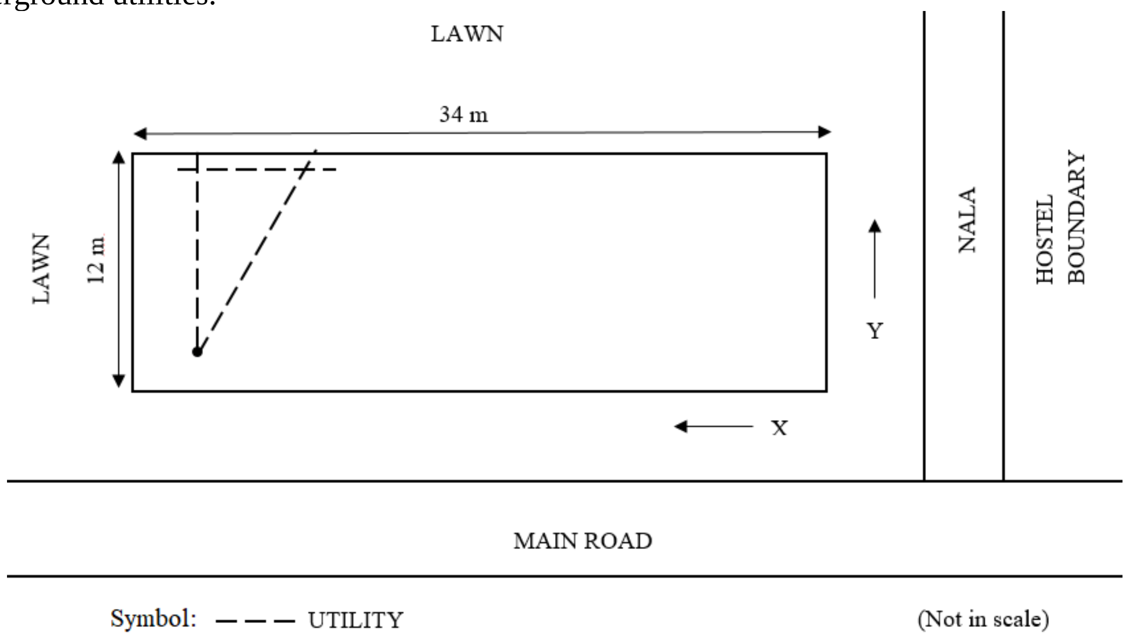


Fig. 8 Plan view of survey area indicating the underground utilities

5. CONCLUSIONS

Non-destructive data collection using GPR is an effective method to determine the presence of underground utilities, presence of void pockets etc. Combination of GPR along with metal detectors and other equipment would be useful in determining the status of pipes carrying live currents, type of conduits etc. However, focus indeed should be paid in realizing the limitations and specific depths to be targeted.

In the present study, GPR survey with 400 MHz antenna was carried out at IIT Delhi campus to identify the underground utilities. The raw data obtained from GPR survey has been converted to noise-free which is being followed by 2-D interpretation. The hyperbolic fitting method was used for processed 2-D GPR data to mark the utilizes. The processed GPR data converted to the 3-D data interpretation in both X and Y direction to locate the underground utilities at various depth. Based on the careful observation of 2-D and 3-D interpreted GPR data and proper ground truthing beforehand, the underground utilities were identified and marked at the field of IIT Delhi campus. Survey using GPR is not only non-destructive method of determining the location of various utilities but also the velocities of various layers can be also be evaluated. However, the material properties of utilities alone by GPR survey is difficult to predict. The GPR survey is found quick to conduct, safe and efficient in collecting data, although interpretation needs care and expertise.

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Sustainable Practice of Remediating Contaminated Sites using Industrial Waste

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ABSTRACT

Due to rapid industrialization, geological characteristics of the landscape are disturbed to a greater extent, mainly contributing to the soil contamination by industrial effluents. Thus, it becomes mandatory to identify suitable treatment techniques for remediating contaminated sites with less effort and resources. This work focuses on identifying the optimized percentage of the industrial waste mix proportion with expansive soil associated with an aqueous solution to depict the soil contamination with heavy metals, specifically Lead, Copper and Iron. The study involves the characterization of swelling behavior of expansive soil with and without the presence of heavy metals, thereby stating the effect of heavy metals on the swelling behavior of four different types of soil.

From the experimental results, the percent increase in the free swell index of expansive soil was identified as 4% due to heavy metal contamination (Pb, Zn, and Fe). On further investigation by utilizing the industrial waste, i.e., fly ash with these contaminated soils earned a productive result, which results in stabilizing the swelling behavior in expansive soil, particularly at contaminated sites. Different proportions of stabilizing agents adopted in the study were 5% of lime followed by 5%, 10%, 15%, 20%, and 25% of fly ash, respectively. Out of which, the optimized percentage of mix proportion was found as 5% Lime and 15% Fly ash, which yields the maximum reduction in the free swell index. The optimized ratio becomes valid by attaining a similar trend in the plasticity index at a percentage of 5% Lime and 15% Fly ash

Keywords: Heavy metals; expansive soil; stabilizing agent

1. INTRODUCTION

With the rapid increase in the exploitation of natural resources, there is a huge demand in the need for sustainable practices in the construction industry as well as the reclamation of contaminated sites. The criteria involved in effective sustainable practices are efficient usage of resources, proper measures for pollution reduction, additional incorporation of renewable energy and enhancement of flora and fauna in the environment. The techniques adopted for implementing such sustainable practices in the construction industry might include prefabricating materials and elements in a controlled environment, construction waste management, improvisation of site environmental conditions, lean manufacturing concerning less energy consumption and ultimately choosing suitable green materials for the conventional construction materials.

One of the common issues across the world is soil contamination, which poses a serious threat to human health and the environment. Hence, there is a great need in adopting a suitable and sustainable practice in remediating the contaminated sites. In the present work, soil contaminated with heavy metals such as Lead, Zinc, and Iron are studied with respect to their swelling behavior in four different types of expansive soil. Sustainable materials such as industrial waste i.e., fly ash and lime is mixed for improvising their swelling potential.

2. MATERIALS AND METHODOLOGY

Two categories of soil are selected for this study namely expansive soil and virgin soil (i.e., Site Soil) which are designated as ES and VS respectively. Since the study is to be carried out in extreme conditions, the most swelling type of soil is required and thus Montmorillonite clay mineral-rich soil Bentonite is chosen which falls under the category of highly swelling soil. In that, commercially available Sodium Bentonite and Calcium Bentonite are chosen and designated as ES1 and ES2 respectively.

Further studies are carried out in two Virgin soils to depict the site situation and designated as VS1 and VS2. VS1 is collected from the Sobanapuram located on the outskirts of Trichy city and VS2 is collected in front of the Department of Civil Engineering at the National Institute of Technology, Trichy.

To depict the most contaminated wastewater, industrial wastewater showing a predominant and maximum concentration of heavy metal is chosen. Test analysis is carried out using three concentrations namely maximum, average and minimum. Maximum concentration is fixed from the maximum concentration identified from the untreated industrial wastewater and similarly, maximum concentration identified from the treated industrial wastewater is fixed as minimum concentration. The average of both maximum and minimum concentration is taken as average Concentration. The concentration of heavy metal considered for analysis is shown in Table 1. Their three concentrations are taken from the maximum values recorded from Paint, Pharmaceutical, and Textile Industries respectively. Salts used for making the heavy metals (i.e., Iron, Zinc, and Lead) of required concentration are Iron Sulfate, Zinc Sulfate, and Lead Nitrate respectively.

Table 1 Concentration of Heavy Metals used

Heavy metal	Concentration (mg/l)			
	Industry	Maximum	Minimum	Average
Pb	Textile	30	1.1	15.55
Zn	Pharmaceutical	50	10.2	30.1
Fe	Paint	120	3.19	61.6

3. RESULTS AND DISCUSSIONS

3.1 Expansive soil classification

In Table 2, the basic engineering properties of four types of soil are tabulated. Generally, for clay soils, the specific gravity should lie in the range of 2.4 to 3.0. Except for VS1, all the three soils show the specific gravity of clay. Specific gravity is lesser in VS1 because of the presence of more organic content (peat) in them. Using liquid limit and plasticity index, soil expansion classification is done as per IS 1498 – 1970. ES1 is classified as very high expansive soil whereas ES2, VS1, and VS2 are classified as low expansive soil.

Table 2 Engineering Properties of Soil

Property	ES1	ES2	VS1	VS2
Specific Gravity	2.63	2.68	2.13	2.43
Liquid Limit	260	36	53	35
Plastic Limit	71	22	31	24
Plasticity Index	189	14	22	11
Optimum Moisture Content	19	17	21	15
Max dry density	1.40	1.71	1.63	1.82
Free Swell Index	76.67	0	16.67	10

3.2 Analysis with heavy metals

Figure 1 depicts the variation of the Free Swell Index of four types of Soil with all the three Heavy metals. Free Swell Index achieved without any heavy metal is taken as Control Value which was mentioned in the basic engineering Properties (Table 1). Swelling behavior in terms of FSI with each heavy metal is presented in Annexure – B. In overall, ES1 is found to be showing more variation than the Control Value. ES2 showing nil variation which confirms No Swelling even after Heavy metal Contamination. In VS1, Free Swell Index is found to be increased only with the maximum concentration of all heavy metals. So, it ensures swelling only with untreated wastewater and swelling is not induced with treated industrial effluent. VS2 is found to be varying only Lead, thus swelling can be expected to be increasing during Lead contamination.

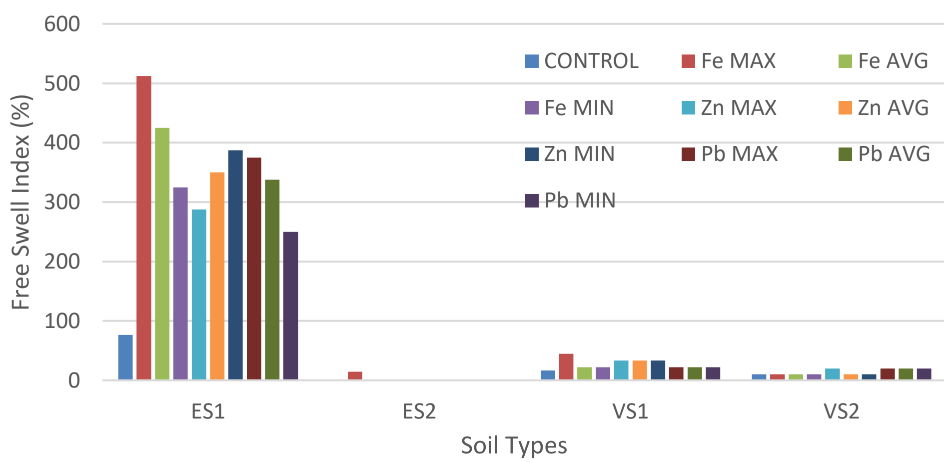

Fig.1 Free Swell Index with different heavy metal concentration

3.3 Treatment with Lime and Fly Ash

The susceptibility to swelling is more in ES1 with the presence of heavy metals, thus further treatment is carried out in that soil alone. Mix proportion adopted for the study is 5% of Lime followed by 5%, 10%, 15%, 20% and 25% of Fly ash with respect to their dry weight of soil. The liquid limit and plastic limit are identified in each mixture in expansive soil. Since the plasticity index is directly influencing the swelling behavior, it becomes necessary to study this before identifying their free swell index. Table 3 shows the variation of PI for different soil mixtures.

Lesser plasticity index at 5% Lime and 15% Fly Ash denotes the possibility of minimum swelling than other mixtures.

Table 3 Variation of PI for different Soil Proportion

Soil Proportion	LL	PL	PI
5%L + 5% FA	127	85.7	41.3
5%L + 10% FA	115.3	84.9	30.4
5%L + 15% FA	101.6	82.1	19.5
5%L + 20% FA	99.9	75.7	24.2
5%L + 25% FA	95	62.9	32.1

3.4 Swelling treatment in Lead

After the addition of Lime and Fly Ash, FSI with lead is found to be decreasing for the increment of Fly Ash till the addition of 15% Fly Ash and 5% Lime which is shown in Figure 2. The percentage reduction in the FSI with three concentration (Max, Avg, and Min) of the lead after adding 5% Lime and 5% Fly Ash is 28%, 24%, and 1% respectively. With the addition of 5% more Fly ash, percentage reduction is found to be 52%, 45%, and 35% respectively with three concentrations. Then, the maximum percentage reduction is observed in the 5% Lime and 15% Fly Ash Mixture which is 61%, 61%, and 53% respectively with three concentrations of lead.

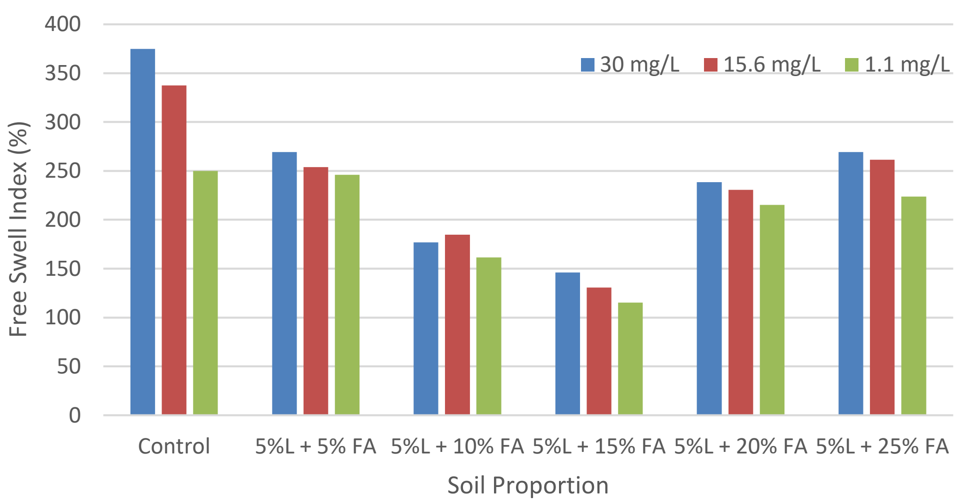

Fig. 2 Variation of FSI with three concentrations of Lead after treatment

Table 4.8 presents the variation of the Plasticity index obtained with all the five soil mixtures in the presence of lead. Lesser the plasticity index, the lesser will be the swelling of soil. Thus, it can be justified that 5% Lime and 15% Fly Ash soil mixture is subjected to lesser swelling because of their lesser plasticity index than other soil mixtures.

3.5 Swelling treatment in Zinc

FSI with Zinc is found to be decreasing for the increment of Fly Ash till the addition of 15% Fly Ash and 5% Lime which is shown in Figure 3. The percentage reduction in the FSI with three concentration (Max, Avg, and Min) of zinc after adding 5% Lime and 5% Fly Ash is 6%, 1%, and

2% respectively. With the addition of more 5% Fly ash, percentage reduction is found to be 24%, 20%, and 9% respectively with three concentrations.

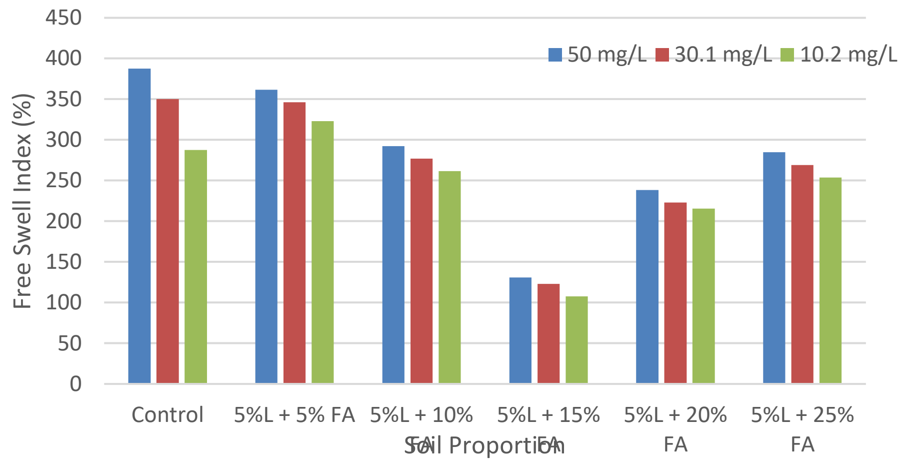

Fig. 3 Variation of FSI with three concentrations of Zinc after treatment

But the minimum swelling is observed in the 5% Lime and 15% Fly Ash Mixture which is 66%, 64%, and 62% respectively with three concentrations of zinc. Table 4.6 presents the variation of the Plasticity index obtained with all the five soil mixtures in the presence of zinc. Lesser the plasticity index, the lesser will be the swelling of soil. Thus, it can be justified that 5% Lime and 15% Fly Ash soil mixture is subjected to lesser swelling because of their lesser plasticity index than other soil mixtures.

3.6 Swelling treatment in Iron

After the addition of Lime and Fly Ash, FSI with iron is found to be decreasing for the increment of Fly Ash till the addition of 15% Fly Ash and 5% Lime which is shown in Figure 4. The percentage reduction in the FSI with three concentration (Max, Avg, and Min) of iron after adding 5% Lime and 5% Fly Ash is 25%, 13%, and 8% respectively. With the addition of 5% more Fly ash, percentage reduction is found to be 32%, 20%, and 1% respectively with three concentrations.

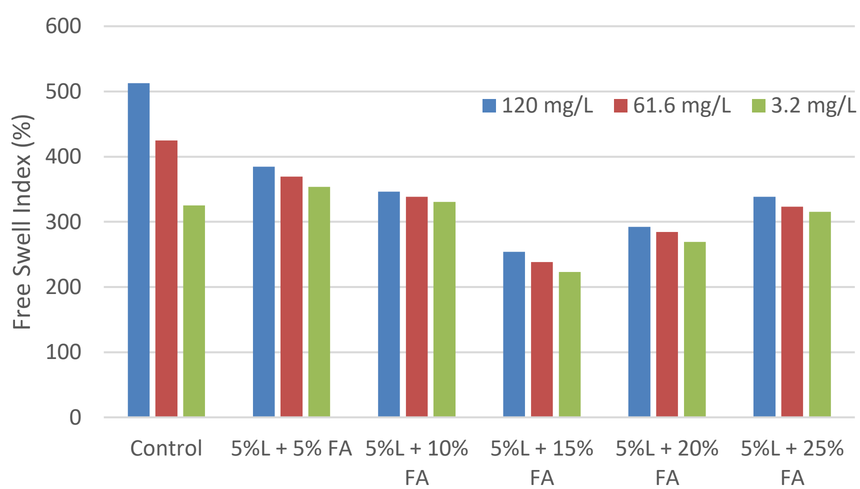

Fig. 4 Variation of FSI with three concentrations of Iron after treatment

Then, the maximum percentage reduction is observed in the 5% Lime and 15% Fly Ash Mixture which is 50%, 43%, and 31% respectively with three concentrations of Iron. Table 4.5 presents the variation of the Plasticity index obtained with all the five soil mixtures in the presence of iron. Lesser the plasticity index, the lesser will be the swelling of soil. Thus, it can be justified that 5% Lime and 15% Fly Ash soil mixture is subjected to lesser swelling because of their lesser plasticity index than other soil mixtures.

4. CONCLUSIONS

The conclusions drawn from the present study are listed below:

- From the experimental results of the Free Swell Index test, ES1 is found to be highly swelling and the order of Soil Expansivity is as follows: ES2<VS2<VS1<ES1.
- By analyzing with the most concentrated heavy metal wastewater till minimum concentrated heavy metal wastewater, changes in their swelling nature are observed. The changes are negligible with minimum concentration and found to be increasing with the average and maximum concentration of heavy metals.
- In ES1, the increase in the swell index is 5.68, 4.5, and 4% with Cr, Fe, Zn, Cu, and Pb respectively. In ES2, the increase in the swell index is 14% with Fe and Zn. In VS1, the increase in the swell index is 1, and 0.3% with Zn, and Pb respectively. In VS2, the increase in the swell index is 1% with Zn, and Pb respectively.
- From the experimental results of the Free Swell Index test, it can be concluded that ES1 is susceptible to an increase in swelling unanimously with the three heavy metals which becomes a negative effect in case of swelling in soil. In other soils, changes in the swell index are minimum or nil.
- The mixture of Lime and Fly ash is found suitable and sustainable material for the treatment of swelling in expansive soil as well as site soil. The complete swelling was inhibited in the site soil while adding 5% Lime and 5% fly ash which may be due to the presence of Illite clay mineral.
- Percentage decrease in the swelling of expansive soil is 50, 66, and 61 with Chromium, Iron, Zinc, and Lead respectively while adding 5% Lime and 15% fly ash which is showing maximum treatment efficiency than other soil mixtures.
- From the results of the Free Swell Index, it can be suggested that treatment efficiency i.e., the percentage reduction of swelling is more in the maximum concentration of heavy metals than average and minimum concentration of Heavy metals. Thus, it can be stated that treatment efficiency increases with an increase in the concentration of heavy metals solutions (i.e. synthetic wastewater).
- Thus, it can be concluded from the results of the Free Swell Index and Plasticity Index, that the optimum percentage of adding Lime and Fly ash for reducing the swelling of expansive soil is identified as 5% and 15% respectively.

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Theme B

Landfills and Slurry Ponds

Efficacy Assessment of Amended Laterite Soil as a Subsurface Liner to Attenuate Migration of Contaminants in Leachate of Ash Pond Structures

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ABSTRACT

Coal-based Thermal Power Plants (TPP) have been a prime source of generation of power in India for the last several decades. Almost 65% of the total electricity generated in India comes from TPP, and 85% of all the TPPs use coal as their fuel. Indian coal being low grade, have an ash content of about 40-45%, which is quite high in comparison to imported coals (10 -15 %). Thus, a large amount of ash is being produced daily, which not only is one of the significant environmental threats to air, water & soil but also requires large areas of land for its disposal. The fly ash produced, are disposed of in the form of slurry in ash ponds. There has been a noteworthy increase in the utilization of fly ash over the last few years, in road sub-base, construction materials, building engineering, backfilling, and agriculture. However, the disposal of fly ash remains a concern for TPP in India. The various heavy metals (Cd, Zn, Ni) present in the leachate tend to contaminate the sub-surface soil and groundwater and, consequently, increase the toxicity of the surrounding ecosystem.

The present study was undertaken to ascertain the efficacy of locally available Lateritic soil (LS) amended with commercially procured Bentonite (B) & Fly Ash (FA) as liner material in the Ash Pond structure. Due to high permeability, in order of ~10^{-5} cm/s and moderate shear strength, lateritic soil was amended with commercially procured Bentonite and Fly Ash in selected proportion i.e., 8 (LS): 1 (B): 1 (FA) to ascertain its contaminants attenuating potential for using as a liner material in ash pond structure to restrict sub-surface migration of heavy metals present in the leachate of ash ponds. It was observed that in the amended soil, plasticity, hydraulic conductivity, swelling and shrinkage properties decrease, and the shear strength and dry unit weight increases with the increase in fly ash content. Batch adsorption test results exhibit metal removal efficiency of the amended soil around 96%, 98%, 97% in the case of Cadmium, Nickel, and Zinc, respectively. In this study, the Linear, Langmuir, Freundlich, and Temkin isotherms were tested for analyzing the equilibrium data. Langmuir proved to be the best-fit isotherm for Cadmium with a regression coefficient (R2) value of 0.9739, while for Nickel and Zinc, it follows Temkin isotherm with R2 values of 0.981 and 0.9759 respectively. The fixed-bed column experiment results also exhibit excellent heavy metal adsorption potential of amended laterite soil. The breakthrough curves (BTCs) predicted by using the HYDRUS 1D finite-difference solute transport software package corroborates well with experimental results with regression coefficients from 0.98 to 0.99. The design life of liner made with amended laterite soil increased significantly in comparison with the non-amended laterite soil for the same liner thickness. Therefore, amended lateritic soil can be considered as a promising adsorbent for the arrest of heavy metal pollutants present in the leachate of ash ponds as well as an excellent candidate for primary liner material in waste containment structures to restrict the migration of pollutants to the aquifer and thereby protecting the precious groundwater from contamination.

Keywords: Thermal Power Plant; Ash Pond; Heavy Metal; Groundwater Pollution; Amended Laterite Soil; Liner Material; HYDRUS-1D

1. INTRODUCTION

In India, Coal based thermal power plant has been a chief source of generation of power where 75% of the total power obtained is from coal-based thermal power plants. Generally, in India, the ash content in the coal used for power generation is in the range of 30–40% resulting in the generation of a large quantity of fly ash. The fly ash produced from Power Plant is mostly disposed of in the form of slurry in ash pond. To provide continuous disposal of a huge quantity of coal fly ash of around 112 million tons, a considerable area of land about 65000 acres has been occupied by ash ponds (Pu and Fox, 2016). Though there has been a significant increase in the utilization of fly ash from 6.6 million-ton in 1996-97 to 102.5 million-ton in 2014-15, in road sub-base, construction materials, building engineering, backfilling, agriculture, etc. (Udoeyo et al. 2010), disposal of fly ash remains a concern for thermal power plants. The trace elements of heavy metals such as Cd, Zn, Ni, etc. present in the fly ash migrate below sub-surface media and be a potential environmental threat (Prasad 2008, Pu 2016). The physical and chemical properties of fly ash primarily depend on the type and fineness of coal, the percentage of ash in coal, the combustion technique, etc.

Earlier researchers had carried out a study on geotechnical properties of lateritic soil-bentonite mixtures for their suitability as liner material in engineering landfills. Expectedly, soil mixtures developed higher Atterberg limits as well as shrinkage potential but exhibited lower hydraulic conductivities and reduced strength with higher bentonite contents.

This has encouraged the authors to ascertain the efficacies of low cost and moderate permeable locally available laterite soil (LS) mixed with Bentonite (B) & Class-“C” fly ash (FA), in selected proportion as a composite liner material for impeding migration of trace elements present in ash pond leachate into the surrounding through the adsorptive mechanism (Dhadse et al. 2008) thereby to assuage risk of health hazards.

It was also observed that in a bentonite-fly ash mixture the plasticity, hydraulic conductivity, swelling, and shrinkage properties decrease, and the dry unit weight and shear strength increase with the increase in fly ash content (Kumar 2004). As per EU directives, for landfills liner, the hydraulic permeability k should be $\leq 10^{-7}$cm/s for hazardous waste and thickness of at least 5 m, whereas for non-hazardous waste permeability remains the same and thickness$\geq$1m. However, in the case of inert waste hydraulic permeability k$\leq 10^{-5}$cm/s and thickness of at least 1m.

Experimental results were also compared with standard adsorption isotherms and the concentration pattern of heavy metals leaching using HYDRUS-1D numerical solute transport modelling of leachate migration in subsurface soil media was also performed to establish good fitting with excremental results.

2. MATERIALS & METHODS

2.1 Laterite Soil

Locally available laterite soil was collected from a borrow pit Kamalpur, Durgapur, West Bengal, India. The basic properties of Laterite soil are given in Table 1.

Table 1 Basic Properties of Laterite Soil

Properties	Value
Specific Gravity	2.6
% sand	49
% silt	39
% clay	12
Liquid limit (%)	42
Plastic limit (%)	22
Max. dry unit wt (gm/cc)	1.85
Optimum Moisture Content (%)	14
Permeability (cm/s)	3.74×10^{-5}
Cohesion(kN/m2)	48
Angle of Internal friction(deg.)	26

2.2 Fly Ash

The chief source of collection of ash samples was done from three different ash pond sites located in and around the industrial city of Durgapur, West Bengal, India. The basic properties of Fly ash collected are given in Table 2.

Table 2 Basic Properties of Fly Ash

Properties	Value
Specific Gravity	1.9-2.3
% sand	6
% silt + clay	94
Max. dry unit wt. (gm/cc)	1.29
Optimum Moisture content (%)	15.4

2.3 Bentonite

The Bentonite used in the study was sodium bentonite procured commercially from the local market. The basic properties of Bentonite are given in Table 3.

Table 3 Basic Properties of Bentonite

Properties	Value
Specific Gravity	2.45
% clay	64
% silt	35
% sand	1
Liquid limit (%)	395
Plastic limit (%)	54

The laterite soil (L), Bentonite (B) & Fly ash (FA) in selected proportions were mixed to check the suitability of the design criteria of liner materials. Laboratory tests like Compaction, falling head permeability, UCC strength was conducted and results are tabulated in Table 4.

Table 4 Geotechnical criteria of Mixed Soil satisfying liner material

% by wt. (L, B & FA)	$\gamma_{d, max}$ (kN/m3)	k (cm/sec)	UCS (kPa)
90 - 5 - 5	17.5	3.2×10^{-6}	227
80 – 5 – 10	17.0	0.9×10^{-7}	219
80 – 10 - 10	16.7	1.3×10^{-8}	208

From the studies, the laterite soil mixed with Bentonite & Fly ash in selected proportion of 80 (LS): 10 (B): 10 (FA) meets the criteria of hydraulic conductivity $<10^{-7}$ cm/s and UCS (>200 kPa) and thereby claims for best liner material under the present circumstances for ascertaining the contaminants attenuating potential in ash pond to restrict sub-surface migration of heavy metals present in the leachate of ash ponds.

Batch absorption tests were performed with synthetically prepared leachate as adsorbate and mixed soil as an adsorbent to examine the heavy metal removal efficiency of the later. Although in ash ponds, the pH heavily varies from highly acidic to highly alkaline conditions, in this present study, the pH of the mixed leachates is maintained in and around 7 as suggested by an earlier researcher (Mohammad 2011). The percentage removal of the heavy metals was calculated using equation (1).

$$\% \text{ removal} = \frac{Co - Ce}{Co} * 100 \tag{1}$$

where C_0 and C_e being the initial and equilibrium concentrations respectively.

The adsorption isotherm experiments were carried out varying the adsorbent dosages and maintaining the fixed values of concentrations of the heavy metals. After the equilibrium is reached, the adsorption capacity value, q_e (mg/gm), is calculated using equation (2).

$$q_e = \frac{(Co - Ce)V}{M * 1000} \tag{2}$$

where V (ml) is the volume of the leachate solution taken for each of the batch setups and M (grams) is the mass of the adsorbent used. Linear, Langmuir, Freundlich and Temkin isotherm models were used to derive the isotherm constants.

Numerical Models have been prepared using HYDRUS-1D simulating both the water flow and the standard solute transport modules together. The Column study experiments have been conducted using different combinations of input parameters and initial and boundary conditions to validate the experimental results.

3. RESULTS AND DISCUSSION

3.1 Acid Digestion Test

Table 5 Acid Digestion test results

Sample No.	Cadmium		Nickel		Zinc	
	mg/l or ppm	mg/kg	mg/l or ppm	mg/kg	mg/l or ppm	mg/kg
1A	0.267	17.8	0.098	9.533	0.024	10.6
1B	0.266	17.733	0.153	10.2	0.156	10.4
2A	0.148	9.867	0.202	13.467	-	-
2B	0.132	8.8	0.037	12.467	-	-
3A	0.127	8.467	-	-	-	-
3B	0.167	11.133	-	-	-	-
4A	**0.370**	**24.667**	**0.332**	**22.133**	0.198	13.6
4B	**0.370**	**24.667**	0.314	20.933	**0.215**	**14.333**
5A	0.259	17.267	0.177	11.8	0.004	0.267
5B	0.261	17.4	0.274	18.267	0.016	1.067
6A	0.141	9.4	-	-	-	-
6B	0.134	8.933	-	-	-	-

The concentrations of the Cadmium were observed to be in the range of 0.127 - 0.37 ppm. In the case of Nickel, it was found to be lying between 0.037 - 0.332 ppm, while for Zinc, it was observed to be within the range of 0.004 - 0.215 ppm.

3.2 Batch Adsorption Test Results

Within the range of values found from the acid digestion test, four values were chosen as the values of initial concentrations of heavy metals in solution, for the batch adsorption test. For Cadmium, the concentrations chosen were 0.1 ppm, 0.2 ppm, 0.3 ppm, and 0.4 ppm. In the case of Nickel, the concentrations selected were 0.1 ppm, 0.15 ppm, 0.2 ppm, and 0.3 ppm. And for Zinc, the concentrations preferred were 0.05 ppm, 0.1 ppm, 0.15 ppm, and 0.2 ppm.

The equilibrium concentration values showed a steady decline in the concentrations of the heavy metals in the solution, thus indicating the strong absorption property of the amended soil. It is seen that in almost all the cases the equilibrium concentrations are the same for 16 and 24 hours. The heavy metal removal efficiency of the mixed soil was observed at 96%,98% and 97% for Cadmium, Nickel, and Zinc respectively, as shown in Fig. 1.

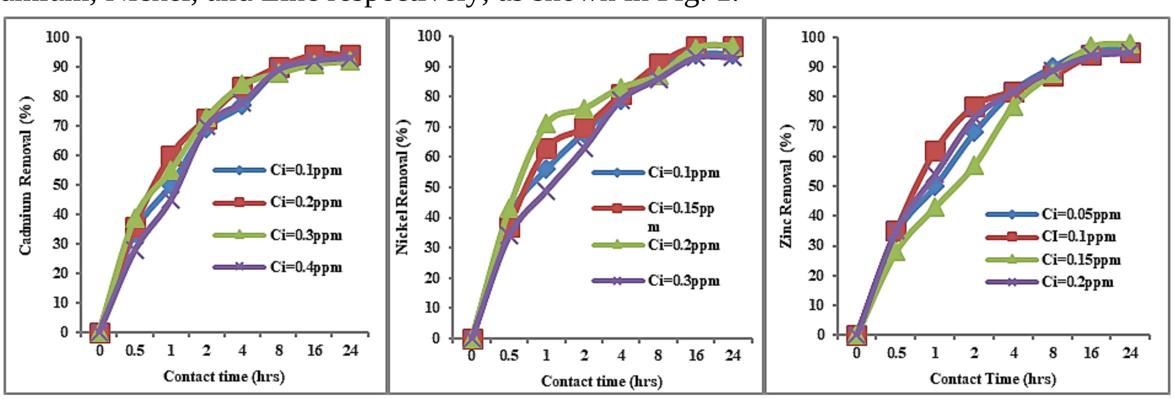

Fig. 1 Heavy metal removal efficiency

3.3 Isotherms

For mixed amended Soil, the equilibrium concentration and the Adsorption capacity values of the 16^{th} hour are taken to plot the Adsorption isotherms, viz. Linear, Langmuir, Freundlich, Temkin, it is seen that for Cadmium, the best fitting Adsorption isotherm is Langmuir and for Nickel and Zinc it is Temkin as shown in Fig 2(a), 2(b) and 2(c) respectively.

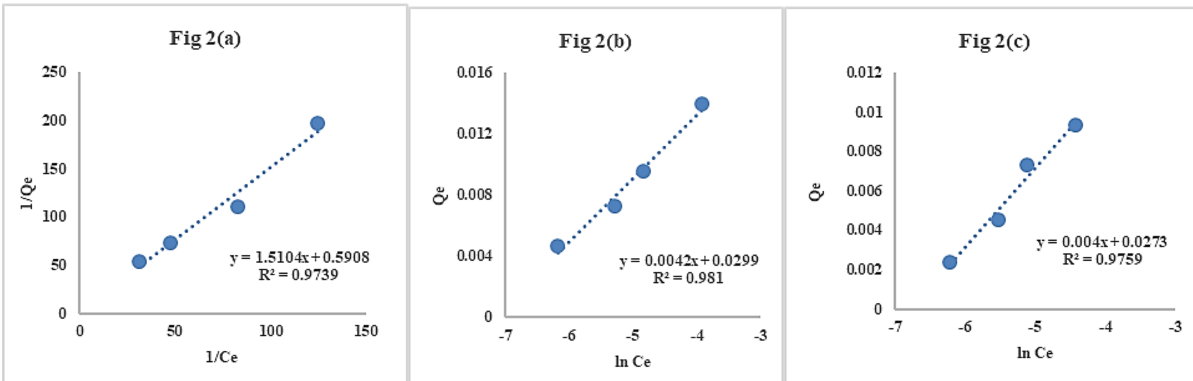

Fig. 2 Isotherm plots for Cadmium, Nickel, and Zinc

3.4 Vertical Column Test Results and HYDRUS-1D modelling

The column test experiments were conducted with mixed soil and the setup was simulated in HYDRUS-1D to validate the results. The experimental result almost matches with HYDRUS-1D simulated results as depicted in Fig 3(a), 3(b) and 3(c) respectively for Cadmium, Nickel and Zinc.

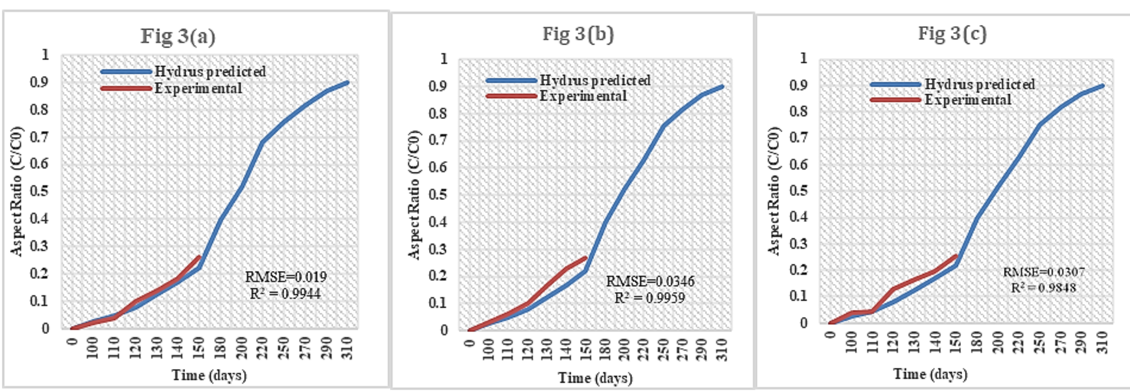

Fig. 3 Vertical Column test and HYDRUS-1D predicted results

Through numerical modeling performed using HYDRUS-1D solute transport software, it is seen that the Amended soil is very effective in terms of permeability & adsorption capacity. It is seen that the useful life of the liner is huge in number of days. Thus, the amended soil as liner material for ash pond structure will prove to be a good choice.

4. CONCLUSIONS

The addition of Bentonite and Fly ash in selected proportion has resulted in the reduction in hydraulic conductivity of soil from 10^{-6} to 10^{-8} cm/sec desired for the liner materials. Based on the experimental & numerical modeling results, it is concluded that

- The mixed soil holds the good potential to be considered as liner material in the ash ponds due to its reasonably higher metal adsorption capacity and very low hydraulic conductivity.

- The experimental results show that metal removal efficiency of the mixed soil is around 96%, 98% and 97% for Cadmium, Nickel and Zinc. Moreover, studies on amended soil show that Langmuir isotherm is the best fitting for Cadmium while Temkin isotherm is the best fitting for Nickel and Zinc.
- Numerical modeling using HYDRUS-1D finite-difference solute transport software shows the amended soil is an excellent choice of liner material.

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Challenges of Eco-friendly Solid Waste Disposal in Ethiopia: The Case of Hawassa Industrial Park

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ABSTRACT
Several Eco-Industrial Parks (EIPs) in Ethiopia dispose of their untreated sludge in open landfills in an unsustainable manner, which later exacerbates public health and pollution to the geoenvironment. The Hawassa Industrial Park (HIP) is among such Textile Eco-industries and has equipped with a Zero Liquid Discharge (ZLD) system with the capacity of treating 11MLD industrial wastewater. The ZLD system then generates a substantial amount of industrial sludge, which later disposed of without any treatment on the nearby municipal landfill site. The leachate from the landfill flows into the adjacent freshwater body crossing a significant size of agricultural land and residential area, posing health and environmental concerns. Besides, there is a lack of comprehensive study which assesses the degree of contamination resulted from the landfill at any specific in the study area. Thus, grab samples of river water, leachate and soil were collected and analyzed for selected physicochemical parameters and heavy metals to investigate the barriers for eco-friendly industrial waste management approaches in Ethiopia, with particular emphasis on HIP. The results revealed a significant contribution of the landfill site in polluting surface and subsurface water as well as the soil.

Moreover, several barriers to sustainable industrial waste management and containment were identified and later confirmed via the laboratory analysis. It was noted that most of the measured parameters have shown that the refuses from the Eco-Industrial Parks (EIPs) were not environmentally friendly. Therefore, the EIPs in Ethiopia have to follow waste reduction, reuse strictly, and recycle (3R's) approaches as a particular way of managing their industrial sludge before the waste containment.

Keywords: Eco-Industrial Parks; ZLD; MLD

1. INTRODUCTION

1.1 Background

The world's ever-increasing population and the progressive espousal of an industrial-based lifestyle have inevitably led to an increased anthropogenic impact on the geoenvironment (Jahagirdar et al. 2013). The rampant growth in population and industrialization has resulted in the generation of a vast quantity of liquid and solid waste in most of the developing countries, including Ethiopia (Adipah and Kwame 2019, Ferronato 2019, Gebre and Debelie 2018).

As one of the prominent industries in the world, the Textile sector provides job opportunities for unskilled employees and plays a significant role in the economic development of many countries, especially in developing countries (Gebremedhin 2018). Currently, the industry is at its peak growth, both in number and type, throughout the world because of different reasons like population growth, the preference for different types of fabrics within the fashion industry, and demand for better fabric quality and look. In this regard, the sector is a source of many human and environmental problems, especially in emerging economies, due to the large quantity waste generation and the consequent poor industrial waste management practices.

So far, most waste management approaches relate to the "cradle-to-grave" concept, which demands high capital, high running costs and is seen by industries as a barrier for further industrial development. Most importantly, disposals of industrial waste deplete natural resources affecting their sustainability (Omar and El-Haggar 2017).

Often industries, especially in the textile and garment sector, get clustered in huge Eco-industrial parks (EIPs), comprising common effluent treatment plants (CETP) to enhance the poor management of industrial wastes. The EIPs can contribute to the reduction, reuse, and recycling (3R's) of the industrial wastes in a sustainable manner. In general, the EIPs aim at achieving sustainable production and consumption patterns by minimizing natural resource consumption and waste generation while still satisfying economic demands. Thus, EIPs are sound ways to overcome environmental impairment and to promote more sustainable and friendly development (Oke 2018).

1.2 Eco-Industrial Parks and Sludge Management Practices in Ethiopia

Ethiopia is witnessing rapid economic growth and social development, aiming at lifting the country towards a middle-income economy by 2025 through its ambitious Growth and Transformation plans (GTP I & II). To this effect, every sector pursues its targets to the fulfillment of the developmental program, since the vision is of national interest. So far, industrial promotion is preferred as a priority economic sector by the government, for it plays a significant contribution to the country's overall socio-economic development and attracts foreign investments (Tafesse et al. 2015).

To make this potential the most effective, the Ethiopian Industrial Parks Development Corporation (IPDC) is becoming an engine of rapid industrialization that nurtures manufacturing industries. The IPDC has made a strategic plan (2015 - 2019) to build 14 of such competitive EIPs throughout the country to attract investors (Delelegn 2018). For this reason, the Ethiopian textile and apparel industries are growing fast supported by cheap, trained, and much-inspired skilled-force.

Several industries in Ethiopia manage their untreated sludge in an unsustainable manner, which later exacerbates pollution (Vaverková et al. 2018). Moreover, the typical way of avoiding sludge is landfilling, whereas finding land for sludge dumping is another problem for industries (Gebremedhin 2018).

The current dumpsite is an abandoned scoria quarry site without any liners, covers, protections, and landfill management facilities. It is in proximity to residential houses, government, and private industries and one private college. The Shalo river and the Chelеleka wetland system in the vicinity of the landfill site are highly vulnerable to leachate contamination from the dumpsite.

This study aims at investigating the practice of existing industrial waste management approaches in Ethiopia with particular emphasis on Hawassa Industrial Park. Besides, the study assessed the significant barriers for eco-friendly industrial waste containment on the existing landfill site through the determination of selected physicochemical parameters and heavy metals in the leachate, soil, and surface water samples.

2. METHODOLOGY

Grab samples of landfill leachate, stream water, and soil were collected and further analyzed using standard procedures. The results from the laboratory analysis recorded and compared with existing national and international standards. The syntheses information would be used for evaluating the level of pollution status of the Hawassa city.

Interviews were performed during the filed visit session. Purposely designated key informants from Hawassa city administration environmental protection and forest development office, private waste companies, and informal waste collectors, City beautification and greening organizations, Kebele administrative bodies and communities residing around waste disposal area, were asked about the waste collection, transport, disposal mechanisms, and associated health and environmental impacts.

The results were further discussed and compared with an existing environmental compliance audit report of the Federal Environmental Protection Authority (FEPA) that is used for evaluating the sustainability of the current trend of industrial waste management in the Country.

3. RESULTS AND DISCUSSION

3.1 Results from Experimental Analysis

The laboratory test results of the measured parameters were presented in Table 1 to Table 6 of the following sections.

3.1.1 Leachate characterization. The leachate characteristics, as shown in Table 1 and Table 2, indicated that leachate samples contain high levels of organic and inorganic constituents beyond the permissible limits.

Table 1 Physico-chemical characteristics of Hawassa MSW Landfill Leachate sample

Parameters[a]	Leachate Conc.	Standards[b]		
		Inland SW*	Public sewers	Land disposal
pH	7.76	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
EC (µS/Cm)	2902.96	1000		
TDS	3230.22	2100	2100	2100
Turbidity (NTU)	16.47	5	10	10
Hardness	20000	300		
BOD_5	1853.81	30		
COD	6700.88	250		
BOD_5/COD	0.28			
DO	0.85			
Chloride (Cl^-)	902.99	600		
Sulphate (SO_4^{2-})	283.33	200	350	100
Nitrate (NO_3^-)	33.49	10		
Phosphate (PO_4^{3-})	30.8	50	1000	100

[an] All values are in mg/Kg.
[b] Municipal Solid Wastes (Management and Handling) Rules, 2000
SW river water sample*

The BOD/COD ratio (0.28) of the leachate is below 0.3, indicating the presence of some toxic components. In general, the ratio describes the degree of biodegradation and gives information on the age of a landfill. Lower values show a high concentration of non-biodegradable organic compounds, and thus the difficulty of being biologically degraded. Most of the heavy metal values were in trace amount except for Mn (111.895 mg/Kg), Fe (51.895 mg/Kg), Zn (5.55 mg/Kg), and Cu (4.182 mg/Kg), as the waste is of domestic origin (Table 2). The exceptional high might come from the new industrial activities in the area. In general, the concentration of heavy metals in landfill leachate is reasonably low. Heavy metal concentrations in a landfill would generally be higher at earlier stages because of higher metal solubility as a result of low pH caused by the production of organic acids.

Table 2 Heavy metal concentrations in Leachate samples

Parameters[a]	Metals Conc.	Standards[b]
Mn	111.895	1
Fe	51.844	5
Zn	5.155	0.25
Cu	4.182	1
Pb	0.712	0.1
Hg	0.159	1
Cd	< 0.0475	0.01
As	< 0.0014	0.001
Co	< 0.001	0.2
Ni	< 0.0006	1
Cr	< 0.0004	

[an] *All values in mg/Kg*

[b] *Municipal Solid Wastes (Management and Handling) Rules, 2000*

3.1.2 Soil Characterization. The heavy metals concentrations in the soil samples were shown in Table 3. The level of heavy metals in the soil sample is insignificant. This may relate to the age of the landfill. The higher pH values (both in leachate and soil), and the BOD/COD ratio revealed might indicate that the dumpsite was very old. Thus, most of the soluble metals could be washed out and transported into either the groundwater or to the nearby receiving inland water bodies.

Table 3 Heavy metal concentrations in Soil samples

Parameters[a]	Metals Conc.	Standards[b]
Cd	0.04	0.01
Cu	0.07	1
Co	0.06	0.2
Fe	1.45	5
Mn	9.78	1
Zn	0.53	0.25
Pb	0.10	0.1
Ni	0.18	1

[a] *All values in µg/l*

[b] *Municipal Solid Wastes (Management and Handling) Rules, 2000*

Moreover, since the area was an agricultural site for a generation and still is a productive farming land for the majority of livelihood, the heavy metals might be assimilated and later bioaccumulated on the plant tissues.

3.1.3 Surface water Characterization. The surface water physicochemical and metal analysis results are shown in Table 4 and Table 5. Accordingly, the river water sample showed values higher than the standards for some parameters such as pH (9.2), Turbidity (67.8NTU), EC (3120.77 mg/L); TDS (2307.14 mg/L), BOD5 (123.71 mg/L), and COD (294.45 mg/L), as shown in Table 4. The higher values are attributed to the organic loads from the nearby landfill site, urban runoff, and agricultural wastes from the catchment. The stream carries this waste and finally disposes of to Lake Hawassa, thereby polluting the lake water.

Table 4 Physico-chemical characteristics of the Sahllo river water samples

Parameters[a]	Concentration	Standards[b]
pH	9.2	6,5-8.5
Temperature (°C)	25.20	40
Turbidity (NTU)	67.80	5
EC (µS/Cm)	3120.77	1000
TDS	2307.14	<500
Hardness	1.15	
BOD_5	123.71	30
COD	294.45	250
DO	2.60	
Chloride (Cl^-)	135.77	600
Sulphate (SO_4^{2-})	12.2	200
Phosphate (PO_4^{3-})	2.68	250

[a] *All values in mg/L except pH, Temperature, EC, and Turbidity.*
[b] *WHO 2000*

Table 5 Heavy metals concentration of Sahllo river water samples

Parameters[a]	Metals Conc.	Standards[b]
Fe	9.81	1
Mn	20.37	5.00
As	0.04	0.25
Cd	0.03	1
Cr	0.83	0.1
Co	0.20	1
Cu	0.12	2.00
Pb	0.64	0.01
Zn	5.19	3.00
Hg	<0.001	0.001
Ni	1.02	0.20
Ag	0.04	1

[a]*All values in mg/l;* [b] *WHO, 2000*

In contrary to the Leachate, the heavy metal concentration in the surface water sample, as presented in Table 5, revealed higher levels for Fe (9.81 mg/Kg), Mn (20.37 mg/Kg), Cr (0.83

mg/Kg), Pb (0.64 mg/Kg), Zn (5.19 mg/Kg), and Ni (1.02 mg/Kg) than the standard values. The high vales are, maybe, because of the higher loadings rates from industrial effluents, medical liquid wastes, garages wastes, etc. that add to the Leachate pollution. The toxic metals might endanger the entire aquatic life both at the river and the lake.

Moreover, the assimilated heavy metals may also be bioaccumulated into the human and animal bodies through the food chain. The high doses of Mn and Fe detected in river water might be due to the leachate of heavy metal contamination from MSW.

3.2 Recap from the Field Observation and Key Informant Interviews

The findings of the study revealed that the current SWM practices in the country are ineffective and inefficient. Notably, the case is evident in the Textile and Leather industries. Several barriers to industrial waste management and containment were identified and later confirmed via the FGD discussions. The physicochemical analysis results have also evidenced the above claims.

The major contributors to the existing ineffective and inefficient SWM system in the City are insufficient collection coverage, improper containment, conveyance and disposal, limited budget allocation, absence of standards for licensing private service providers, weak capacity of the municipality to enforce by-laws and create awareness to the community.

From the observations at the HIP, the daily sludge generation rate was identified as 500kg/day. However, the park is operating at its minimal capacity. This amount may rise by many folds when it starts working at its full scale. Such a considerable amount of resources need not end up at the hazardous waste landfill sites. Sustainable recycle options need to be considered on these residues. The high pollution load appearing in the wastewater needs to be managed adequately before causing significant environmental hazards. Therefore, attempts should be made to improve the primary and secondary treatment stages and to reduce sludge production from clarifiers.

This study also addressed an alternative method of management, and utilization of sludge for different uses has to founded on the '3R's of sustainability.

4. CONCLUSIONS AND RECOMMENDATIONS

During the field visit and key FGDs, it was noted that most of the measured physical parameters have revealed that the refuses from the Eco-Industrial Parks (EIPs) were not environmentally friendly. They dispose of hazardous and poorly managed industrial sludge to the surrounding community, thereby polluting water bodies and soil. Moreover, the laboratory analysis has revealed a similar concentration increase in some of the physicochemical parameters and heavy metal levels in the study area.

The crucial advantage of the concept of zero liquid discharge facilities lies in potential water recycle, which ensures the process of the water supply of nearly constant characteristics. One of the major concerns for zero liquid discharge facilities is the management of hazardous solid waste generated from the treatment facility. The sludge discharged from currently evolving Ethiopian industrial parks treatment plants is the exerting practical problem.

In the study area, Hawassa industrial park, a significant quantity of sludge is generated that has a potential of negative impact on public health as well as the environment. Since there is no standard for sludge treatment and disposal in Ethiopia, a stringent standard and guideline should be established as early as possible.

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Height Raising of Iron Ore Tailing Dam over Soft Tailings

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ABSTRACT
Tailing waste management is a great concern in the context of the availability of suitable space for mine owners of India. This is becoming more critical due to stringent environmental laws being enforced on tailing management. Dry disposal and high concentrate slurry disposal (HCSD) systems are gaining momentum. However, the conventional wet disposal method is still viable in view of project cost and ease of operation. Construction time between two successive phases of height-raising is reducing because of the non-availability of space. The normal upstream method of height-raising of a dam in such a situation becomes very difficult since tailings within pond remains unconsolidated and have very poor shear strength. This paper presents a case study on the initial design of height-raising and subsequent modification to suit the changing scenario as well as the construction schedule while maintaining the safety of the designed embankment structure. Various ground improvement techniques were adopted for the rapid consolidation of deposited tailing slurry and strengthening of existing embankment. The design involved the use of geotextiles, prefabricated vertical drains (PVDs), internal drainage blankets, etc. The construction work was planned to be completed before monsoon season so that the effect of additional runoff water that could destabilize the slope safety could be mitigated. However, the rapid construction work caused few local failures and uneven settlements in the embankment, especially near the site of the decantation tower. The designed slope profile was rechecked, and counter-berm was provided to stabilize the toe. With these additional stabilizing elements, the embankment construction was found to be stable. Construction of the tailings dam was thereafter executed successfully.

Keywords: Upstream Raising; Limit Equilibrium Method; PVD; Geotextile

1. INTRODUCTION

The management of tailings generated from mining activity and safe storage is the need of the hour for most mine owners of India. The challenges are mostly related to the adaptation of new technology in an old operating plant to make the operation compliant to stringent environmental policy. Tailings are conventionally transported from ore processing units to disposal sites in slurry form to facilitate pumping. However, the high-water content poses disadvantages in respect of both increased volumes to be handled and longer time required for the slurry to dry out before it can be handled for further use. High concentration slurry disposal (HCSD) technology has been developed to alleviate these problems. The up-gradation from wet disposal to dry disposal for an existing tailing dam would take time during which period adequate space will be required for the sustainability of the plant operation. Therefore, a feasibility study for height-raising was carried out for the tailing dam which got filled during its service period up to the designed height. Height raising of tailing dam is done by downstream raising method when space beyond the original dam section is available and shear strength of deposited material is uncertain or by upstream raising method where land is restricted, and the deposit has gained adequate shear strength. The study for this project case revealed that the tailings were still undergoing a natural consolidation process, but no space was available for down-stream construction. The only option left was to go for height-raising by the upstream method of construction. The engineering challenge was to make raising feasible through the use of advanced geosynthetic products with detailed analysis. The construction issues were also addressed in the design with continuous site feedback and redesigning during the execution stage. The sustainability of plant operation was enhanced due to the proposed engineering solution for an abandoned tailing dam.

2. SITE LOCATION & GEOLOGICAL RECONNAISSANCE

The earthen dam for the initial tailing pond was constructed in a valley in between two hills in one stage construction. The height of the dam at northside valley from the lowest point was about 34m and the height at south side valley was 19m. Thereafter, dam height was raised once for 8m all around by upstream method of construction. There was no space within mine lease area further beyond the toe on both valley sides. The system for recovery of clear water with decantation tower was on the north side which was connected to the existing tank and water flow through the pipeline to plant pumping station was by gravity. The slurry discharge was done sequentially from the south side and east-west hillside so that water accumulation was achieved at the north side decant tower.

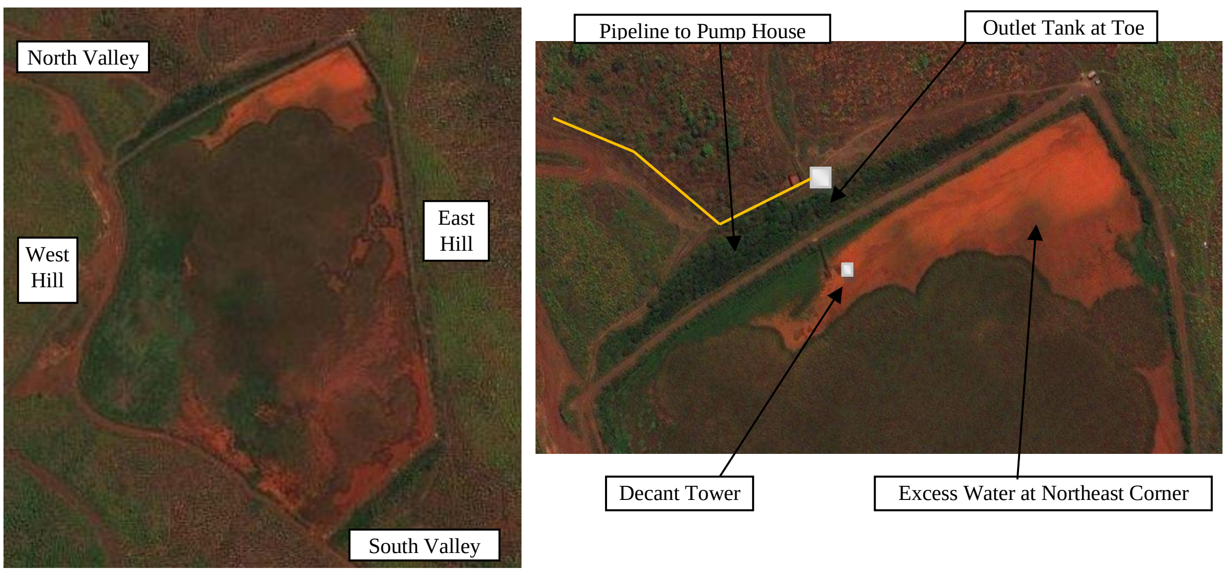

Fig. 1 Bing Image of Tailing Pond showing Existing Condition before Height Raising

The plant owner did not have space for further tailing disposal and the continuation of mining operation was in jeopardy. Hence the owner was investigating the feasibility of increasing the pond volume by raising the dam height. This could be made feasible only by the “upstream method” since in most of the areas around the periphery of the pond, the required space in downstream direction was not available. The existing dam had been constructed in the year 1999-2000 and the drawings for the original design were made available by the owner. However, the first height-raising drawings were not available and as such a need for geotechnical investigation was essential to establish the condition of the dam.

3. SITE STRATIFICATION & GEOTECHNICAL CHARACTERIZATION

The existing pond was operated and filled up to the freeboard and left to sun-dry for an approximate period of 3 months. Thereafter, a detailed geotechnical investigation program was planned out in the year 2015 (February & March) both on existing dam alignment and up-stream side tailing deposits. Altogether, eight (8) boreholes of depth from 11 m up to 19.8m, eight (8) trial pits and sixteen (16) nos. of field permeability tests at different depths were carried out along with laboratory tests. The existing dam material was found to comprise thoroughly compacted heterogeneous fill materials consisting of reddish-brown, lateritic soil mixed with pebbles, gravels, boulder, ferruginous nodules, etc., which were encountered up to the termination depth of boreholes. The bore logs on deposited tailings exhibited consistency of very soft/soft, reddish-brown fine material from a depth of 4.0 to 6.65m below EGL. The proposed dam would rest on this soft slime deposit and the stability design was considered to be critical in terms of bearing capacity and settlement. For calculation of bearing capacity, settlement, design of PVD-Geogrid-Geotextile and slope stability analysis, design parameters of soil for different layers were summarized in Table 1.

Table 1 Geotechnical Properties of Different Materials for Analysis

Material Description	Bulk Weight (kN/m^3)	Cohesion (c) (kN/m^2)	Angle of Internal Friction (ϕ)°
Fresh Tailing Deposit	19	25	3°
Old Tailing Deposit	20	35	5°
Starter Dam (Core)	18	50	30°
Starter Dam (Shell)	22	25	35°
First Raising	18	10	30°
Second Raising	18	20	32°
Dam Foundation (Soil)	22	50	32°
Dam Foundation (Rock)	24	0	45°

4. DESIGN BASIS & DESIGN PHILOSOPHY

Due to the unavailability of undisturbed samples within the tailing deposit, shear strength of the in-situ tailings could not be ascertained at the laboratory. However, considering the SPT N-value and index properties from laboratory tests, the ultimate bearing capacity of slime deposit was estimated at 53.5 kPa which could sustain a maximum 2.4m safe height-raising over it. To fulfill the required operational pond capacity, the proposed dam was required to be raised by a minimum height of 6.0 m. The primary consolidation of the tailings deposit due to the proposed dam was calculated as 838 mm. The secondary consolidation time would go theoretically up to 5.7 years with the proposed dam loading. It was evident from the above that the available bearing capacity of the slime deposit was not adequate for the required height-raising. Due to the low permeability of the fine tailings, a long time would be required for the completion of consolidation settlement. Therefore, it was required to increase the shear strength of the deposit so that it could withstand the new embankment load. At the same time, the drainage property of the deposit also needed to be improved so that the significant settlement of the deposit occurs within a reasonably short period. This, in turn, necessitated the adoption of ground improvement techniques so that the load-bearing capacity of the existing slurry deposit could be enhanced to withstand the superimposed additional loads due to dam height-raising. For design purposes, we consider 90% of the total settlement required to be over within 2 months of construction of dam embankment. Based on the detailed analyses, it was concluded to increase the overall bearing capacity of the deposit by introducing Geo-textiles at multi-levels. In the case of an iron mine tailing pond, primary consolidation is the principal source of settlement. Hence, to improve the drainage, Prefabricated Vertical Drains (PVD) was selected which would accelerate the consolidation of the deposit by initiating three-dimensional drainage. It was aimed to achieve 90% of primary consolidation settlement within one month after completion of the new embankment by suitably designing the PVD of depth 15m and spacing of 1.5m in a triangular grid. Geotextiles were used in two layers to increase overall bearing capacity and to reduce differential settlement. The typical detail of the dam cross-section is presented in Fig. 2.

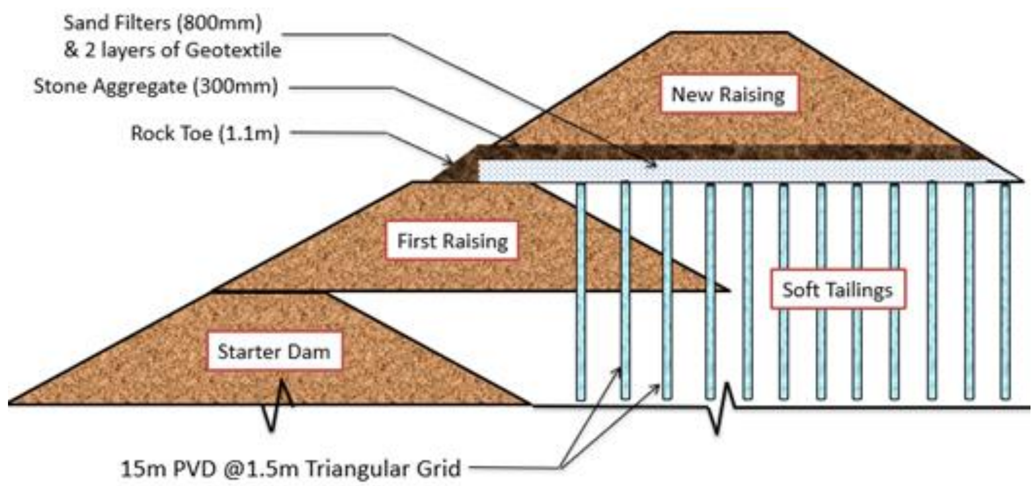

Fig. 2 Typical Detail of Dam over Soft Tailing with PVD, Geo-textile, Filter Drain & Rock Toe

The side slopes of proposed dams were designed with 1(V):2(H) after placement of the drainage layer over PVD. The horizontal blanket drain over PVD was connected to the garland drain through rock toe at the downstream side. The upstream and downstream slopes were analyzed and FOS results were found satisfactory as per IS 7894. Based on the analysis, the detailed construction drawings were developed, and construction methodology was finalized.

5. STABILITY PROBLEM DURING EXECUTION

The soft tailing deposits were unstable for the movement of PVD installation equipment. Therefore, dry tailing excavated within the pond was filled from the freeboard level to the dam top-level existing at that time. The PVDs were installed on the entire area of the tailing deposit except near the existing decant tower due to the presence of rainwater from the pre-monsoon shower. The construction sequence was planned from the south side to the north side so that excess water collected from flow along natural gradient could be pumped out. The height of the decant tower was also required to be raised along with the dam. To facilitate the movement of man & machinery for this construction, gabion wall was constructed near the decant tower approach. This gabion wall would stabilize the existing dam to bear the load of construction equipment and also provide a drainage path for escape of free rainwater through the decant tower.

Fig. 3 Installation of PVD from North Side to Northeast Corner Side after Slime Filling

Fig. 4 Subsidence of Gabion wall at one side of Decant Tower (Top & Bottom View)

The soft tailings with PVD could not sustain the load from the immediate construction of the gabion wall. One side of the gabion wall settled and created local subsidence. The lesson learned from the incident triggered the question on the stability of up-stream toe of the proposed dam, especially along the decant tower stretch. The deposited tailings on this stretch were very soft compared to other areas due to the continuous presence of water from the earlier decantation system. The unexpected pre-monsoon rain also aggravated the situation further and called for the adoption of a necessary precautionary measure. Therefore, redesigning the dam with the provision of counter-berm was planned for this area around decant tower, keeping in mind resources, materials and most importantly the project schedule which had an impact on the plant sustainability.

6. SLOPE STABILITY WITH COUNTER-BERM

Stability analysis of the dam with steady seepage during construction as well as at the end of construction were carried out by established classical limit equilibrium methods with the help of commercial software. A detailed investigation into the incidence of dam subsidence at the location of the gabion wall was carried out involving site visits and further design checks. The apprehension was that the soil strength parameters from the investigation would not hold good for the material at this location. To determine the reason for the failure, the analysis was carried out multiple times with discounted soil strength parameters to simulate potential failure conditions at the critical location. The reduced soil parameters were compared with actual failure patterns and the discounted values were used for further analysis of dam stability. The dam alignment along the waterlogged stretch was entirely redesigned with these reduced parameters. Counter berm of various geometries with different width-length-height parameters was considered along with the proposed dam section and analyzed to evaluate stability factors. The most optimum geometry of counter berm that met the minimum factor of safety criteria was chosen as the design option. The proposed dam section with reduced soil parameters was found to have the required slope stability factors with the addition of counter berm on the upstream side. The design was then discussed with the execution team to schedule these additional activities of counter berm construction within the overall project execution schedule to meet project completion targets. FOS was calculated for different cases like "Steady Seepage" both for Static and Seismic (Pseudo-Static) conditions.

Table 2 Factor of Safety (FOS) of Dam with Counter-berm

Cases	Dam Condition	Up-stream Side	Fellenius Method	Bishop Method	Janbu Method	Spencer Method
Static	Steady Seepage	No Berm	1.18	1.32	1.18	1.30
Seismic	Steady Seepage	No Berm	0.92	1.02	0.86	1.00
Static	Steady Seepage	4m Berm	1.41	1.52	1.41	1.51
Seismic	Steady Seepage	4m Berm	1.06	1.14	1.02	1.13

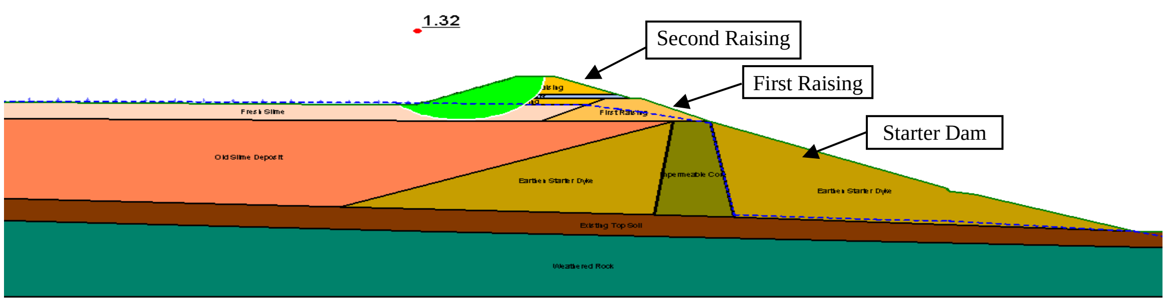

Fig. 5 Up-stream side static FOS with “No Berm” (Bishop Method)

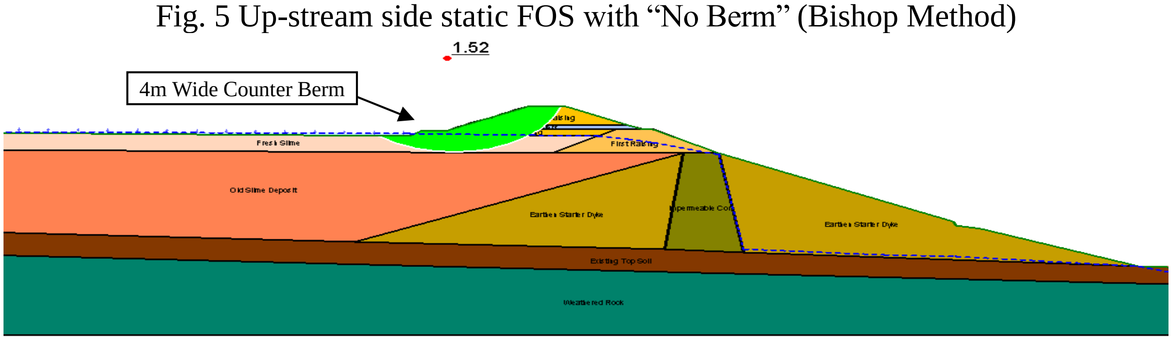

Fig. 6 Up-stream side static FOS with “Counter Berm” (Bishop Method)

7. BUTTRESSING WITH COUNTER-BERM

According to selected optimum design, the counter berm had a width of 4m and depth varying from 1.5m to 2m. The material selected for counter berm construction was the locally available lateritic soil mixed with gravels. The counter berm on the upstream dam side was provided along the northern and partly eastern embankment for a stretch of approximately 400m covering both east and west sides from the location of the decant tower area. This had diverted rainwater away from the new filling allowing it to settle and consolidate quickly with additional loading. This had also enabled ease of movement of PVD installation equipment. PVD installation and further engineering fill work were completed without any further settlement issues on the upstream side of the new embankment. In addition to that, dewatering of the tailings pond of the accumulated rainwater and slurry recovery water at the decant tower location was carried out both by pumping and gravity discharge through the decant tower. This allowed the slurry to dry quickly and gain shear strength in less time ensuring the stability of the dam in the staged construction process.

Fig. 7 Counter-berm of 4m wide on upstream tailing deposits

8. MONITORING

Adequate stability of the earthen dam during operation is ensured by a valid design that considers actual soil properties for obtaining the required factor of safety backed up by careful construction planning and quality monitoring. Monitoring the construction process plays a very vital role in ensuring the work quality which was measured by survey throughout the construction period for assuring adherence of the construction process to the design requirements. To achieve this quality monitoring objective, dam instrumentation was provided in the form of piezometers and settlement gauges along the alignment of the dam. The water level in piezometers and readings from settlement gauges were taken periodically during the operation stage. These instruments were retained for future monitoring of the dam performance to detect seepage and subsidence problems after the operation of the dam and safe closure of pond in the future.

9. CONCLUSIONS

The height-raising was successfully implemented with the application of PVD and geotextiles over the soft tailing deposits that had low shear strength. The problems raised during the construction period were also eliminated with the provision of counter-berm. The approach had opened a new possibility for height-raising without endangering the stability and safety of the tailings dam. Continuous monitoring of the construction to ensure adherence of actual construction to design and verification of design conditions provided the required data to the engineering team to evaluate the effectiveness of the solution. This approach of continuous interaction between the design and construction team paved the way for the successful implementation of the critical project and meeting the desired outcome within the project plan.

Fig. 8 Bird's eye view of tailing dam after one year of slurry discharge

ACKNOWLEDGMENT

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Stability Assessment of Pond-Ash Embankments for Static and Seismic Conditions

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ABSTRACT
From the combustion of pulverized coal, coal ash is generated in large quantities as a by-product in thermal power plants. Recently, due to environmental protection acts and awareness built-up, the use of coal ash in various geotechnical applications, e.g. in road sub-grade making, embankment construction, etc. has increased. Engineering characterization has shown that fly ash has a high void ratio and low cohesion. Hence, an embankment constructed by pond-ash only is susceptible to a low degree of stability which makes the use of pond ash challenging for embankment construction. In this regard, RBI grade 81 is a natural soil-stabilizer for the stabilization of a wide spectrum of soils in an efficient and cost-effectively manner. In the present study, static and seismic stability of two different pond ash embankment slope models has been evaluated without and with stabilizer inclusion at different dosages. The obtained results record an increasing improvement in the stability of both the embankments due to an increase in stabilizer dosage.

Keywords: Pond-Ash Embankment; Soil Stabilizer; Static Stability; Seismic Stability; FoS.

1. INTRODUCTION

From the combustion of pulverized coal, coal ash is generated in large quantities as a by-product in thermal power plants. At present, each year about 112 million metric tons of coal ash is being generated in India among which only 38% is utilized or recycled, while the rest is disposed of in ash ponds. Pond ash is the evaporated slurry of wet disposed fly ash from the boilers mixed with disposed bottom ash. Recently, due to environmental protection acts and awareness built-up, it has become vital to find an effective engineering solution for the disposal of this hazardous by-product (Jakka et al., 2011). The use of coal ash in various geotechnical applications, e.g. in road sub-grade making, embankment construction, etc. has increased in the past few years. Engineering characterization has shown that fly ash has a high void ratio and low cohesion. Hence, an embankment constructed by pond-ash only is susceptible to a low degree of stability which makes the use of pond ash challenging for embankment construction. To improve the engineering properties of pond ash, a natural soil stabilizer such as RBI grade-81 is a popular choice. Once added, the inter-bond of particles improves and correspondingly the stability also improves. In the present study, different proportions of this stabilizer (4% and 8%) have been utilized with the pond ash material collected from a thermal power plant of NTPC located at Ramagundam, Telangana. The engineering characterization (such as specific gravity, grain size analysis, Atterberg limits, modified Proctor test, California Bearing Ratio test, direct shear test, and permeability test) of the untreated pond ash and pond ash treated with stabilizers has been conducted at the laboratory by Reddy et al., 2017. The evaluated test results are listed in Table 1. Once, the properties are determined, static and seismic stability of two different pond ash embankment slope models (Fig. 1) with crest heights of embankments as 4.25 m and 5.0 m have been evaluated by using two-dimensional limit equilibrium and finite element methods without and with stabilizer inclusion at different dosages. The obtained results record an increasing improvement in the stability of both the embankments due to an increase in stabilizer dosage.

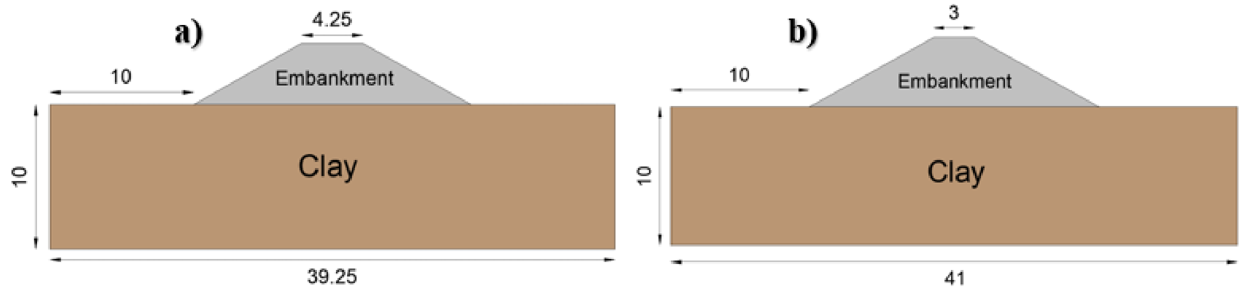

Fig. 1 Cross-sectional view of pond ash embankment slope models with crest heights of (a) 4.25 m and (b) 5.0 m

Table 1 Evaluated properties of pond ash with 0%, 4% and 8% mix of RBI Grade-81

Sr.No.	Property	Pond Ash	Pond Ash + 4% RBI Grade-81	Pond Ash + 8% RBI Grade-81
1	Grain size distribution (%)			
	Gravel	3	2	1
	Sand	87	82	78
	Silt	5	8	11
	Clay	5	7	10
2	Modified Proctor Compaction test			
	a) MDD (kN/m^3)	10.87	11.82	12.6
	b) O.M.C. (%)	32.8	27.8	22.6
3	CBR Value (%)			
	a) Un-soaked	27.45	29.2	36.61
	b) Soaked	8.95	16.51	19.93
4	Angle of Internal Friction (φ)			
	a) At OMC condition	36.86°	38.65°	39.28°
	b) At SMC condition	34.13°	34.65°	34.99°
5	Coefficient of Permeability (cm/sec)	$1x10^{-3}$	$0.86x10^{-3}$	$0.79x10^{-3}$

2. METHODOLOGY

The behavior of pond ash is quite similar to mine tailings in nature, hence in high seismic regions, the design and construction of embankments with ash call for performance evaluation of this kind of earth structures subjected to seismic loading (Havanagi et al 2011, Jakka 2011). The present study includes two-dimensional stability analyses of two different slope profiles of embankments made of pond ash mixed with various dosage percentages of a soil stabilizer, RBI Grade-81. For this, firstly, the engineering and physical properties of collected raw pond-ash samples and pond-ash mixed with RBI Grade-81 stabilizer at different weight proportions of 4% and 8% have been evaluated and reported. It has been observed that a steady improvement in shear strength of the pond-ash occurs with increasing the dosage percentage of the stabilizer. The stability analyses of both the slope profiles have been performed by Limit Equilibrium Method (LEM) as well as by the Finite Element Method (FEM). The factor of safety of the embankments has been calculated through various methods in LEM, such as Fellenius, Bishop, Janbu, Spencer and GLE/Morgenstern – Price. Again, a comparison has been made between the safety factors obtained from both LEM and FEM analyses.

The horizontal seismic coefficient (α_h) and vertical seismic coefficient (α_v) required for pseudo-static analysis were found out by using IS: 1893 (Part 1) 2002. Inertial force in the horizontal direction is computed using equation (1) while inertial force in the vertical direction is computed using equation (2) as shown below:

$$F_h = \frac{Z \times I \times S \times W}{3} \quad (1)$$

$$\alpha_v = \frac{2 \times \alpha_h}{3} \quad (2)$$

Where, Zone factor (Z) = 0.24 for earthquake zone IV, Importance factor (I) = 1.5, Coefficient for ground motion is “S” and weight of sliding mass is “W”. The computed (α_h) and (α_v) are 0.144 and 0.096 respectively.

In structural engineering, the safety factor is usually defined as the ratio of the collapse load to the working load. For soil-structure interaction problems, however, this definition is not always useful. For embankments, most of the loading is caused by soil weights and an increase in soil weight would not necessarily lead to collapse. Hence, a more appropriate definition of the factor of safety is that it is a ratio of maximum shear strength available to the shear strength needed for equilibrium which is conventionally used in soil mechanics. By introducing the standard Coulomb condition, the safety factor (FoS) is obtained as:

$$FoS = \frac{c - \sigma_n \tan\varphi}{c_r - \sigma_n \tan\varphi_r} \quad (3)$$

Where c and φ are the input strength parameters and σ_n is the actual normal stress component. The parameter c_r and φ_r are reduced strength parameters that are just large enough to maintain equilibrium.

3. RESULTS

For the finite element analysis, before meshing (Fig. 2), first, an optimum mesh density is required to be evaluated so that the outcomes do not get influenced by the mesh density in the model. For the present study, a mesh sensitivity analysis has been performed and an optimum mesh density has been obtained which is 50k for both the slope profiles in this study (Fig. 3).

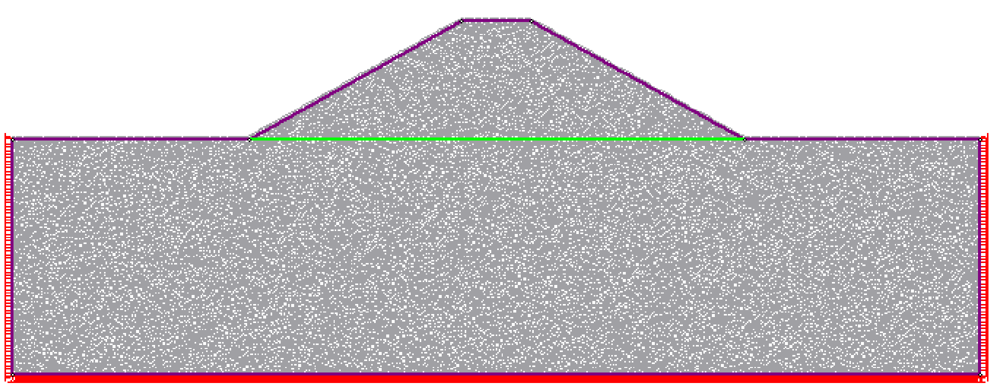

Fig. 2 A typical pond-ash embankment slope model after meshing and applied boundary conditions

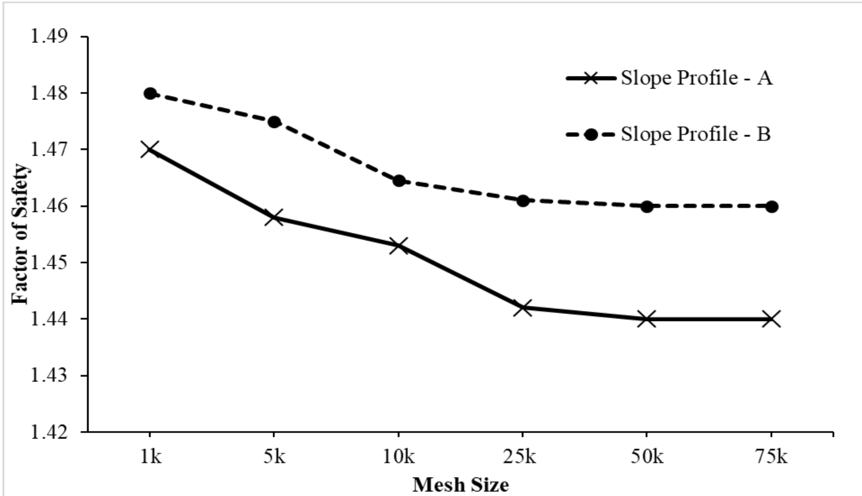

Fig. 3 Mesh sensitivity analysis for the two slope models

The interpretation after the finite element analyses shows that the slip surfaces are generated along the slope face of the embankments (Fig. 4 & 5). The same has been confirmed by the slip surfaces generated from different limit equilibrium methods (Fig. 6 & 7).

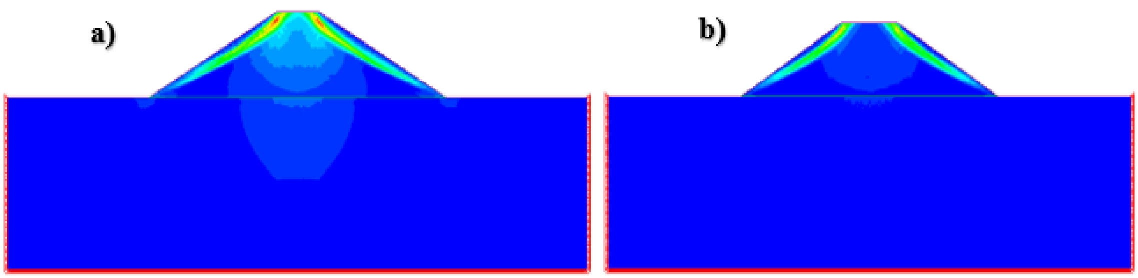

Fig. 4 Contour plots of the maximum shear strains from static analysis of one typical slope model with pond ash and stabilizer dosages of (a) 4% and (b) 8%.

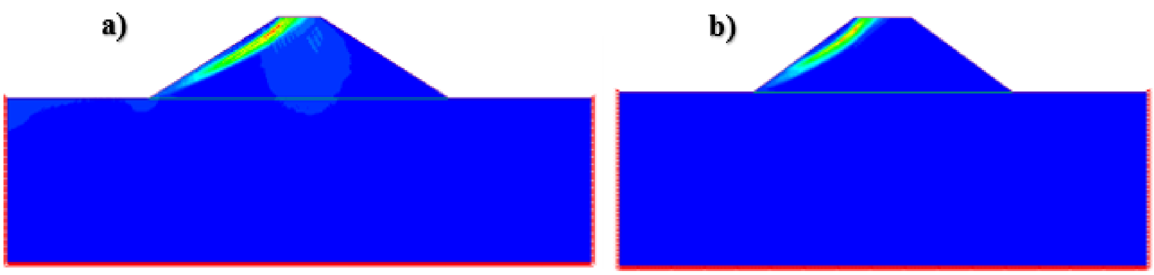

Fig. 5 Contour plots of the maximum shear strains from pseudo-static analysis of one typical slope model with pond ash and stabilizer dosages of (a) 4% and (b) 8%.

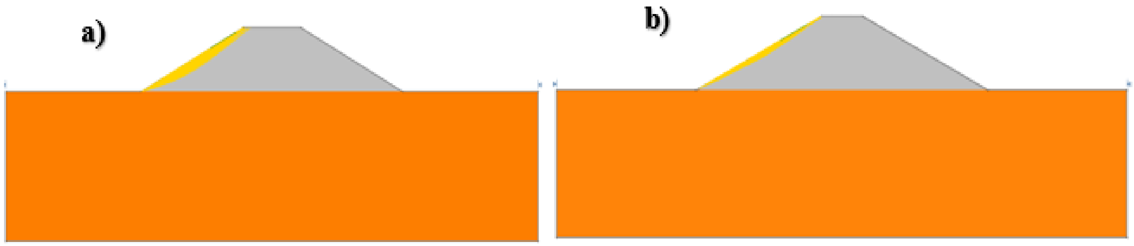

Fig. 6 Slip surfaces generated from static analysis of one typical slope model with pond ash and stabilizer dosages of (a) 4% and (b) 8%.

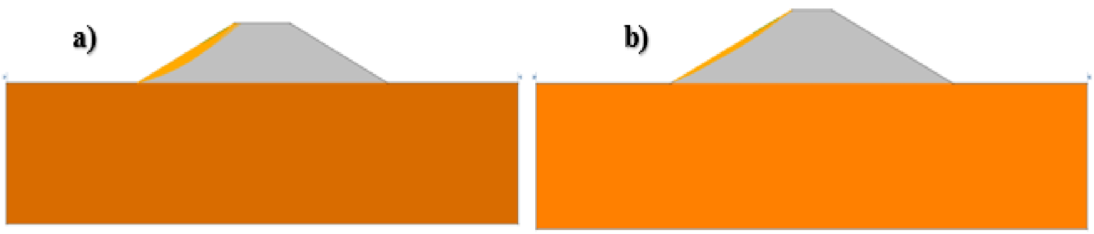

Fig. 7 Slip surfaces generated from pseudo-static analysis of one typical slope model with pond ash and stabilizer dosages of (a) 4% and (b) 8%.

Improvement in the factor of safety has been noted in both static and pseudo-static analysis after increasing the percentage of the natural soil stabilizer, RBI grade-81 (Table – 2).

Table 2 Factor of safety values obtained from LEM and FEM analyses

Slope ID	Pond Ash (%)	RBI Grade-81 (%)	LEM					FEM
Static Analysis								
			Felllinius	Bishop	Janbu	Spencer	GLE	
Slope A	100	0	1.32	1.34	1.323	1.323	1.323	1.44
	96	4	1.41	1.412	1.412	1.412	1.412	1.54
	92	8	1.443	1.444	1.444	1.444	1.444	1.58
Slope B	100	0	1.35	1.35	1.35	1.35	1.35	1.46
	96	4	1.44	1.44	1.44	1.44	1.44	1.55
	92	8	1.472	1.473	1.472	1.472	1.472	1.56
Pseudo-static Analysis								
Slope A	100	0	0.98	0.98	0.98	0.98	0.98	1.13
	96	4	1.045	1.046	1.045	1.046	1.046	1.21
	92	8	1.069	1.070	1.069	1.069	1.069	1.25
Slope B	100	0	0.966	0.966	0.995	0.966	0.966	1.14
	96	4	1.062	1.063	1.062	1.062	1.062	1.21
	92	8	1.086	1.087	1.086	1.087	1.087	1.22

4. CONCLUSIONS

Results obtained from two-dimensional FEM and LEM analysis of the embankments show that the use of a natural soil stabilizer is an effective option for improvement in the stability of the embankments. With an increase in the percentage of the dosage of the stabilizer, the stability of pond ash embankment increases for both static and pseudo-static loading cases. It was also observed that the factor of safety obtained by Bishop's LEM method gives the most conservative result among all other slope stability methods utilized in the present study. It was also observed that with an increase in slope gradient the factor of safety decreases with the same geotechnical characteristics. The pseudo-static analysis performed using the LEM method unveils that both the slope profiles fail in stability analysis while FEM performed on the same shows the slope to be moderately stable. This kind of numerical investigation work helps in finalizing the degree of stability required for the final design of embankment for the optimum dosage of stabilizer chosen. This, in turn, helps in reducing the overall cost of construction since stabilizers come with a cost.

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Hybrid Bioreactor Landfill: A Novel Approach for Enhancement of Rate of Degradation in Anaerobic Bioreactor Landfill

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ABSTRACT
With a rise in the population, the quantity the municipal solid waste (MSW) has also seen the steep rise. India alone generates 531.53*10^5 MT MSW daily. The organic fraction of MSW (OFMSW) varies from 50-60% in India. Only 12.5% waste is scientifically processed and the rest gets disposed to the open landfills. Open dumping or landfilling has been associated with a lot of environmental concerns like leachate percolation, groundwater contamination, frequent landfill fires, unhygienic conditions, etc. Also, the rate of degradation in open landfills is very slow and happens with no human control. Bioreactor landfills are better options than open landfilling. In bioreactor landfills, the rate of degradation can be controlled and all the environmental concerns of open landfilling can be addressed. Anaerobic bioreactor landfills are the most preferred amongst bioreactor landfills. Anaerobic bioreactor landfill can degrade the OFMSW and also generates the landfill gas containing the methane which has the potential of being used as fuel. Many researchers have carried out studies to enhance the rate of degradation of the OFMSW in an anaerobic bioreactor landfill.

This paper proposes the novel approach of a hybrid bioreactor landfill. Hybrid bioreactor landfills will operate in both aerobic and anaerobic phases. The proper placement of these phases will enhance the degradation rate of the OFMSW resulting in economical operation and maintenance of the bioreactor landfills.

Keywords: Organic fraction of municipal solid waste (OFMSW); bioreactor landfill; hybrid bioreactor landfill

1. INTRODUCTION

Urbanization has a concentrated population in urban areas. Urbanization has its advantages but it has resulted in putting a lot of stress on the resources available. One such problem because of urbanization is municipal solid waste (MSW) management. In developing countries like India, the MSW is collected and is dumped on the open land assigned for the purpose of local authorities. The practice is called open dumping. Only 12.5 % of the collected waste in India is scientifically processed (CPCB, 2013). The unprocessed waste after reaching open dumping sites has adverse effects on the environment. Open dumping results into groundwater contamination because of leachate percolation, air pollution because of frequent landfill fires, unhygienic conditions, etc. Also, there is no control over the degradation of the organic fraction in MSW (OFMSW).

An engineering solution for open landfilling is the bioreactor landfill. The bioreactor landfill is an engineered landfill addressing the majority of the environmental concerns of the open landfill site. It accelerates the rate of degradation of OFMSW with the help of the microbial reactions and other enhancement techniques. Anaerobic bioreactor landfills (AnBLF) are capable of generating landfill gas having a maximum proportion of methane which has the potential to be used as fuel.

1.2 Literature Review

To enhance the rate of degradation of OFMSW in the AnBLF, many researchers have carried out experimentation. Researchers have reported that the rate-limiting step in AD having complex OFMSW is hydrolysis (A. Cesaro, 2014) Hydrolysis is the process in which the complex organic substrate is converted into the relatively simpler organic substrate on which acidogens act in the acidogenesis process. To reduce the time of the enhancement process, the various pretreatment methods are experimented in various studies. The pretreatment method includes physical, chemical and biological treatment.

1.2.1. Mechanical Pretreatment. The mechanical pretreatments researchers experimented with are sonication, lysis-centrifuge, liquid shear, collision, a high-pressure homogenizer, maceration, liquefaction, shredding, press extruding, ultrasonic, microwave irradiation and thermal treatment. (Hartmann, 2000).

The size reduction i.e. shredding of the particles increases the surface area available for the microbial reaction (Kim et al. 2000). Also, particle size reduction has resulted in a 28% higher biogas formation (Izumi et al. 2010). The mechanical removal of the excess moisture content by press extruding machines helped the innoculum to suitably bind with OFMSW for the reaction (Bernstad et al. 2013). The thermal treatment makes the less amenable substrate into amenable form for biodegradability by making the organic compounds soluble (Ferrer et al. 2008). Microwave irradiation is found to use less energy than the thermal treatment (Jackowaik et al, 2011).

However, the pretreatment methods are substrate-dependent and proper selection amongst them is necessary to avoid process failure. Many methods researched, require a batch process which is not possible at the site. A huge quantity of source sorted OFMSW is continuously received at the landfill site and the pretreatment method which can be done without consuming much time should be employed. Shredding is one such method that can handle the huge quantity and increases the degradation rate.

1.2.2 Chemical Treatment. Chemical pretreatment destroys the organic compounds with the help of strong acids, alkalis or oxidants (S. Jain, 2015). Chemical treatments like ozonation and addition of chemicals have been studied by the researchers.

Ozone is found to react with the higher-order complex organic compounds into smaller molecular weight compounds for further reaction and is also found to kill pathogens (Weemaes et al. 2000) Both acids and alkaline chemical are being researched for their effect as a pretreatment (Hendriks et al., 2009). Alkaline chemical $Ca(OH)_2$ has promising results in the study. The chemical pretreatment, however, can be considered as a temporary option to curb the inhibitory reactions. (Cesaro et al, 2014)

Alkaline chemical is also found to increase the surface for reaction by the process of salvation and saponification thus making enlarged solid particles available for the microbial action. Acids react with high lignocellulosic contents breaking the lignin and reducing the time for its degradation.

The use of alkaline and acidic chemicals can be preferred over the high-cost ozonation process. Also, the chemical decided as the addictive should be easy to prepare, should have no harmful effect on the humans at the site and should be economical.

1.2.3 Biological Treatment. Apart from the use of innoculum with the substrate, enzymes that assist in biological reactions have also been found useful in biological treatment. Mixing manure and aerating the substrate before feeding for anaerobic reaction have shown good results in an experimental study (Fdéz-Güelfo et al, 2011) However over-aeration can hamper the quantity of the methane generated. The concept of micro aeration i.e adding a small quantity of oxygen during the anaerobic reaction was also investigated. Microaeration study resulted in concluding that the methane yield achieved is less compared to other biological pretreatments. Studies have shown that the rot fungi help in better biodegradation of lignin. Enzymatic pretreatment is the best pretreatment for promoting biogas production.

Studies for the pretreatment of the substrate have been also focused on the additive materials which adsorb the inhibitory products and facilitate the hydrolysis reaction without the disturbance.

Researchers have studied the use of enhancement techniques in various combinations to increase the rate of biological treatment. The techniques studied were leachate recirculation, variation in the rate of leachate recirculation, size reduction of the waste, pH adjustment, addition of gravel, addition of sludge, control of moisture content and temperature, addition of the nutrients, etc. (Warith. 2002, Reinhart et al. 2002; Valencia et al.,2009, Mali et al, 2012). Use of different inoculums like cow dung and waste activated sludge has also been studied. The co-digestion of the OFMSW with waste activated sludge has resulted in the rise of methane production significantly (Naran, E., et al., 2016)

1.3 Hybrid Bioreactor Landfill

1.3.1 Need of Hybrid Bioreactor Landfill. The gas generation graph for the AnBLF including all the intermediate stages i.e. Stage 1 initial adjustment, Stage 2: hydrolysis, Stage 3: acidogenesis, Stage 4: acetogenesis, Stage 5: methanogenesis and stage 6: maturation is shown in Fig. 1

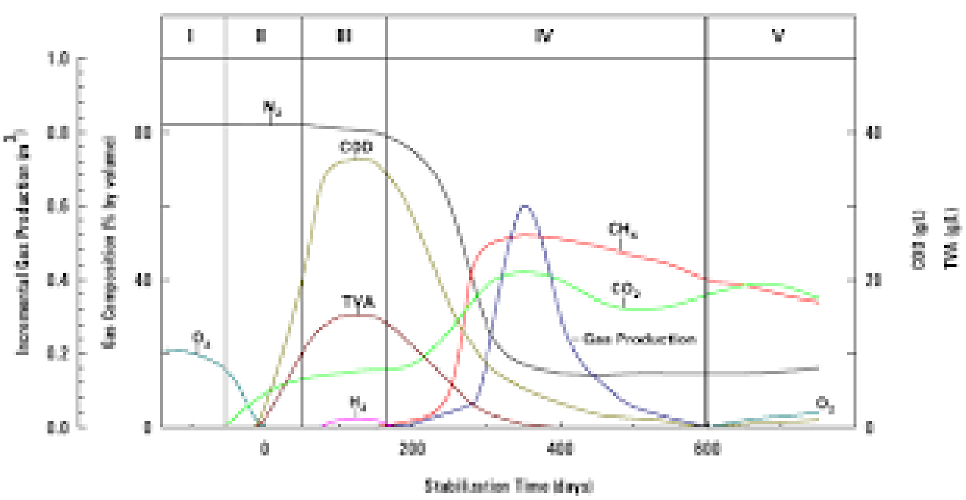

Fig. 1 Gas Generation Graph in Anaerobic Bioreactor Landfill (Source: geoengineer.org)

The majority of the researches in the enhancement of the rate of degradation is focused on the hydrolysis stage. Researchers studied the combination of pretreatments and enhancement techniques to accelerate the conversion of complex higher molecular weight compounds into relatively lower molecular weight compounds. This enhanced the hydrolysis stage and overall time duration for the anaerobic reaction.

The landfill gas generation production pattern in the anaerobic reaction follows the pattern shown in Fig.1. No landfill gas generates in the hydrolysis, acidogenesis and acetogenesis stage. The landfill gas starts to generate in the methanogenesis stage and has a considerable proportion of methane in it. The gas continues to generate and achieve its peak in the methanogenesis stage. After achieving the peak, the landfill gas generation falls to achieve a stable value. The stable gas generation then continues until all the volatile solids in the landfill are utilized. Generation of the landfill gas falls to extremely low in the maturation stage but doesn't achieve the zero value as anaerobically slowly degrading material like lignin is still present and the degradation continues for a larger duration of the time till all the anaerobically slowly degrading matter gets stabilized.

It has been reported in the literature that the maturation stage too requires a longer time. Because of the prolonged degradation process in the maturation phase, the operation and maintenance of the AnBLF cell become uneconomical. Hence, there is a need to focus on the maturation stage along with the hydrolysis stage to make the entire process of AnBLF economical.

1.3.2 Concept of Hybrid Bioreactor Landfill. The hybrid bioreactor landfill focuses on the reduction of the stabilization time of AnBLF as a whole. It focuses on enhancing the degradation rate of the AnBLF by specifically focusing on increasing the degradation rate in the hydrolysis and maturation stage.

In a hybrid bioreactor landfill, the proper placements of the aerobic and anaerobic stages are proposed so that the overall stabilization time for the AnBLF cell reduces. The graphical representation of the proposed process in hybrid bioreactor landfill is Fig. 2

The hybrid bioreactor is proposed to operate aerobically twice. The bioreactor will operate aerobically at the initial stage for the pretreatment of the OFMSW. This will help in the faster hydrolysis process. The bioreactor will also operate in the aerobic phase after a considerable amount of the landfill gas has been extracted from the anaerobic stage. The later aerobic phase will enhance the process of the degradation of the anaerobically slowly degrading organic matter.

Hybrid bioreactor landfill is not just the placement of the aerobic phases, it also focuses on having the proper combination of pretreatment and enhancement techniques in both aerobic and anaerobic stages so that the stabilization time for the OFMSW can be reduced.

1.4 Summary

Reduction in the overall stabilization time of the AnBLF is needed to reduce the operation and maintenance cost in the maturation stage by increasing the rate of the degradation of the anaerobically slowly degrading matter. The proposed hybrid bioreactor landfill can be a solution to it. The hybrid bioreactor would take care of both rate-limiting steps of hydrolysis and maturation in the AnBLF for the early stabilization of the landfill cell.

Hybrid bioreactor landfill is not just the placement of the aerobic phases, it also focuses on having the proper combination of pretreatment and enhancement techniques in both aerobic and anaerobic stages so that the stabilization time for the OFMSW can be reduced. However, extensive experimental research for a hybrid bioreactor landfill is required. Also, the practical difficulties for the operation and maintenance of the hybrid bioreactor landfill need to be thought upon.

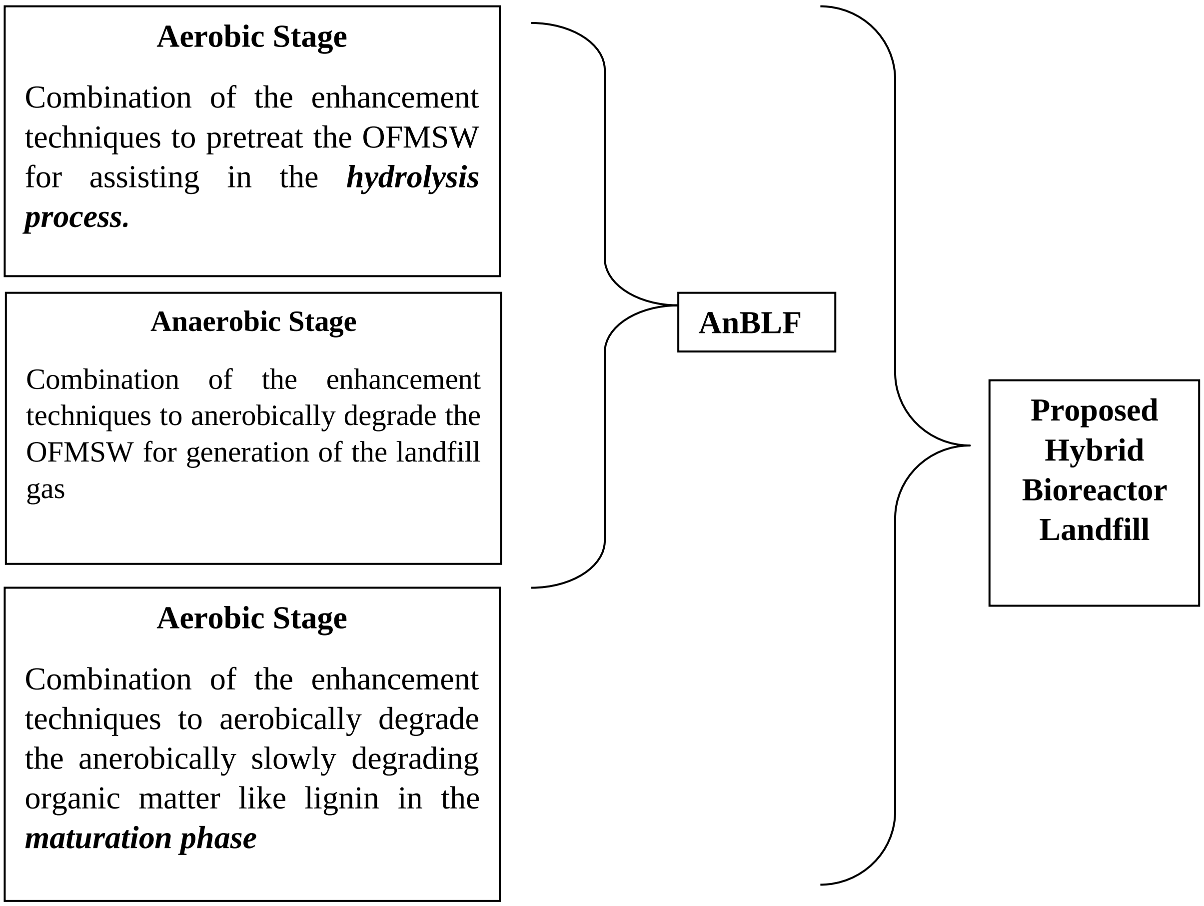

Fig. 2 Proposed Hybrid Bioreactor Landfill

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Environmentally Sustainable Alternative of Coal Ash Disposal in Mine Void filling

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ABSTRACT
As the generation of coal ash from thermal power plants is huge and the scope of its utilization is not 100% everywhere, the unutilized ash shall be safely disposed of in an environmentally sustainable manner. As per the present practice, mostly the unutilized ash from the thermal plants is disposed off in ash ponds requiring a hundred acres of land. Not only involving huge areas of land, but it also poses challenges in the safe operation of ash ponds to ensure a pollution-free environment. There are examples world over of re-use application of coal ash in mine void filling and quarry reclamation. In the United States of America (USA), mine reclamation has been identified as a long term, large volume beneficial use for coal ash. NTPC Limited (NTPC) has been striving for sustainable application of generated ash and has been always looking towards various eco-friendly alternatives for disposal of un-utilized ash. For our thermal plants, we have succeeded to get some abandoned mine voids after detailed scientific studies and establishing safe & sustainable operations during mine void filling.

In mine void, disposal of coal ash in the form of slurry is found to be a better option as it avoids plying of a large number of vehicles on the road leading to traffic congestion. This method also facilitates the recycling/ reuse of decanted water back to the plant for the preparation of ash slurry. The use of coal ash as mine backfill provides the additional potential benefit of limiting the impacts of Acid Mine Drainage (AMD). Many Indian coal ashes are alkaline materials that can neutralize acidic groundwater and/ or inhibit the production of acid. Placement of coal ash in mine void reduces the permeability of mine strata and divert water away from acid-generating materials.

Various scientific studies have been carried out by NTPC on the ongoing mine void filling and proved that this is an environmentally sustainable alternative for disposal of unutilized coal ash which also has the advantage of preventing groundwater contamination along with other potential benefits.

Keywords: Thermal Power Plant; Coal Ash; Mine Void

1. INTRODUCTION

Indian coal has high ash contents and presently about 245 million tonnes of ash is generated annually from thermal plants. The extent of production is posing a serious challenge at its disposal. Although the utilization of coal ash is growing leaps and bounds, but still not sufficient at all to supersede the rate of production at many thermal plants. Hence, the major challenge faced by the thermal power plants is in the disposal of the by-product of coal used. The main sink of its disposal remains to be an ash pond site adjacent to the site of its production. The most economical and commonly used method to dispose of ash is by hydraulic transport, in the form of a slurry, to the ash pond. Despite the proper design, the operation of ash ponds poses certain challenges and environmental concerns during operation. The above situations necessitated to explore alternate avenues for disposal of ash and it was evolved that, the unutilized coal ash from thermal plants can be best disposed to the places where it came from i.e Mine Void. During the late 1990s, ash filling in abandoned mine voids was advocated by MoEF and CPCB as an alternative to ash disposal on land.

2. COAL ASH DISPOSAL

2.1 Ash Ponds

Conventionally, the unutilized coal ash from thermal power plants is being disposed off in ash ponds. Ash ponds are designed as multi-lagoon systems with minimum two storage lagoons and one over-flow lagoon (OFL). Having two or more storage lagoon facilitates the sequential raising of lagoons by putting one lagoon for ash filling while the other lagoon is used for raising its dyke. OFL helps in controlling the effluent quality of the supernatant, which is recycled back to the plant for making ash slurry. The typical cross-section of storage lagoon constructed with the upstream method and OFL is shown in the following Fig.1.

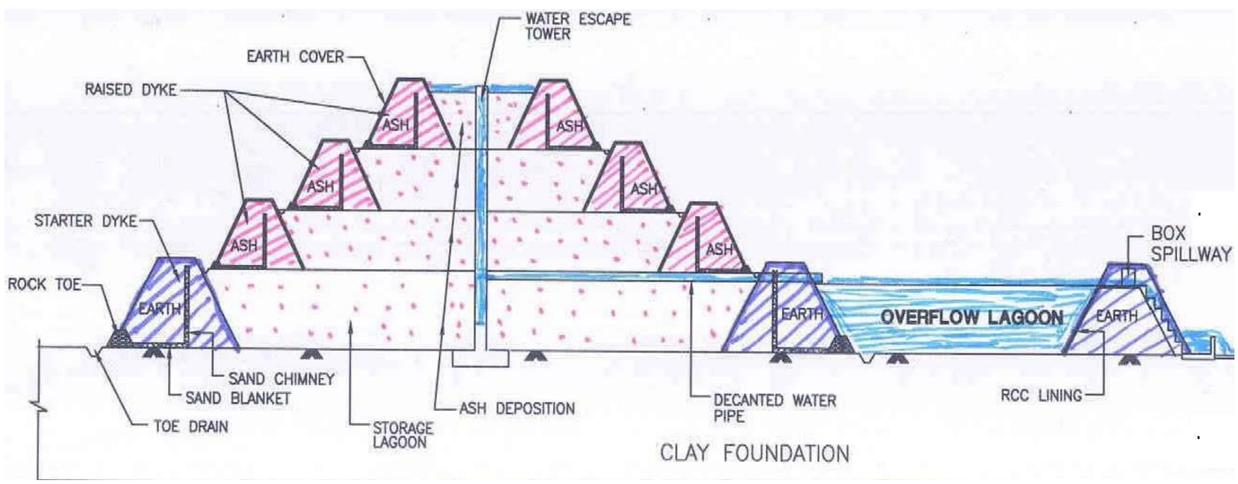

Fig. 1 Typical cross-section of storage lagoon and OFL

2.2 Mine Void filling

As an alternative to ash ponds, the unutilized coal ash from thermal plants can be best disposed to the places where it came from i.e. Mine Void. The chemical and physical characteristics of coal ash coupled with consideration of issues such as the demand for its alternate uses, cost, and locations of disposal options and the local regulatory environment are key factors to determining its best utilization options. Many options for secondary utilization of coal ash, including those in mining activities, are available today worldwide. Coal ash, in general, may be utilized in mine void filling for the following purposes.

- Arresting advances of mine fires
- Neutralization or encapsulation of toxic materials
- Alkaline amendment to neutralize acid-producing rocks
- Subsidence control in underground mines
- Control hydraulic pressure buildup in underground mines
- Filling underground mine voids to control acid drainage
- Stabilization of caved out areas
- Stowing in underground workings

- Reclamation of subsidized areas and reshaping
- Reclamation of mined-out areas in opencast mines

These few examples of secondary utilization of coal ash in underground and open cast mines in India, which need to be adopted on a large scale. Bottom ash has been used in underground coal mines of M/s SCCL and M/s SECL for underground stowing and coal ash (bottom ash and fly ash) in open cast mines of M/s CCL and M/s MCL for reclamation purposes. However, there are plenty of cases where coal ash (bottom ash and fly ash) has been used in underground and surface coal mines of the United States of America for stabilization, reclamation, acid mine drainage treatment, and other purposes. The unutilized coal ash can be utilized in the Mine void filling in the following two ways.

a) Reclamation of old and abandoned open cast mine voids
b) Mixing coal ash in internal and external dumps of all operational mines.

A picture indicating the layout of Gorbi mine voids of M/s NCL allotted to NTPC is shown in the following Fig.2.

Fig. 2 A picture of Gorbi mine voids allotted to NTPC

3. CHALLENGES & STRATEGIES IN MINE VOID FILLING

3.1 Environmental concerns

Although coal ash possesses beneficial physical and chemical properties, still serious concerns prevail in minds of mine planners, operators, regulators and environmental groups about the potential for release of toxic chemicals in the leachates from coal ash. Therefore, sound scientific methodology of disposal is needed so that environmental concerns are reliably addressed.

While recognizing the potential risk of negative environmental impacts associated with the filling of coal ash in mine voids, it has shown through research findings in the USA that benefits can accrue in some cases. The use of coal ash as mine backfill may provide additional potential benefits of limiting the impacts of Acid Mine Drainage (AMD). Many Indian coal ashes are alkaline materials that can neutralize acidic groundwater/ or inhibit the production of acid. Placement of coal ash in mine voids may also reduce the permeability of mine strata and divert water away from acid generating materials. Extensive studies conducted by NTPC indicate that the placement of coal ash in mine voids usually results in no harmful impacts on human health and the environment when used to mitigate other potential mining hazards. However, where the placement of coal ash for reclamation in a mine void is determined to be a viable option, an integrated process of coal ash characterization, management of placement activities, and post-placement monitoring will be essential.

3.2 Stability of overburden dump

Stability of coal ash mixed overburden dump may be another area of concern. The dump failure is characteristically a shear failure and therefore following parameters affecting shear strength of ash mixed dump needs to be carefully examined and studied.

- Size analysis of broken fragments in the dump.
- Physical and chemical properties of coal to be mixed with overburden
- Moisture content in the ash mixed overburden
- Type and characteristics of binding material if required to be used.

The effects of the above parameters may be studied in the laboratory and validated under field conditions for short term and long-term stability of the ash mixed overburden dump. Based on the same, optimum size and shape of the dump including the slope of the individual bench of the dump, ramp slope angle, overall slope angle, width and height of benches, ultimate height of dump, etc. are decided.

3.3 Mine Identification

Extensive studies need to be conducted for the identification of potential mine voids. NTPC has conducted extensive studies for prospective mine voids for backfilling with coal ash. Based on the extensive studies, NTPC has been allocated some abandoned mine voids as mentioned below:

- Medipalli open cast mines (M/s.SCCL) with a capacity of 250 million cum are allocated to NTPC's Ramagundam STPS. It is about 7 km from NTPC Ramagundam Power Station and is comparatively very large and can cater to the ash disposal requirement for about 20 years.
- Jagannath OCP mine (of M/s MCL) with a capacity of about 11 million cum allocated to NTPC's Talcher Thermal Power Station (410MW).
- Jagannath OCP mine (of M/s MCL) allocated to NTPC's Talcher Super Thermal Power Station (3000MW).
- Gorbi mine voids (M/s NCL) allocated to NTPC's Singrauli Super Thermal Power Station. This mine can accumulate about 22 million cum of coal ash up to the ground level and 54 million cum up to the overburden level.
- Abandoned mine void at Karar and Bodri village at Bilha block is allocated to NTPC's Sipat Super Thermal Power Station. The mine void is located at a distance of about 35 km

from plant and the coal ash is to be disposed of through mechanical means.

- South Balanda mine voids (of M/s MCL) with a capacity of about 17 million cum allocated to NTPC's Talcher Thermal Power Station (410MW). Schematic map of pilot quarry and quarries 2,3A&3B of South Balanda mine voids is shown in the following Fig.3.

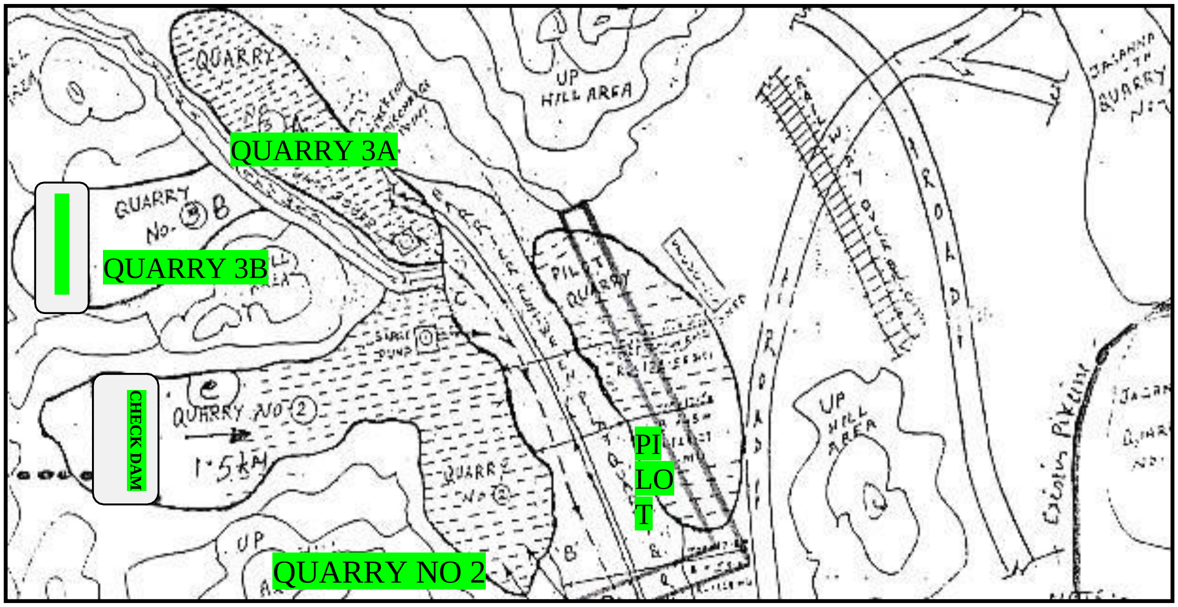

Fig.3 Schematic map of South Balanda mine void allotted to NTPC.

3.4 Method of Disposal

There are in general two methods of disposal of ash, i.e. dry method and wet method. The dry method results in a solid material that does not bleed water whereas the wet method results in the discharge of water that must be re-handled after disposal in mine voids. Dry placement of ash may avoid leaching but it may not be compactable as obtained in wet placement and dust emission may be a problem. The decision for adopting a particular method largely depends on the cost, material characteristics, equipment, and operational hazards.

Based on extensive studies, initially, the NTPC's Talcher Thermal Power Plant (410MW) (TTPS) has been allotted abandoned South Balanda coal mine voids of M/s MCL. South Balanda has 3 voids in an area of 70.75Ha and the volume of the void is 14.73 million cum. The void filling has started since 2005 and the estimated life of this void is 15 years. There are three ash slurry disposal pipelines (2 working and 1 standby) of about 9 kilometers length each for transportation of coal ash (bottom ash and fly ash both) to mine voids. The ash slurry discharged at mine void travels through gravity towards a lower level and ash particles settle down while traveling. The decanted water is being re-circulated back to the plant using submersible pumps for making ash slurry. The NTPC has been analyzing the decanted water samples quarterly and the quality of water is within the permissible limits of BIS. Coal ash presently being disposed of using wet method into South Balanda mine void is shown in the following Fig.4. However, the decanted water re-circulation from the same is shown in Fig.5.

Fig.4 Coal ash disposal with the wet method in South Balanda mine void

Fig.5 Decanted water re-circulation from South Balanda mine void

3.5 Coal ash characterization

Characterization of coal ash and the mine placement sites is essential to engineering design, permitting decisions, backfilling management and the development of monitoring programs. The mobility of coal ash derived constituents varies widely in the mine environment depending on the physical and chemical characteristics of coal ash and the geologic materials, the pH, oxidation-reduction potential, the chemical composition of water encountered at the mine site.

It would be desirable that coal ash is characterized before its placement in mine void with each new source of coal. Coal ash characterization involves understanding its composition and testing its potential for hazardous chemicals (if any) to leach into the environment under all possible conditions in the target mine, particularly with respect to various pH levels. More precisely, coal ash characterization would involve, inter-alia, the followings:

a) Analysis of bulk chemical and physical properties including trace element leaching potential
b) Other characteristics such as permeability upon compaction that might impact their behavior in the mine setting.

3.6 Monitoring

Monitoring is an essential tool to confirm the predictions of contaminant behavior and detect it to find what extent contaminants are moving into the surrounding environment. To address the concern, comprehensive monitoring (pre-monsoon and post-monsoon) of groundwater quality in the surrounding of the ash disposal sites is to be done for each mine void filling. It is desirable that taking several factors into account such as the rate of groundwater flow and estimated risks from contamination, monitoring wells be placed in a manner that yields early data on potential water contamination. A very perspective monitoring regulation may be desirable in this context. The number of monitoring wells, the spatial coverage of wells and the duration of monitoring at mine fills should be given proper consideration. Based on the extensive monitoring programs in the ongoing mine filling by NTPC in south Balanda mine voids, the following is observed.

i) Analytical results of groundwater samples collected from 36 locations show that the values are within the permissible levels of BIS guidelines.
ii) As per a study conducted by CSIR-NEERI (Impact assessment of ash filling by TTPS on water resources in the surrounding of South Balanda mine void) also did not indicate leaching of heavy metals in the observation wells surrounding the ash-filled mine voids.
iii) As per the study conducted by CSIR-NEERI, titled "Study of effects due to Ash fill of TTPS on Flora and Fauna in the surrounding area of South Balanda mine void and Jagananth Mine void", there is no ecological sensitive flora or fauna in the study area. Leaf injury symptoms due to coal ash disposal were also not observed. Although dust deposition was observed on leaves, microscopic studies revealed that there were stomata indicating that deposition of dust/ash is not having an adverse impact on the flora surrounding the ash dumping sites.

4. CONCLUSIONS

It has been observed that, due to high ash content in Indian coal, a huge area of land is required for ash ponds for disposal of unutilized coal ash. On the other hand, the filling of the void created in the coal mine requires a huge quantity of overburden / external soil/sand to be transported from some other sites creating air pollution and environmental effects. However, if coal ash is used in mine voids as part of reclamation, it may solve the above daunting problem of disposal of unutilized coal ash as well as the requirement of a huge quantity of backfill material. As the generation of coal ash by the thermal power plants is too high and the scope of its utilization is not 100% for all plants, mine void, and quarry reclamation by backfilling with coal ash seems to be the most feasible option for sustainable disposal of unutilized coal ash.

Disposal of coal ash in the form of slurry is found to be the better option as it avoids plying of a large number of vehicles on the road leading to traffic congestion. This method also facilitates the recycling / reuse of decanted water back to the plant for the preparation of ash slurry. For quick consolidation of slurry, High-Density Slurry Disposal (HDSD) may also be evaluated and preferred for mine void filling based on the techno-economic feasibility study. Although coal ash possesses beneficial physical and chemical properties, still serious concerns prevail in minds of mine operators, regulators, planners and environmental groups about the potential for release of toxic chemicals in the leachates from coal ash. To address the concern, comprehensive monitoring (pre-monsoon and post-monsoon) of groundwater quality in the surrounding of the ash disposal sites is to be done for each mine void filling. However, the extensive studies of CSIR-NEERI (done during south Balanda mine void filling by NTPC) indicate that there are no signs of heavy metal contamination in the groundwater if coal ash is used in mine void backfilling with the proper engineering design of placement activity.

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Performance Evaluation of Sand-Bentonite as Barrier Material in Engineered Landfills

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ABSTRACT
The satisfactory disposal of municipal/hazardous/nuclear waste requires a detailed geo-engineered solution. Isolation of the waste material and the protection of geoenvironment are important considerations. An impermeable barrier material is required for isolating the waste, finding its applicability mainly in landfill liners and covers, cut-off walls for existing landfills and as a backfilling material for nuclear waste disposal facilities. In the absence of low permeability clays in the vicinity, the locally available sand, which is deficient in itself to meet the mandatory criteria of hydraulic conductivity being < 10^{-9} m/s was chosen in this study with bentonite as an admixture for use as a barrier material. For testing purposes, specimens were prepared with different percentages of bentonite added to locally available sand. In addition to a low hydraulic conductivity ($k < 10^{-9}$ m/s), various aspects associated with bentonite enriched sand including unconfined compressive strength, matric suction, adsorption characteristics have been considered in this study. The optimum percentage of bentonite to be added to sand considering the essential low permeability criterion and matric suction test results of the bentonite enriched soils was evaluated. Four target heavy metals namely Cadmium, Zinc, Nickel, and Lead were considered to carry out the adsorption studies on the different categories of soil mixes. It was observed that with an increase in bentonite content in the sand-bentonite mixes, the adsorption capacity improved significantly. Only the emphasis on permeability had been given that may be rational only if clayey materials are used. But if barrier materials are to be fabricated from other soils enriching with bentonite, various considerations come into play. Therefore, the proposed plan of the study envisages considering these effects and designing an optimum mix by adding requisite percentages of sand and bentonite to act as a liner material.

Keywords: Sand; Bentonite; Matric Suction; Adsorption

1. INTRODUCTION

Landfills have become a requirement of every city, as heaps of waste are being added every day and contribute to the existing management burden. The present scenario demands the construction of landfills in every city to dispose of waste in an engineered way, addressing global environmental concerns. Compacted clay liners have been widely used as hydraulic barriers and cover in waste containment facilities (Benson and Daniel 1994; Fan *et al.* 2014). However, it is not always possible to procure good quality clayey soils locally. If it is to be transported from long distances, it puts a financial constraint on the development of such disposal facilities. For instance, considering a typical MSW landfill of 600 m x 600 m as base area laid at a slope of 4(H):1(V), covering an area of about 90 acres, the amount of soil required for a single layer of liner (0.90 m thick) is nearly 6,08,634 tons. For hazardous waste landfills, double layers of clay are provided owing to the highly polluting nature of waste. Due to the burgeoning increase in the population and industrialization, the land availability for taking out the earth/borrow sites has been limited and expensive. Therefore, more emphasis should be on using locally available soil for economical and sustainable development.

Keeping this in mind, an effort has been made to fabricate liner and cover material using local sand which is deficient in meeting the basic requirement of permeability to serve as a barrier material along with bentonite as an admixture. Bentonite has been chosen as an admixture owing to its inherent low permeability and retention behavior. The optimum bentonite content to be added to the soil mix needs to be assessed carefully, considering the essential requirements of barrier material. Usually, the liner materials are compacted at 1-2% wet of optimum and are not fully saturated at the time of placement. In the unsaturated state, the hydraulic conductivity of soil decreases with a reduction in water content in the soil. As the flow takes place in the unsaturated conditions, matric suction and soil-water characteristic curves are significant and have an important bearing on the design of liner material.

The migration of contaminants through clay barriers is retarded due to its low permeability and sorption. It is desired that the liner system should be able to restrict the discharge of leachate to the admissible concentration level of contaminants in subsoil and groundwater. This characteristic was studied by carrying out the batch adsorption tests using four target heavy metals for various sand-bentonite mixes. These aspects pertaining to bentonite enriched soils have not been adequately addressed in the literature and hence, studied in detail.

2. MATERIALS

The grain size distribution of the sand and bentonite used in the study was done using sieve analysis and hydrometer test as per Indian Standard IS 2720 (Part 4) - 1985 procedure to determine the particle size distribution of sand and bentonite. The grain size distributions of the sand and bentonite are shown in Fig. 1. Their chemical composition adjudged by the X-ray Fluorescence technique is grouped in Table 1. The index properties of the materials used in the present study including the specific gravity, plasticity characteristics, etc. are reported in Table 2.

2.1 Sand

The sand investigated in this study was local fine-sand, which is typical to that used in local construction. The uniformity and curvature coefficients for this sand were C_u= 2.82 and C_c=1.21 respectively. It was classified as poorly graded sand or 'SP' as per the Indian Standard Soil Classification system (IS 1498: 1970, Reaffirmed 1987).

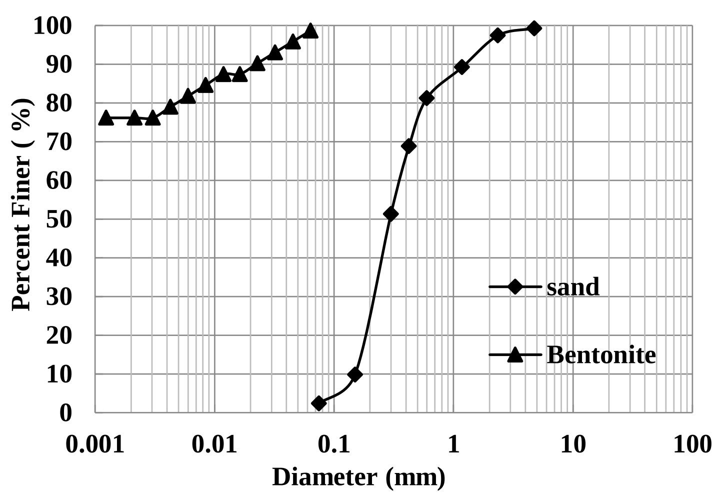

Fig. 1 Grain size distribution curves

2.2 Bentonite

Bentonite refers to any material that is primarily composed of the smectite group of minerals (mainly montmorillonite) possessing characteristics of smectite minerals which include large cation-exchange capacity, large specific surface area, high swelling potential, and low hydraulic conductivity to water (Gleason *et al.* 1997, Zhang *et al.* 2012). The ratio of SiO_2 to Al_2O_3 is around 3.27, which lies between the range of values stated from 2 to 5.5 (Gueddouda *et al.* 2016) as shown in Table 1.

Table 1 Chemical composition of bentonite and sand

Constituents	Bentonite	Sand
SiO_2	54.42 %	83.45%
Al_2O_3	16.64 %	7.68%
Fe_2O_3	15.58 %	2.67%
MgO	3.74 %	0.79%
CaO	3.50 %	1.80%
Na_2O	3.18 %	1.03%
TiO_2	1.71 %	0.58%
K_2O	0.28 %	1.55%
MnO	0.17 %	0.07%
SO_3	0.17 %	0.03%
P_2O_5	0.15 %	0.15%
V_2O_5	0.07 %	-
SrO	0.03 %	60 ppm
CuO	0.02 %	28 ppm
ZnO	0.02 %	-
Cr_2O_3	0.02 %	0.02%
ZrO_2	0.02 %	0.09%
NiO	0.01 %	33 ppm
BaO	17 ppm	0.03%
SeO_2	-	0.03%

Table 2 Index properties of materials used

Property	Standard Specification	Sand	Bentonite
Specific gravity, *G*	IS: 2720 (Part 3)-1980	2.66	2.82
Liquid limit, *LL* (%)	IS: 2720 (Part 5) – 1985	Non-Plastic	363
Plastic limit, *PL* (%)	IS: 2720 (Part 5) – 1985	Non-Plastic	65.2
Plasticity index, *PI* (%)	IS: 2720 (Part 5) – 1985	Non-Plastic	297.8
Max Void Ratio, e_{max}	IS: 2720 (Part 14)-1983	0.91	-
Min Void Ratio, e_{min}	IS: 2720 (Part 14)-1983	0.32	-
Unified soil classification system	IS 1498: 1970 Reaffirmed 1987	SP	CH
Hydraulic Conductivity (m/s)	ASTM D 5084-16a	1.75×10^{-5}	-

3. RESULTS AND DISCUSSION

3.1 Plasticity and Compaction Characteristics

The index and engineering properties of soil mixes including the plasticity characteristics and compaction test results as per the relevant Indian standards are depicted in Table 3.

Table 3 Geotechnical properties of soil mixes

Soil Mixes	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Optimum Moisture Content (%)	Max-Dry Density (kN/m^3)	Specific Gravity
95S + 5B+0F	NP	NP	NP	13.40	16.86	2.65
90S+10B+0F	33.80	17.42	16.38	15.32	17.54	2.67
85S+15B+0F	41.10	26.10	14.90	14.36	17.64	2.68
80S+20B+0F	53.00	27.40	25.60	15.60	17.44	2.69
75S+25B+0F	60.50	31.40	29.10	15.80	17.23	2.70
70S+30B+0F	72.50	42.50	30.00	18.81	16.46	2.71
60S+40B+0F	118.01	66.19	51.81	19.00	16.27	2.72

3.2 Hydraulic Conductivity

The hydraulic conductivity was obtained for all the formulated mixes using the Flexible wall permeability apparatus as shown in Fig. 3. The tests were carried out at 2% wet of optimum following the pattern as practiced in the field conditions.

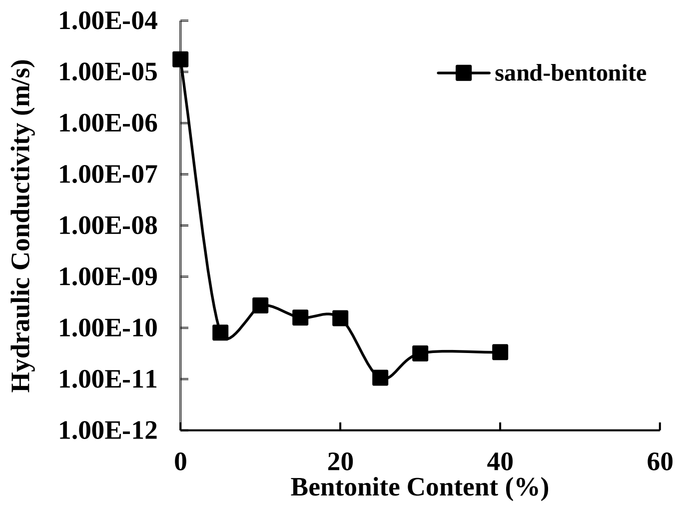

Fig. 2 Effect of increased bentonite content on hydraulic conductivity

The hydraulic conductivity varies for sand-bentonite mixes as shown in Fig. 2. It can be seen that hydraulic conductivity decreases with increasing bentonite content. The values range from 1.75 x 10^{-5} m/s for 0% bentonite to 3.34 x 10^{-11} m/s for 40% bentonite content for bentonite-enhanced sand. Upon the addition of bentonite to the soils, the plasticity indices of the mixes increased. It was observed that soil with higher plasticity possessed lower hydraulic conductivity values at any stress level as compared to the less plastic soil. This can be related to the diffuse double layer (*DDL*) theory. The thickness of the diffuse double layer for highly plastic soil would be more as compared to less plastic soil. This would lead to a reduced effective pore size for flow, and therefore, a reduced hydraulic conductivity of the soil. A high swelling potential of bentonite could be the reason behind the reduced hydraulic conductivity. Upon addition of 5% bentonite to sand, a drastic decrease in the hydraulic conductivity was observed. This erratic behavior at the addition of 5% bentonite in the soils in terms of hydraulic conductivity can be attributed to the uneven distribution of bentonite in the mix due to low bentonite content.

Fig. 3 Samples were tested in Flexi-wall permeameter and Pressure plate Apparatus

3.3 Matric Suction

The pressure plate apparatus was used to determine the matric suctions of soil specimens as shown in Fig. 3. Fig. 4 shows the effect of increasing bentonite content in the measured soil-water characteristic curves for various sand-bentonite mixes. With the increase in the bentonite content, the slope of the curve for volumetric water content versus suction decreased. The residual water content at 1500 kPa was quite low for 5% bentonite and kept on increasing as the bentonite content in the mix increased.

Thus, while optimizing the soil mixes for use as a barrier material, the effect of greater suction pressures encountered needs to be kept in mind with increasing bentonite content to ensure the safety and good performance of the liners.

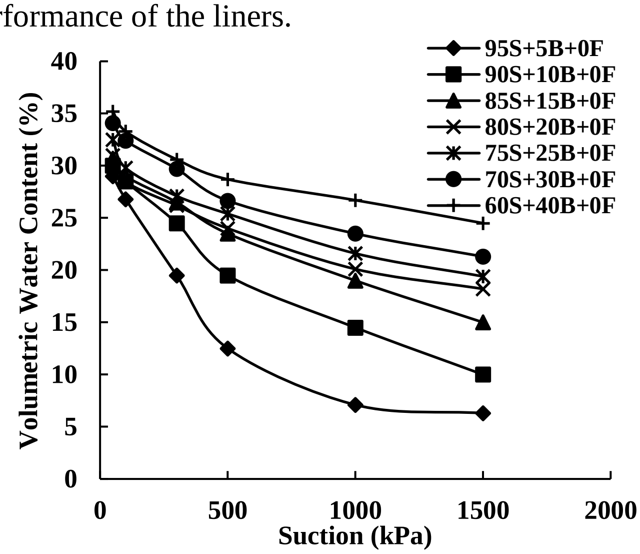

Fig. 4 Volumetric Water Content versus Matric Suction

3.4 Unconfined Compressive Strength (UCS)

Stress-strain curves for all the soil mixes formulated were plotted from the UCS test. Fig. 5 shows the stress-strain curves for different mixes prepared by proportioning sand and bentonite in varying percentages. It can be observed that in the case of sand-bentonite mixes, beyond the 20% addition of bentonite to sand, the UCS increased at a steep rate and the strength is very high. The failure occurs at a maximum strain level of 6% in the case of bentonite contents ranging from 30-40%. At low bentonite contents in the range of 5 to 20%, a very early failure (brittle failure) is reported at a low strain rate ranging from 1.5-2.5 % of the axial strain. Upon an increase in the bentonite content beyond 20% up to 40%, a very high compressive strength is witnessed ranging from 322 kPa at 30% and 455 kPa at 40% bentonite content. The increase in unconfined compressive strength of the soil specimens can be attributed to the change of soil structure with the addition of bentonite (Lambe 1958)

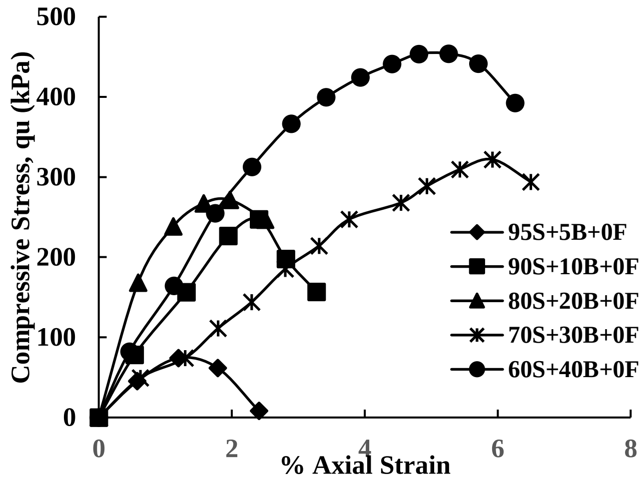

Fig. 5 Compressive Stress versus Axial Strain

3.5 Batch Adsorption Test

On account of low hydraulic conductivity, the discharge of the outflow of leachate will be very small. This outflow can be further decreased if the barrier material has good adsorption capacity towards the contaminants present in the leachate. This study shows the sorption capacity of the soil mixes for Cd, Zn, Ni and Pb as the target metals with the plotting of adsorption isotherms (Freundlich and Langmuir).

The adsorption isotherms of two types were plotted for the various soil mixes formulated using sand and bentonite for use as a barrier material in landfills from the batch adsorption test results, expressed as the relationship between the amounts of metal adsorbed per unit mass of dry soil and the equilibrium concentration of the metal. These isotherms relate concentration retained in the adsorbent phase, q_e, to the equilibrium adsorbate concentration in the bulk fluid phase C_e.

$$q_e = \frac{(C_i - C_e)V}{W} \tag{1}$$

where C_i and C_e are the initial and equilibrium concentrations (mg/L) of metal solution respectively; V is the volume (L), and W is the mass (g) of the adsorbent.

The sorption capacity of the soil mixes for Cd, Zn, Ni and Pb were fitted to the experimental data using Freundlich isotherm curves given by:

$$S = Kf\,(C_e)^{\,b} \tag{2}$$

where S = adsorption degree (mg/g); C_e = equilibrium concentration (mg/L); Kf = Freundlich partition coefficient (L/g); b = empirical constant of the Freundlich isotherm.

The Langmuir isotherm is given by:

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m K_L}\frac{1}{C_e} \tag{3}$$

where q_m (mg/g) and K_L (L/g) are the Langmuir constants.

Fig. 6 and 7 show the Freundlich and Langmuir Isotherms with Cadmium and Zinc respectively for sand-bentonite mixes with bentonite percentage ranging from 0 to 40%. By analyzing the experimental results, it was observed that with the increase in bentonite content, the adsorption capacity of the soil mixes increased significantly as predicted by the Freundlich and Langmuir isotherms with nearly whole of the metal content getting adsorbed upon increasing the bentonite content from 10% to 40% in the sand. This similar behavior of adsorption characteristics getting improved by increasing the percentage of bentonite in the mix was observed in all the four target metals. However, the isotherms here are shown for Cadmium and Zinc only due to the similar nature of results and can be sought in a research paper by the authors (Sobti and Singh, 2017).

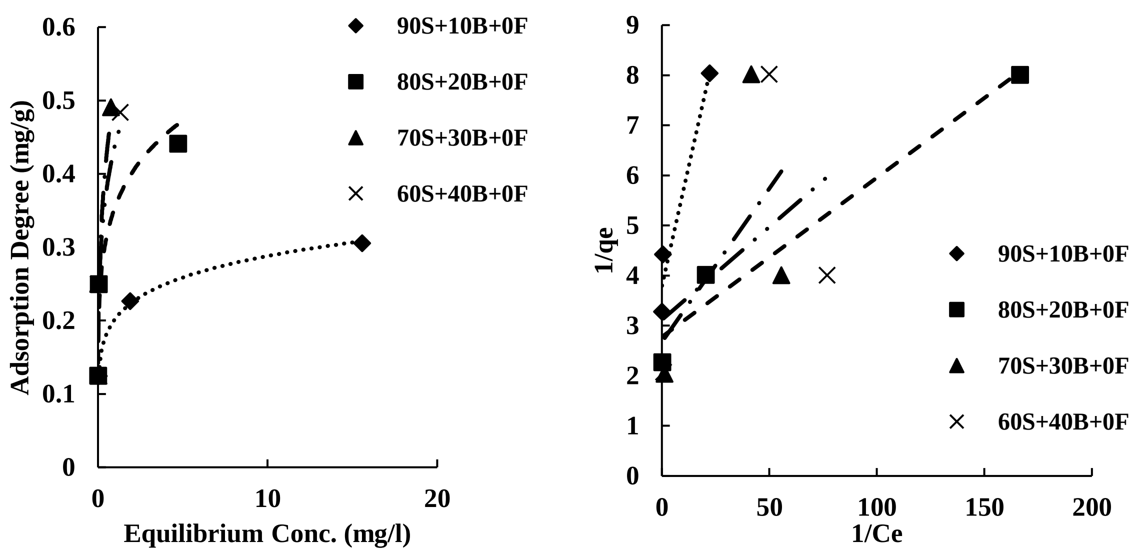

Fig. 6 Freundlich and Langmuir Isotherms with Cadmium

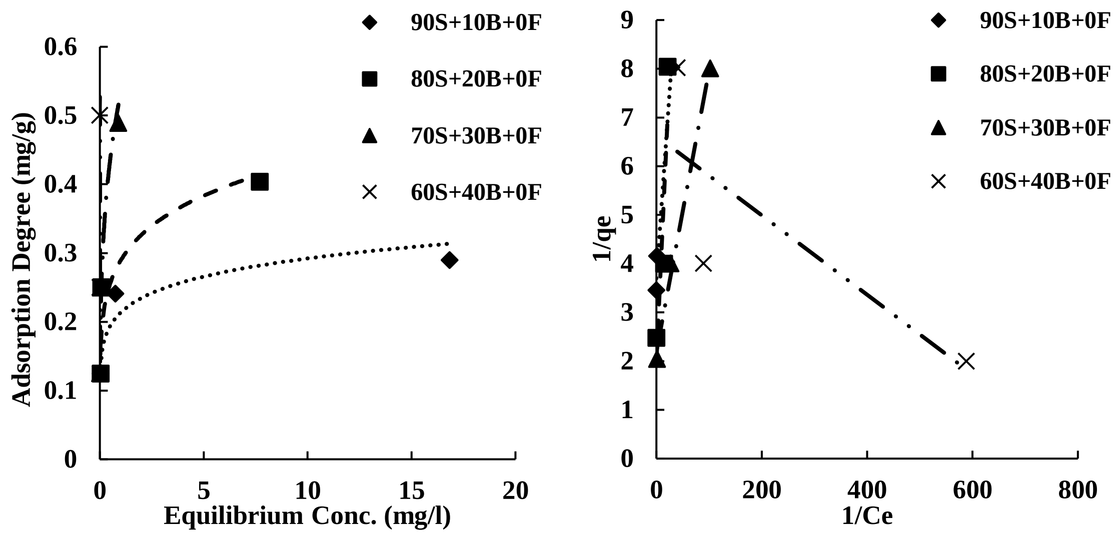

Fig. 7 Freundlich and Langmuir Isotherms with Zinc

In general, it was observed that as the soil to the metal solution ratio in the suspension increased, the adsorption of the metal under consideration in the soil increased. This may be attributed to the increase in the available adsorption sites. Upon analyzing the effect of the addition of bentonite to sand an increase in the adsorption capacity is witnessed in all the metals considered in the study.

4. CONCLUSIONS

Data regarding the compaction characteristics, hydraulic conductivity studies and compressibility characteristics of bentonite–sand mixtures have been accumulated using an extensive experimental program. The following conclusions can be drawn from the study:

- Bentonite addition to sand causes an increase in optimum moisture content and a reduction in the maximum dry density of the mixes. Plasticity characteristics of soil mixes increase with an increase in bentonite content.
- The hydraulic conductivity values for sand-bentonite mixes decrease with the increase in the bentonite content, with k ranging from 10^{-5} to 10^{-11} m/s with bentonite content varying from 0 to 40%.
- At 5% bentonite content for sand, the hydraulic conductivity value is found to be very low. The significant difference in k values for the sand-bentonite mix with 5% bentonite may be attributed in part, to an insufficient amount of bentonite added to that required to fill the void spaces between the sand particles.
- The matric suction increased in sand-bentonite mixes upon an increase in the percentage of bentonite in the mix which may prove to be detrimental to the stability of a landfill and thus the percentage of bentonite to be added was curtailed considering the suction characteristics.
- The strength of mixes increases with the addition of bentonite and hence, not any stability issues occurred under static loading.
- The addition of 10% bentonite in sand satisfies the requirement as a barrier material for use in engineered landfills.

- The adsorption phenomenon was best described by the Langmuir isotherms for all the four heavy metals considered in the study.
- All the metals got adsorbed when bentonite content exceeds 10% in sand-bentonite mixes.

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Indicators-Based Performance Evaluation of Municipal Solid Waste Management System – An Insight

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ABSTRACT

Solid waste generation has become a concerning issue due to the uncontrolled growth of the urban population and booming industrialization over the last few decades. Strategic decision making in municipal solid waste management is a challenging subject for decision and policy-makers as it comprises of the economic and capital aspects along with environmental and social aspects. Without competent and decisive solid waste management programs, the enormous amount of solid waste generated from various sources will subsequently result in serious health problems to human beings as well as potential hazards to the surrounding environment. Performance indicators (PI's) provide a broad spectrum for analysis and representation of performance focusing on loopholes in the existing solid waste management system as well as scope for future improvements. The use of performance indicators is essential for achieving sustainability concepts as it helps in providing information that is sometimes strenuous to obtain for complex environmental problems. Therefore, it becomes crucial to develop and implement simple, illustrative yet reliable performance evaluation tools capable of processing data inputs of fluctuating nature to provide a substantial amount of information in the solid waste management field.

The objective of this paper is to summarize the literature available on existing indicators for evaluating municipal solid waste management systems for developed as well as developing countries of the world. The present research work emphasizes formulating a comprehensive performance evaluation methodology for the municipal solid waste management system particularly relating to developing countries and then validating the proposed methodology for various urban centers of India in the future. The performance indicators-based framework is outlined for the performance evaluation of important domains of municipal solid waste management system such as Generation, Collection, Transfer and Transportation, Segregation, 3R's (Reduce, Reuse, Recycle), Treatment of MSW, Final Disposal, Economic aspect, Decision, and Policy-making, etc. The present study will help to cover the complete municipal solid waste management as a tool to help in planning, constructing and operating the facility towards an efficient and sustainable solid waste management system.

Keywords: Strategic Decision Making; 3R's; Comprehensive; Performance Indicators (PI); Municipal Solid Waste (MSW)

1. INTRODUCTION

1.1 Municipal Solid Waste Management

Municipal solid waste management is emerging out to be one of the most serious environmental problems confronting local municipalities in developing countries due to continuous expansion in the urban population. At present, about 54.75 million tons of municipal solid waste is produced annually i.e. 1.50 Lac tons Per Day (LTPD) from various urban centers of India. Per capita waste generation in cities varies from 0.20 kg to 0.60 kg per day depending upon the size of the population. The waste collection efficiency in India ranges between 70-90% in major Metro cities, whereas, in several smaller cities it is ranging between 50-70% or so (Ministry of Urban Development Government of India, 2013). Unsustainable waste disposal and unorganized management methods ultimately lead to environmental deterioration particularly in the form of pollution of land, water, and air. Most of the research studies have concluded that about 90% of municipal solid waste (MSW) is disposed of unscientifically in the open dumps and landfills, creating hazards to public health and the environment (Rathi, 2006).

The developing countries are observed to be more complex in the evaluation of municipal solid waste management (Guerrero et al., 2013). It's the need of the hour that municipal services must be evaluated and monitored for their qualitative and quantitative performance. Performance Indicator based assessment tools is very useful to measure the progress of waste management and planning strategies. The use of Performance Indicators for municipal solid waste management systems has been commenced with the publication of guidelines by various government agencies, starting in 1969. From the 1990s onwards, most of the research work started defining, formulating and implementing the performance indicators for the municipal solid waste management system. This work was later associated with benchmarking studies, commencing in 1998, by various international institutions (Sanjeevi & Shahabudeen, 2015).

The objective of this research work is to suggest the appropriate performance evaluation strategy to measure the qualitative and quantitative performance covering all the aspects of the solid waste management system. The research work is aimed to select and formulate the necessary key performance indicators to design the indicators-based comprehensive performance evaluation methodology emphasizing mainly on Indian conditions.

1.2 Performance Evaluation of Municipal Solid Waste Management System

Performance Evaluation of municipal solid waste management (MSWM) is a challenging issue because it includes composite, interdependent assessment criteria and thus needs proper modeling approaches to clearly identify the highly important criteria and their correlation to initiate more effective strategies for improving MSWM activities (Liao & Chiu, 2011).

It is generally a multi-dimensional process with many potential management options such as incineration, gasification and composting as well as many system elements that include storage, collection, transportation, and final disposal. Assessments are required to make effective and informed decisions in the selection of preferred options (Batagarawa et al., 2015). To understand and evaluate zero waste management, it becomes necessary to formulate a comprehensive performance assessment tool or a set of indicators (Zaman, 2014a).

1.2.1 Key Performance Indicators (KPI's). Performance Indicators are measures to describe how well a program is fulfilling its objective. These are simple measures, easy to analyze, accessible and reliable for monitoring various types of systems including solid waste management services. The process of selecting accurate and useful performance indicators is straightforward, but at the same time, it requires careful thinking, continuous-time refinement in the selected indicators, collaboration, and consensus-building (Monitoring, 1996). For any performance monitoring system, the key performance indicators are considered as 'main building blocks' of evaluation as they define the data to be collected to measure the development and enable actual results achieved over time to be correlated with the prospective results. Thus, they are fundamental management tools for making performance-based decisions about program strategies and activities (Ristić, 2005).

1.2.2 Benchmarks for MSW Performance Evaluation. Benchmarking is the systematic identification and evaluation of the best practices employed by the jurisdictions which lead to superior performance (Folz, 2001). The benchmarking process identifies the gap between current conditions or performance and the desired benchmark, evaluates it, and focuses primarily on closing out this gap (Budgeting, 2000). Benchmarks provide a uniform platform for defining, data collection; describing and assessing the service level key performance indicators, and help the ULBs to define 'Where They stand' as against the defined Benchmarks (Hassan et al., 2012).

1.2.3 Performance Evaluation Methods/Tools. The Performance evaluation tools are used to significantly identify strengths and loopholes in the existing management systems in a structured way and thereby highlighting the factors of success and failure. Assessment methods evaluate and compare different possible alternatives as in project scenarios. These assessment tools help to ensure a structured way of thinking and provide a comprehensive method for data collection and analysis carried out for the collected data (Zurbrü, 2014). Currently, large number of methods, approaches, and tools have been designed and implemented by the researchers to support the use of decision making in the field of municipal solid waste management as well as for evaluating the benchmarking performance e.g. Life Cycle Assessment, Multi-Criteria Decision Analysis, Life Cycle Costing, Cost-Benefit Analysis, Analytical Hierarchy Process, etc.

2. LITERATURE REVIEW

In the last couple of years, large numbers of research studies have been extensively undertaken by researchers from all over the world to determine the influential factors affecting solid waste management systems and to improve the management process in various urban centers. The growing concern over the critical environmental issues in recent decades drives the need for more comprehensive and reliable evaluation in terms of qualitative and quantitative performance. Assessment methods are common tools to support the decision-making process regarding the solid waste management system. For this purpose, commonly used evaluation methods are reviewed, categorized, and summarized. Various research studies are considered in view of their goals and policies, adopted methodologies, systems evaluated, and results regarding economic, environmental, and social issues and their evaluation.

2.1 Performance evaluation for developed countries

Interest in the development of performance indicators for solid waste management in developed parts of the world is in existence for a long time now. It is evident that most of the published research works have focused on high-income (developed) countries whereas very few that have focused on developing countries (David C. Wilson et al., 2015).

To promote the overall development and further improvements of municipal solid waste management in different areas, several studies are based on the use of performance indicators. Some of the examples are for zero waste management systems (Zaman, 2014a, 2014b), for Integrated solid waste management framework (Ristić, 2005; D. C. Wilson et al., 2012; David C. Wilson et al., 2015; David C Wilson, 2013), for waste collection service (Macdonald, 2007; Simões et al., 2012; Xue et al., 2015), for solid waste prevention (Wilts, 2013), for planning and multi-criteria decision making (MAIMONE, 1985), for comparing different MSWM systems (Căilean & Teodosiu, 2016; Desmond, 2006; Greene & Tonjes, 2014; Passarini et al., 2011). In some of the case studies, the performance of a specific component, based on data collected from various municipalities, was evaluated using a set of a few PI's for regional or global comparison (Guerrini et al., 2017; Zaman, 2014a). In another study, bias issues in the then-standard set of three solid waste benchmark indicators such as waste generated per capita; proportion of waste being managed by different methods; and proportion of households with a regular collection service were studied (Macdonald, 2007). On the basis of referred literature, the performance indicators formulated and implemented for developed countries are given in following Table 1.

Table 1 Performance indicators proposed for assessing performance in developed countries

Author	Application	Criteria Studied	PI	Scope
(Bertanza et al., 2018)	Italy	technical efficiency, the economic aspect	13	operational/ waste collection
(Ferreira et al., 2017)	Portugal	selective waste collection, recycling, collection trends	3	operational / waste collection
(Rigamonti et al., 2016)	Italy	environmental sustainability, cost	12	environmental/ waste management
(Căilean & Teodosiu, 2016)	Romania	Solid waste generation, the socio-economic, sustainability aspect	18	Environmental / Waste management
(David C. Wilson et al., 2015)	Global	collection, recycling, disposal, inclusivity; financial sustainability; sound institutions and proactive policies	12	operational / waste collection
(Zaman, 2014b)	South Australia	geo-administrative, socio-cultural, economic, environmental, organizational and policy	165	environmental/ waste management
(Mendes et al., 2013)	Portugal	production of waste, the quantity of recyclables, clients' satisfaction with the service, quantities of waste in landfills, and service costs	57	operational / waste collection
(Tanguay et al., 2010)	Western countries	economic, environmental and social aspect	188	environmental/ waste management

2.2 Performance evaluation for developing countries

In developing countries, waste management has the highest share in municipalities' budgets, spending from 20% to 50% of their available budget on solid waste management. A significant part (up to 80–90%) of the solid waste management budget is used for waste collection Services typically cover, however, only about 40–70% of all urban solid wastes, with the remaining being uncollected and less than 50% of the population being served (Proceedings and Stage 2003).

It is evident from most of the research works that MSW collection, transfer, and transport practices are affected by improper bin collection systems, poor circuits planning and lack of schedule information, insufficient infrastructures, poor roads, number of collection vehicles and waste processing (Findikakis and Leckie 1989). The performance indicators which are currently available for the developing countries' context have limited application in understanding the sustainability concerns. Some of them measure just one out of the three dimensions of sustainability - social, economic and environmental (Kwatra et al. 2016).

Based on the referred literature, the performance indicators formulated and implemented in developing countries are given in the following Table 2.

Table 2 Performance indicators proposed for assessing performance in developing countries

Author	Application	Criteria Studied	PI	Scope
(Kwatra et al., 2016)	Indian cities	environment, social and economics	19	environmental/ waste management
(Parekh et al., 2014)	Surat, Ghaziabad	collection coverage, transport, disposal, complaint, unit cost, outcome, segregation, 3R's, environmental factors	44	operational / waste collection
(Guerrero et al., 2013)	Developing countries	generation, separation, collection, transfer and transport, disposal	103	operational / waste collection
(Bringhenti et al., 2011)	Brazil	cost, scale, operation, social participation	25	Service/ Waste Collection
(Huang et al., 2011)	Taiwan	Selective waste collection	5	Service/ Waste Collection
(Armijo et al., 2011)	Mexico	service coverage, cost, service satisfaction, composition, recycling, recovery, disposal	18	operational / waste collection
(Rana et al., 2008)	Chandigarh	collection, recycling, disposal, inclusivity; financial sustainability; sound institutions and proactive policies	12	operational / waste collection

3. METHODOLOGY

To achieve the overall aim of this research work, the performance evaluation components (criteria) for the municipal solid waste management system were defined and finalized depending on a review of some of the publications: (Munizaga Plaza & Lobo, 2013; Parekh et al., 2014; Turcott Cervantes et al., 2018; David C. Wilson et al., 2015). Also, the existing number of performance indicators' sets used for municipal solid waste in the last few decades were thoroughly studied. The performance indicators which are repeated in most of the referred literature are grouped into 'Common Performance Indicators' while the performance indicators which are yet to be studied or very rarely studied are grouped as 'Uncommon Performance Indicators'. For this research work, the final set of performance indicators is formulated in such a way that it would be the combination of common and Uncommon PI's for Indian conditions. The questionnaire survey is developed for obtaining survey feedback from various experts working in the solid waste management field. From the survey feedback, all performance indicators were rated between high to very high priority in the range of 0 to 5 scale. The ratings obtained for each performance indicator will help to give the exact weightage of respective criteria in the whole municipal solid waste management system. The schematic representation of the methodology adopted for the formulation of a comprehensive performance evaluation model for the MSW management system is shown in the following Fig 1.

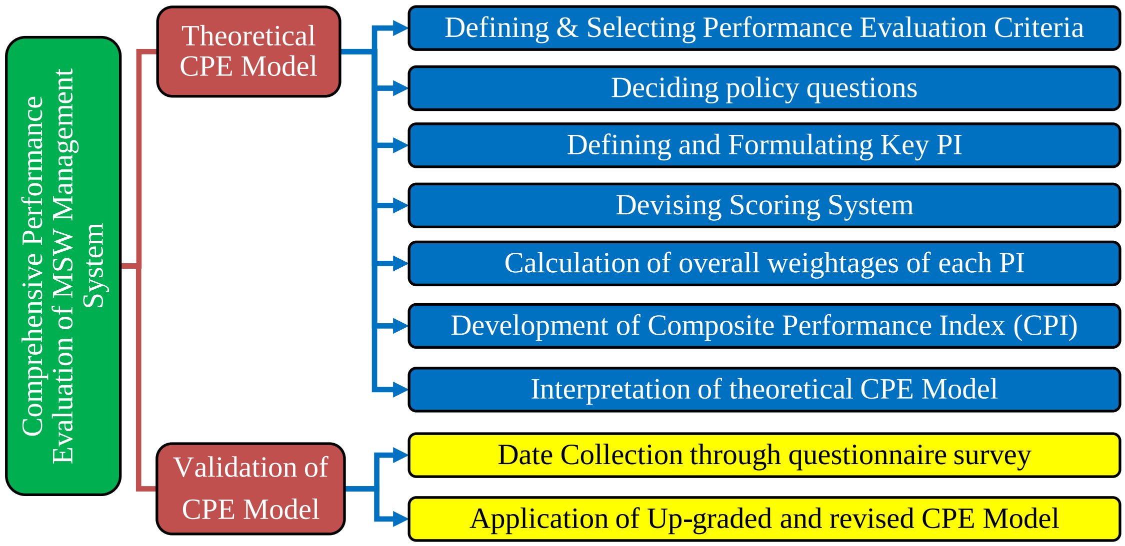

Fig. 1 Proposed Comprehensive Performance Evaluation (CPE) Methodology

4. CONCLUSIONS

Though assessment methods for solid waste management have greatly been improved in the last few decades, many research gaps still have been observed and that should be corrected, in particular to the use of performance indicators in developing countries. Appropriate data is still lacking, in particular, baseline information and few performance indicators which can be used for performance evaluation models. The performance indicator framework for developed countries focuses on significantly wider criteria of research. For developing countries, assessment tools need to be more practical and elaborative as compared to developed countries. The challenge lies in developing a set of tools that is robust, flexible, and as universal as possible in terms of its applicability and usefulness. Regardless of all the efforts made to measure progress made on specific aspects of sustainability, there has been no comprehensive reporting of sustainability in the Indian context. The research studies carried out in India have not resulted in an aggregate measure of sustainability. Thus, there is a need to formulate an index that comprehensively measures sustainability and provides a baseline to the decision & policy-makers in the strategy-making process for improving the overall performance of the municipal solid waste management system.

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Stability Assessment of Water Retention Type Tailings Dam under Static and Pseudostatic Conditions

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ABSTRACT
Water retention type tailings dams (WRTDs) are constructed to store the non-hazardous tailings waste generated by the mining industry. These tailings may pose great threat upon direct contact to natural and the built environment. Therefore, it is pertinent to design such tailings storage structures in such a way that their long-term stability during the design life is maintained in the wake of instability arising from natural and anthropogenic events. The aim of present study is to understand the stability behavior of WRTDs when subjected to steady-state seepage and pseudostatic conditions. The dam section considered here is having a height of 12 m and side slopes of 1V:2H. Seepage and slope stability analyses are carried out numerically using finite element-based Soil Vision software. The influence of various drainage provisions, reservoir filling material, side slopes, and horizontal seismic coefficient (K_h) is investigated. With the provision of drainage, the phreatic surface is restricted within the dam section away from downstream face thereby increasing the stability against seepage failure. It is observed that the WRTD is more prone to failure with water as upstream reservoir filling material instead of tailings material. Also, the factor of safety (FoS) values of the dam sections are observed to decrease upon subjecting to higher seismic coefficient values. It is concluded that the long-term stability of small tailings storage dams and embankments can be enhanced by considering water in upstream reservoir as the worst-case scenario during design, with mild to gentle downstream slopes, with adequate provision of drains.

Keywords: Tailings dams, slope stability, pseudostatic stability analysis, seepage analysis

1. INTRODUCTION

A tailings dam is typically an earth-fill embankment dam used for storage of non-hazardous residues/tailings originating from mining and milling operations. It is in practice to construct large tailings storage reservoirs, impoundments, dams, embankments, and dykes for their deposition and storage. The main job of a tailings dam is to contain the tailings slurry, and recycle the water from the impoundment after settling of solids. However, these are designed as a water retention type dam (WRTD) for slope stability and seepage requirements (Cowherd et al. 1993). Tailings material placed within the impoundment consolidate very slowly, and there always remains a possibility for the development of high pore water pressure during a seismic event. It can lead to the reduction of effective stress; subsequently, the shear strength of the tailings material also reduces. Due to this, the slope of embankment becomes unstable and prone to failure. It is pertinent to design these storage structures in such a way that they are stable on the wake of instabilities arising due to natural and anthropogenic activities. In terms of mechanical instability, tailings dams are reported as very high-risk structures. Statistics indicate that tailings dams have failed majorly due to slope instability triggered by natural hazards/rainstorms (Rico et al. 2008). In case of failure, landslide like situation prevails, the saturated and viscous tailings then start flowing in the direction of the breach. Other causes of tailings dam failures include overtopping, piping failure due to erosion, weak foundations, liquefaction, and increased pore water pressure. Some of the recent failures caused due to one of these causes include Brumadinho dam failure in Brazil in 2019, Cadia mines in Austrailia in 2018, Mount Polley dam in Canada in 2014 etc. and have caused tremendous devastation to the natural environment, resources, and the built environment.

Various studies have been carried out to quantify the behavior of tailings dams under static and seismic conditions through finite element based numerical methods, full-scale model tests in the field at normal gravity, and small-scale model tests in a geotechnical centrifuge at high gravity. However, many challenges lie in full-scale field tests, including the cost of the model and testing facility; space constraints, duration of the test and the surrounding environment; and repeatability of full-scale tests for parametric studies. Such issues do not arise while using finite element based numerical techniques with an appropriate choice of material model and boundary conditions. Many researchers like Byrne et al. (1984), Castro et al. (1985), Leshchinsky and San (1994), Akhlaghi and Neishapouri (2007), Chakraborty and Choudhury (2009, 2013) have carried out seismic slope stability analyses of tailings dams using different FEM and FDM based software. Akhlaghi and Nikkar (2014) carried out seismic slope stability analyses of 24.4 m high Upper San Fernando Dam and 24 m high Kitayama Dam using Plaxis-2D. Sitharam and Hegde (2017) performed seismic analyses for rock-fill tailings dam using $FLAC^{2D}$. However, these modelling techniques do not replicate the exact behavior of the prototype structure owing to inherent approximations in material models and the physical phenomenon a model can represent. Over the past few decades, physical modelling techniques such as centrifuge-based model studies have also emerged as a tool to understand in detail the deformation and stability aspects of similar structures like retaining walls, road embankments, reinforced soil walls, levees, and hill slopes.

The present study addresses the seepage and slope stability behavior of a 12 m high WRTDs carried out using SVOFFICE 5 (2018) software. The influence of various parameters viz. drainage provisions, type of upstream reservoir filling, downstream slope, and effect of horizontal seismic coefficients are studied.

2. NUMERICAL MODELLING CONSIDERATIONS FOR WRTDs

2.1 Model Geometry and Material Properties

The seepage and slope stability analyses of WRTDs under static and pseudostatic conditions is carried out for a 12 m high dam having upstream and downstream side slopes of 1V:2H. The dam crest width, B_{crest} is 6 m and a free board of 1 m is provided to maintain reservoir level at 11 m at all times. Figure 1 represents the typical cross-section of the tailings dams considered for the present study. The dam is built on a 1.5 m thick impermeable foundation constructed by blending shell material with 20% of commercially available kaolin (by dry weight). The dam shell section is prepared by blending locally available Goa Sand with kaolin in 4:1 ratio by dry weight. The silty sand mix is having maximum dry unit weight $\gamma_{d,max}$ of 19.25 kN/m^3 and optimum moisture content (OMC) of 7.5% (standard Proctor compaction). The cohesion (c) and interface friction angle (ϕ) for this model soil are 11.6 kPa and 28° obtained from saturated and drained direct shear tests. The coefficient of permeability, k of the soil is measured as 1.54×10^{-6} m/s obtained from falling head permeability test. The average value of permeability of Goa sand determined from constant head permeability test is 0.7×10^{-4} m/s and the value of internal friction angle is observed as 33° with zero cohesion. Similarly, for the pond tailings material the cohesion (c), interface friction angle (ϕ), and coefficient of permeability (k) are 14.7 kPa, 12º and 1×10^{-8} m/s.

2.2 Seepage Analysis

A 2D steady state seepage analysis is conducted using a finite element based SVFLUX-GE module of SVOFFICE 5 (2018) geotechnical software. The governing partial differential equation for the steady state seepage (assuming vapour flow is negligible) considering saturated soil conditions is given by Equation 1, where, k_w is the hydraulic conductivity function.

$$\frac{\partial}{\partial x}\left[k_x^w \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[k_y^w \frac{\partial h}{\partial y}\right] = 0 \qquad [1]$$

In the present study, respective hydraulic heads at strategic locations are assigned constant values to serve as necessary seepage boundary conditions, as shown in Figure 1.

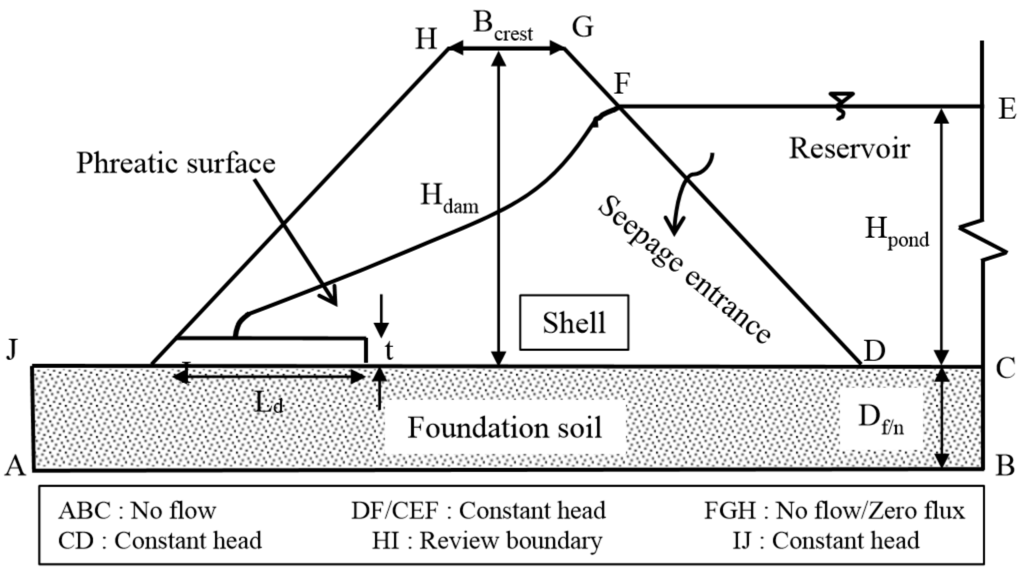


Fig. 1 Typical cross-section of a WRTDs with seepage boundary conditions

2.3 Slope Stability Analysis

The seepage analysis results obtained at various stages of analyses using SVFLUX are incorporated into the limit equilibrium based SVSLOPE module of SVOFFICE 5 (2018) for computing the static and pseudostatic slope stability of WRTDs. Here, Bishop's method (Bishop, 1955) is used for calculating the FoS values by considering circular slip surfaces by the static limit equilibrium procedure in which horizontal (F_h) and/or vertical inertia forces (F_v), destabilising effect of the earthquake, are applied to the potential sliding mass of the dam section. In an actual analysis, inertial forces F_h and F_v acting through the centroid of the sliding mass, as computed using Equations 2 and 3, are applied which acts in out of the slope direction. In this method, the cyclic earthquake motion is replaced with constant horizontal acceleration (a_h) and vertical seismic accelerations (a_v) expressed as ($K_h g$) and ($K_v g$), respectively where K_h and K_v are horizontal and vertical seismic coefficients. The FoS is given by Equation 4.

$$F_h = ma_h = \frac{Wa_h}{g} = K_h W \qquad [2]$$

$$F_v = ma_v = \frac{Wa_v}{g} = K_v W \qquad [3]$$

$$\text{FoS}=\frac{\text{Resisting Forces}}{\text{Driving Forces}}=\frac{cl+\left[(W-F_v)\cos\beta-F_h\sin\beta\right]\tan\phi}{(W-F_v)\sin\beta+F_h\cos\beta} \quad [4]$$

Where, W is the weight of the soil failure wedge, and β is the inclination of failure plane with the horizontal. The stability of sliding mass depends critically on the selection of appropriate seismic coefficients. For analyses, K_h for various seismic zones is obtained from IS 1893-Part 1 (2016).

3. PARAMETRIC STUDIES ON WRTDs

This study aims at long-term stability of WRTD section subjected to steady-state seepage and pseudo static conditions. Given this, the main focus of parametric studies is to understand the influence of (a) drainage, (b) downstream slope, (c) upstream reservoir ponding, and (d) horizontal seismic coefficient. The analyses details are discussed under following headings.

3.1 Influence of Drainage provision

The influence of drainage is studied by considering the effect of a horizontal drain and a chimney drain on the seepage. The length of the horizontal portion of both the drains (L_{hd}) is kept up to centre of the crest with thickness of the drain (t_{hd}) as 800 mm. The vertical height of the chimney drain is considered as 11 m and the upstream reservoir is impounded with water with minimum freeboard of 1 m. Figure 2 compares the phreatic surfaces for 12 m high WRTD for above configurations. Figure 3 clearly depicts the distribution of pore water pressure for case without any drainage provision, and a case with clayey core and horizontal drain. The presence of drains ensures that phreatic surface is contained well within the dam section, away from downstream slope, thereby, enhancing stability against seepage. Further, it is observed that the presence of chimney drain helps in dissipating the pore water pressure faster, subsequently lowering down of the phreatic surface as compared to when the horizontal drain. From slope stability analysis, the FoS values (Bishop's method) observed for the dam sections without drainage, with horizontal drain, with chimney drain, and with impermeable clayey core are 1.192, 1.566, 1.547 and 1.598, respectively. Figure 4 shows the static FoS and slip surfaces for case without drainage, and for case with clayey core and horizontal drain. It is clearly seen that the presence of drainage resulted in containing the phreatic surface and maintaining the static FoS values greater than 1.5.

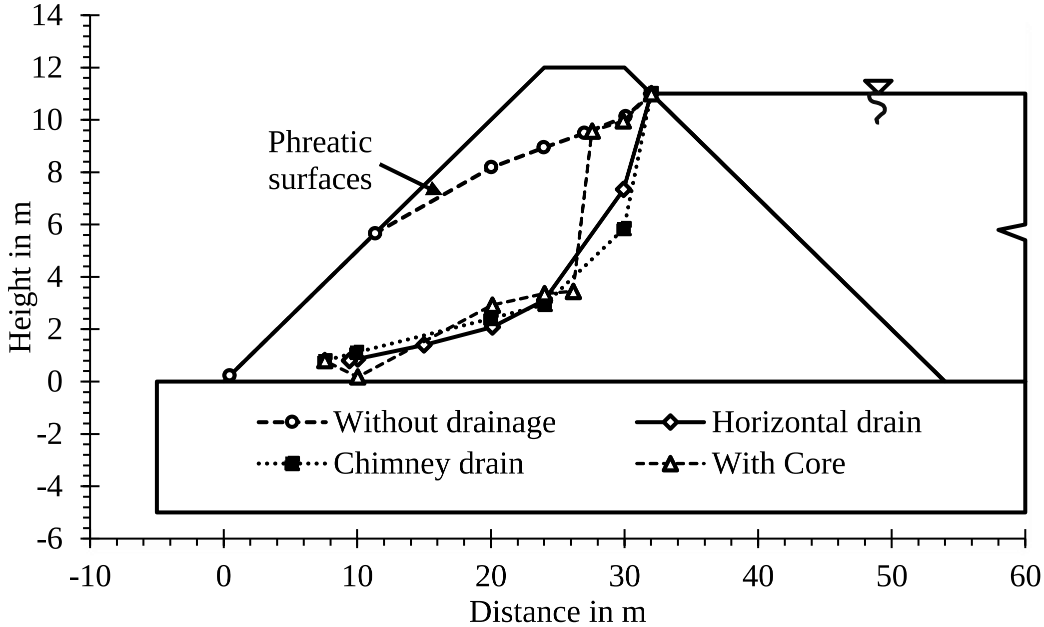
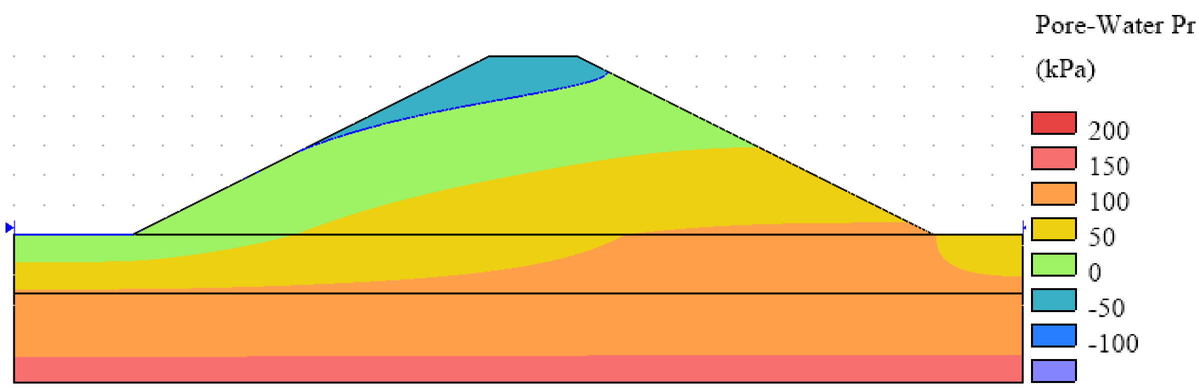
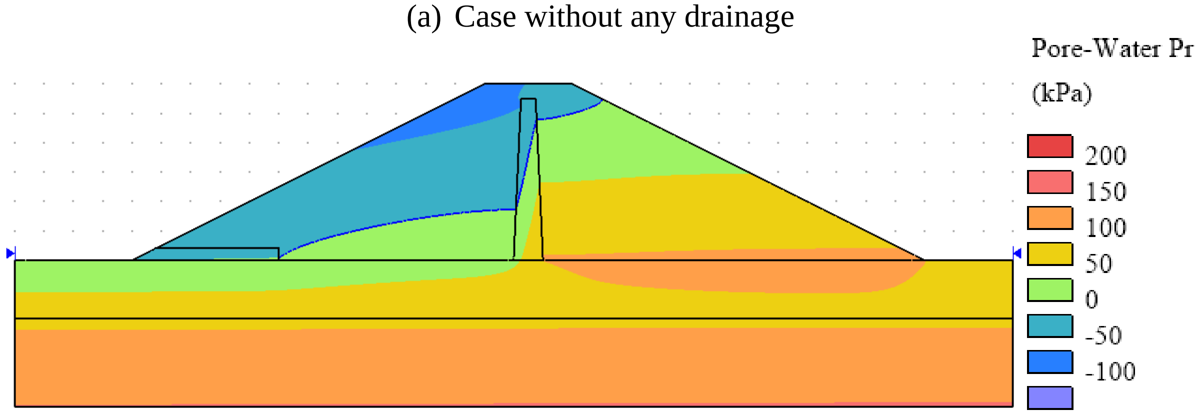


Fig. 2 Comparison in phreatic surfaces for various drainage provisions

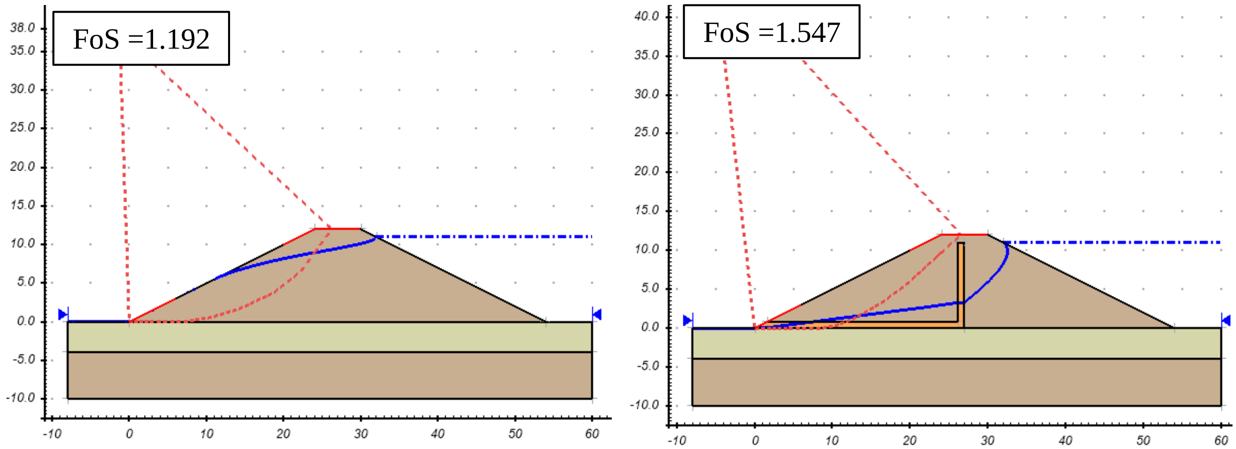


(a) Case without any drainage



(b) Case with clay core and horizontal drain

Fig. 3 Distribution of pore pressure (in kPa) for the dam sections modelled using SVFlux

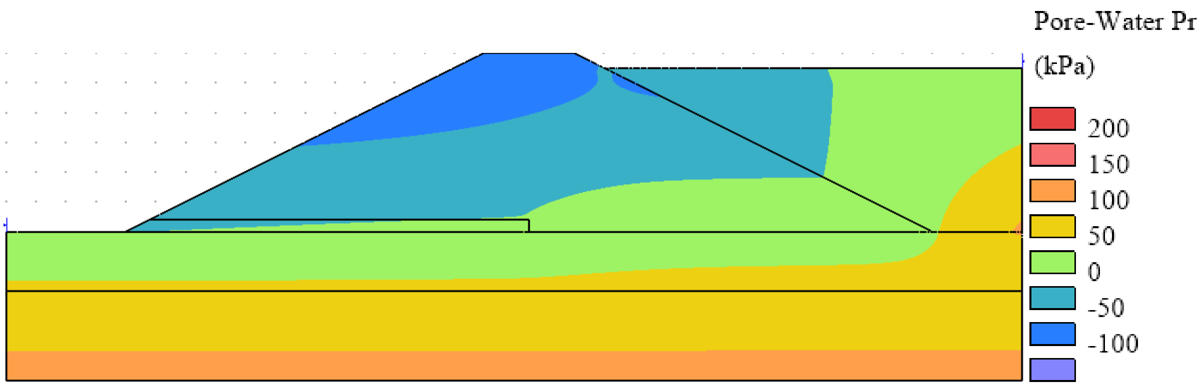


(a) Case without any drainage (b) case with chimney drain

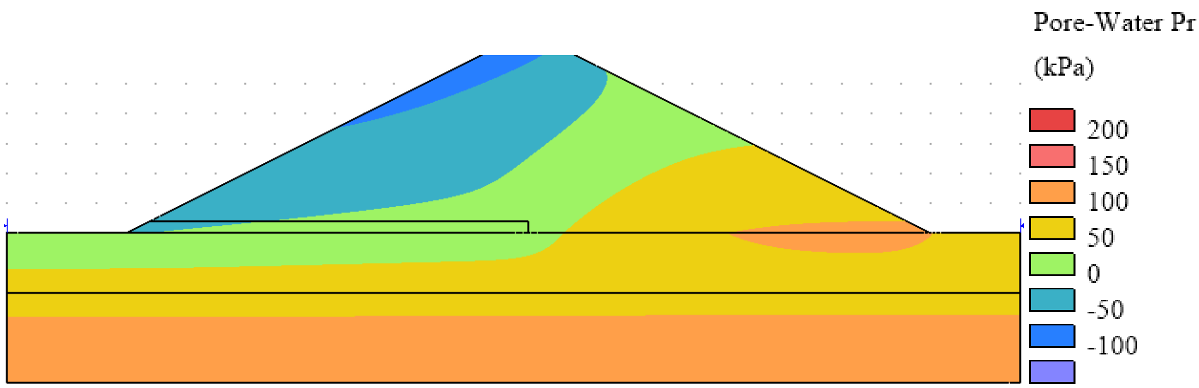
Fig. 4 Static FoS values (Bishop's method) for 12 m high WRTD modelled using SVSLOPE

3.2 Influence of Upstream Reservoir Ponding

The influence of reservoir ponding on the stability of WRTDs is studied by considering two cases viz. (a) the upstream reservoir filled with water only, and (b) the upstream reservoir filled with pond tailings only. The dam configurations having horizontal drainage up to centre of crest, are modelled using Soil Vision (2018). Figures 5 depicts the variation of pore water pressure and phreatic surface for dam section having horizontal drain for both the scenarios. Figure 6 depicts the slip surface and static FoS value when the upstream reservoir is filled with pond tailings only. Clearly, the development of pore water pressure is less and static FoS values are marginally higher for the cases having pond tailings as upstream reservoir material depicting greater downstream slope stability during steady-state conditions as compared to when there is water in the upstream reservoir.

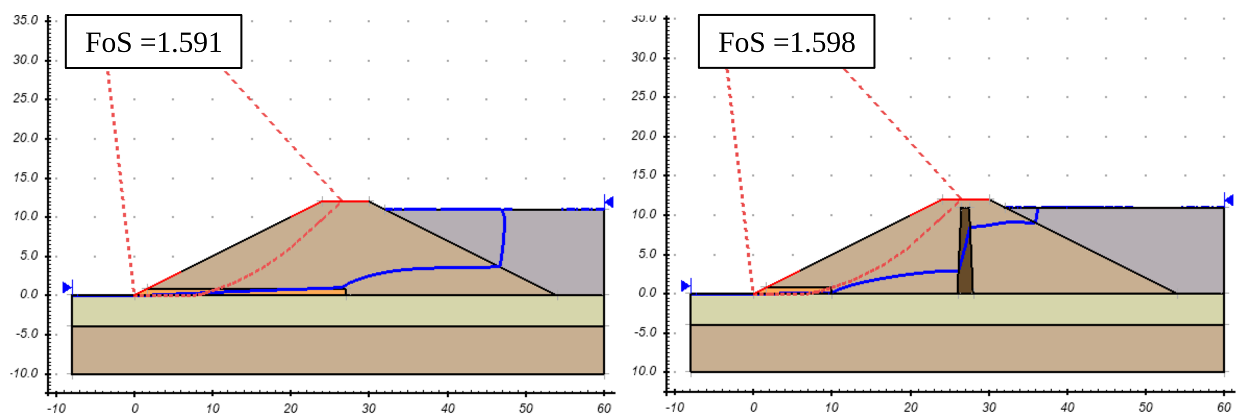


(a) Pond tailings as upstream storage



(b) Water as upstream storage

Fig. 5 Distribution of pore water pressure (in kPa) for the dam sections having horizontal drain modelled using SVFlux



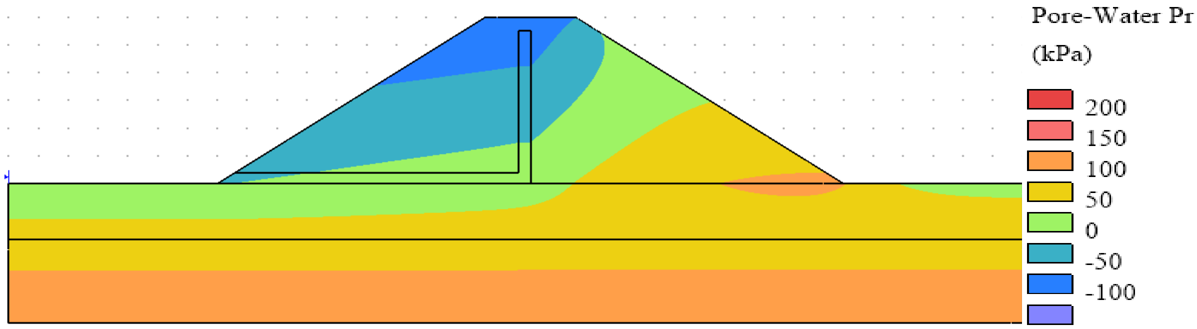
(a) Case with horizontal drain (b) case with clay core and horizontal drain

Fig. 6 Static FoS values for 12 m high WRTD with impounded tailings slurry

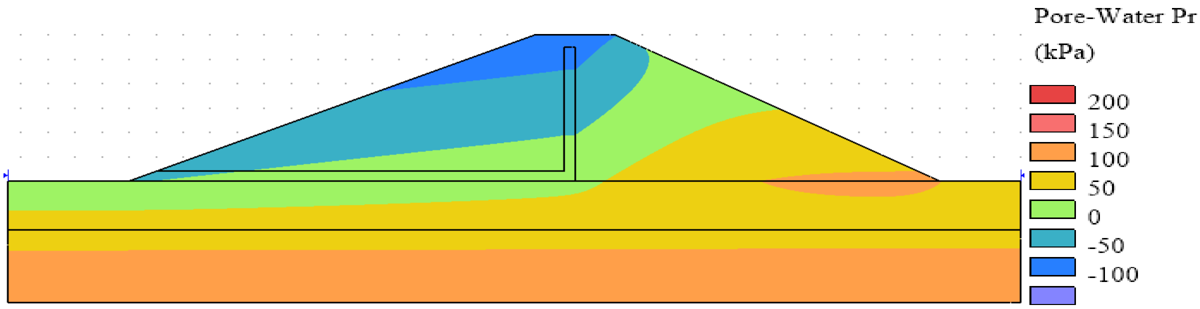
In the present case, when tailings are present the infiltration of the leachate or contaminated water through the dam foundation is restricted by the impermeable layer. However, additional safety in terms of liner materials shall also be deployed for the same.

3.3 Influence of downstream slope

The influence of the downstream slope is studied by considering additional slopes viz. (a) 1V:1.5H and (b) 1V:2.5H. All these dam sections are having provision for chimney drain and water is filled in the upstream reservoir. The upstream slope is considered same as the downstream slope for above cases. From slope stability analysis, the FoS values are observed to be higher for gentler slope as compared with the steeper slope. Figure 7 depicts distribution of pore water pressure for the above dam sections which is very much same in all these cases. The static FoS values and slip surfaces obtained from slope stability analyses are depicted in Figure 8.

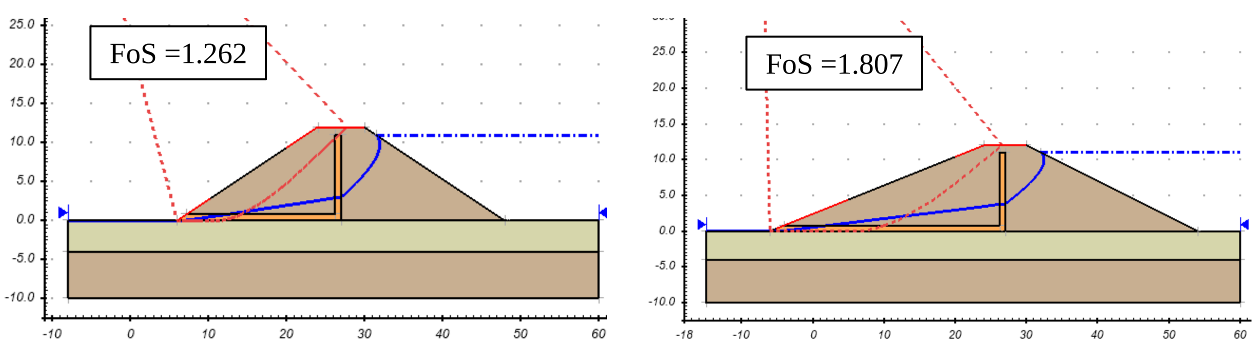


(a) For 1V:1.5H



(b) For 1V:2.5H

Fig. 7 Distribution of PwP (in kPa) for WRTDs section with different downstream slopes



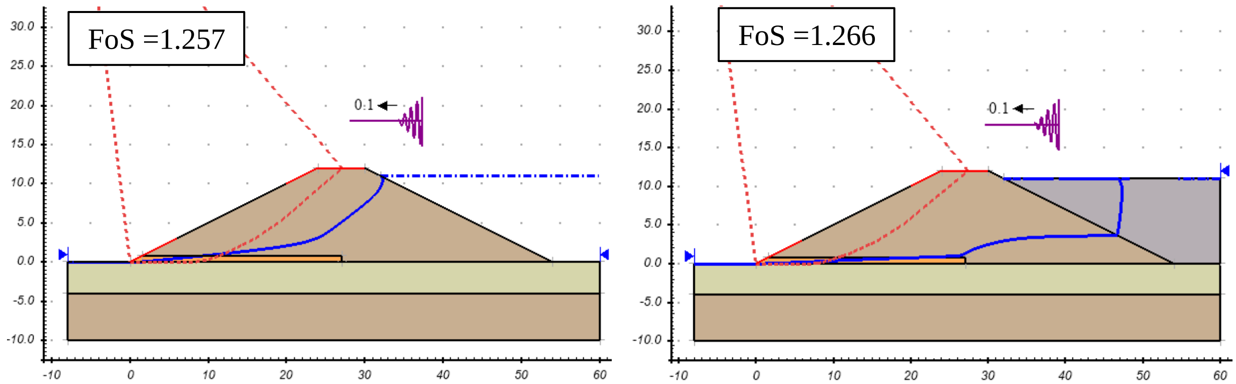
(a) slip surface for 1V:1.5H (b) slip surface for 1V:2.5H

Fig. 8 Static FoS for WRTDs section with different downstream slopes

The FoS values observed for the dam sections with 1V:1.5H, 1V:2H, and 1V:2.5H downstream slopes are 1.262, 1.547, and 1.807, respectively. Hence, gentler the slope i.e. greater than 1V:2H, the static FoS values are greater than 1.5.

3.4 Influence of Horizontal Seismic Coefficient

Herein, the dam sections discussed above are subjected to different horizontal seismic coefficient (K_h) values viz. 0.05, 0.10, 0.15, and 0.20 acting in a horizontal direction towards the downstream side with the vertical component (K_v) taken as zero. The dam configurations are modelled using SV Flux for generating phreatic surfaces under steady-state seepage condition. SV Slope is used for static and pseudostatic slope stability assessment.



(a) with water in upstream reservoir (b) with pond tailings in upstream reservoir

Fig. 9 FoS values for WRTD section having 1V:2H slope with different reservoir storage subjected to K_h=0.1

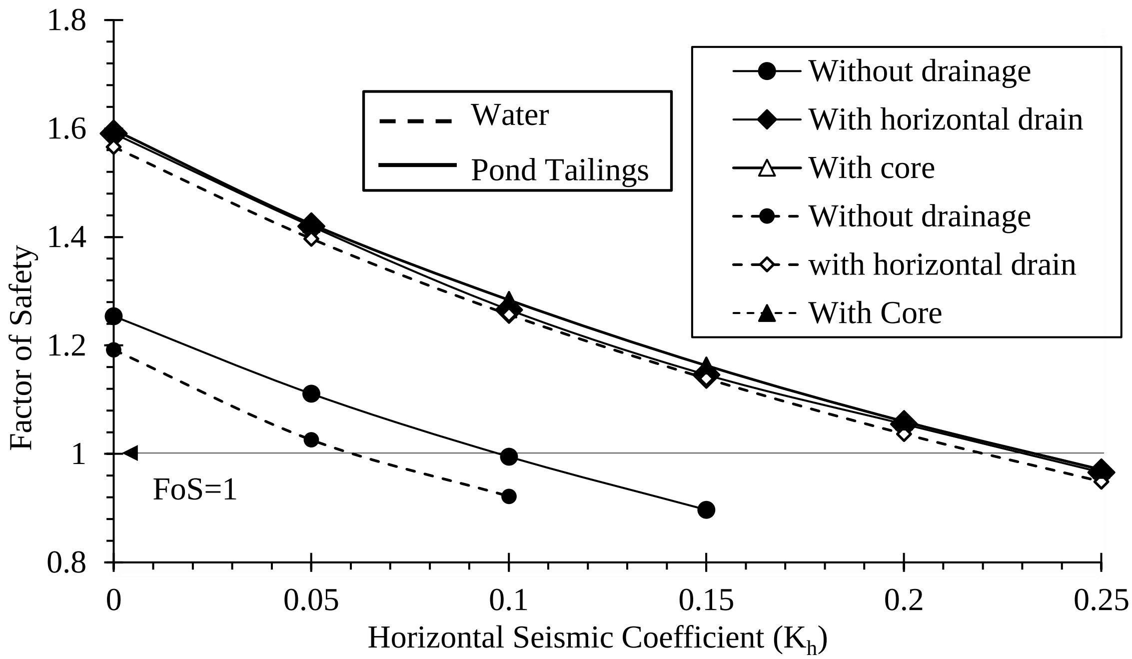


Fig. 10 Variation of FoS values (Bishop's method) with K_h value for different configurations of WRTDs

Figure 9 depicts the slip surfaces and FoS values for a dam section having horizontal drain subjected to K_h = 0.1 and retaining water and pond tailings in the upstream reservoir. It is observed that the Bishop's FoS values keep on decreasing with the increase in the design K_h values for all the WRTDs configurations, as shown in Figure 10.

4. CONCLUSIONS

The paper presents the results of numerical analyses to understand the seepage and slope stability behaviour for a 12 m high WRTDs under static and pseudostatic conditions using Soil Vision (2018) software. Based on the parametric studies and interpretation of results, the following conclusions can be drawn:

a) For dam section having 1V:2H slopes, presence of drain have considerable reduced the pore water pressure within the dam section leading to lowering down of the phreatic surface and containing well within the dam body. Presence of drains has also led to increase in the static FoS values. However, there is very minimal change noticeable, almost negligible in the FoS values amongst various type of drainage provisions. The counter measures for seepage of the tailings leachate into the groundwater also need to be deployed by constructing thick impermeable barriers and/or liners to avoid underground contamination.
b) The water retention type dam section having pond tailings in the upstream reservoir is more stable against seepage failure due to lower pore water pressure within the dam section and lower level of phreatic surface as compared to when water is ponded. Also, the static FoS values for the tailings pond case is marginally higher than the water reservoir. Therefore, design of the tailings impoundment structure shall be based on the worst case scenario where water is stored in the upstream reservoir.
c) The static FoS values observed for the dam sections with 1V:1.5H, 1V:2H, and 1V:2.5H downstream slopes are 1.262, 1.547, and 1.807, respectively. Therefore, dam section with slopes greater than 1V:2H have the static FoS values greater than 1.5. Also, the slopes and vicinity areas require to be highly vegetated to prevent contamination of the nearby environment by dried up tailings transported by wind/rains etc.
d) As the dam sections are subjected to increasing horizontal seismic coefficient, the stability of the downstream slope has reduced. For K_h value greater than 0.2, the dam sections are indicating failure. In such risk conditions, there is a high possibility of release of the impounded material after a seismic event. Therefore, constant monitoring of the crest and slopes for any deformation, and fluctuation in piezometers readings etc. installed if any shall help in timely decision making and reduce the damage.

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Theme C

Reuse and Sustainability

Assessment of Microsilica as an Ameliorate Material for Municipal Solid Waste Clay Liner System – A Case Study

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ABSTRACT
Currently, in many countries, urban solid waste disposal has become a concern. The leachate that comes from the dumping of solid waste contaminates the environment around it. Compacted clay liners are widely used to shield natural soil from pollution at municipal waste disposal sites. The preclinical studies for composite clay liner promote the calculation of coefficients for adsorption distribution. These values were used for forecasting groundwater content in the Pollute v7 program. The pristine earth would have experienced the changes over the fifty years of solid waste disposal, introducing the toxins into the groundwater. By using the assumptions, groundwater contamination was performed with the Pollute v7 model, and the distribution coefficient determined the experimental studies. The samples collected from the in-situ were analyzed and correlated with analytical results. For liner variance Mg^{2+}, in which pattern feedback was considered. The input parameters of the model are taken as in three different ratios of 1:20 and 1:10 cement, microsilica-clay composites.

Keywords: Microsilica; Magnesium; Pollute v7 model

1. INTRODUCTION
Nowadays most of India's urban solid waste is unscientifically disposed of. This does not only adversely affect biodiversity but also the human climate. Unsubstantiated management methods leave the waste unaccompanied at the dumpsite, enticing rats, mice and fleas to its garbage, producing filthy conditions such as odor, the release of airborne contaminants, etc. When water flows into the dump, it mixes to create leachate with liquid from the garbage. The leachate is absorbed into the subsurface causing pollution of the subsoil and groundwater. The solid waste persists at its place for years, hence the cycle of incorporation of leachate into the subsurface system proceeds slowly and steadily over several years. Leachate is very complex by itself. This comprises a broad spectrum of chemical compounds ranging from organic to inorganic salts.

A composite liner consists of two barriers, made of different components, positioned in intimate contact to provide a favorable combined effect of both barriers (MSWM, 2000). Geosynthetic clay liner consists of powdered sodium bentonite sandwiched between geotextiles. Geosynthetic clay liner is used as a landfill liner due to its low permeability (1x 10^{-9} cm / s), ease of placing, and potential environmental hazard tolerance (Robert et al; 1995; Daniel 1996).

Shackelford et al. (2000) and Lake and Rowe (2000) used diffusion testing for geosynthetic clay liner (GCL) using the compaction mold form. The coefficient of diffusion was determined to be directly proportional to the volume of permeated air. Studies of diffusion dominant transport and sorption through single clay liner soils were carried out by many researchers, e.g., Shackelford and Daniel (1991), Thornton et al. (2001, 2002), Malusis et al. (2004), Rowe et al. 1988 and Barone et al.(1990) However, studies on diffusion characteristics double liner materials was relatively few e.g., Yeon-Soo Jang et al.(2003), Yan Jun Du et al. (2005) and Madalenabarroso et al. (2006).

Program Pollute v7 is used to acquire a match to the trial information and foresee future contaminant transport of landfills. The business Pollute code actualizes a few answers for the one-dimensional theoretical models examined in Pollute v7. Further, instances of the calculated execution of one-dimensional models and application to hindrance frameworks are given by Simunek et al., (2005) and Rabideau (2004). Simunek et al., (2005) talked about the HYDRUS-1D Software bundle, The HYDRUS-1D Software Package is for simulating the one-dimensional development of water, heat, and various solutes in dynamically immersed media

In this paper, the effect of a landfill on groundwater quality and underscores the required precautionary steps to be taken during landfill site expansion in adjacent areas. Specifically, the results from the laboratory studies used Pollute v7 software in mathematical modeling. The performance of the study was compared with the outcomes of the sector and a distinction was made.

2. MATERIALS AND METHODS

2.1 Collection of Clay Soil

The samples of bulk clay soil were collected from a place called killiyur. The soil color is very reddish brown-grey, and a fine grain textured. The soil was used for testing in accordance with ASTMD4647-93 and Indian Standard 36(part 1):1987.

2.2 Microsilica

Silica fume is a highly effective pozzolanic substance because of its intense fineness and high silica content [ACI, 1987]. The microsilica was collected from Elkem Grade 920-D Grade Microsilica. Supplied by Elkem India Pvt Ltd., Mumbai conforming to ASTM C1240-03, PREN 13263 specifications. The American Concrete Institute (ACI) characterizes silica fume as "fine non-crystalline silica delivered in electric circular segment heaters as a side-effect of the generation of essential silicon or amalgams containing silicon" (ACI 116R).

2.3 Collection of Municipal Solid Waste Leachate

The leachate was gathered from Municipal Solid Waste Landfill Ariyamangalam, Tiruchirappalli, India, which is arranged on the banks of the stream Cauvery. The municipal solid waste composition was analyzed.

2.4 Model

The experimental studies facilitate the determination of coefficients for the adsorption distribution. Pollute v7 model used these values in modeling leachate penetration through the soil matrix. Pollute v7 is a one-dimensional contaminant model.

2.5 Column Setup for Composite Liner System

Column tests, otherwise called miscible dislodging tests, are the most usually utilized technique to study solute transport in soils. Contaminant transport through the mud liner in landfills was examined through a research facility test and examination technique on the vehicle of leachate in a composite dirt layer soil framework. In the composite clay liner framework, geosynthetic clay liner (GCL) was put over the dirt soil included with microsilica (see Fig 1). The tests were directed like the one accomplished for single earth liner frameworks.

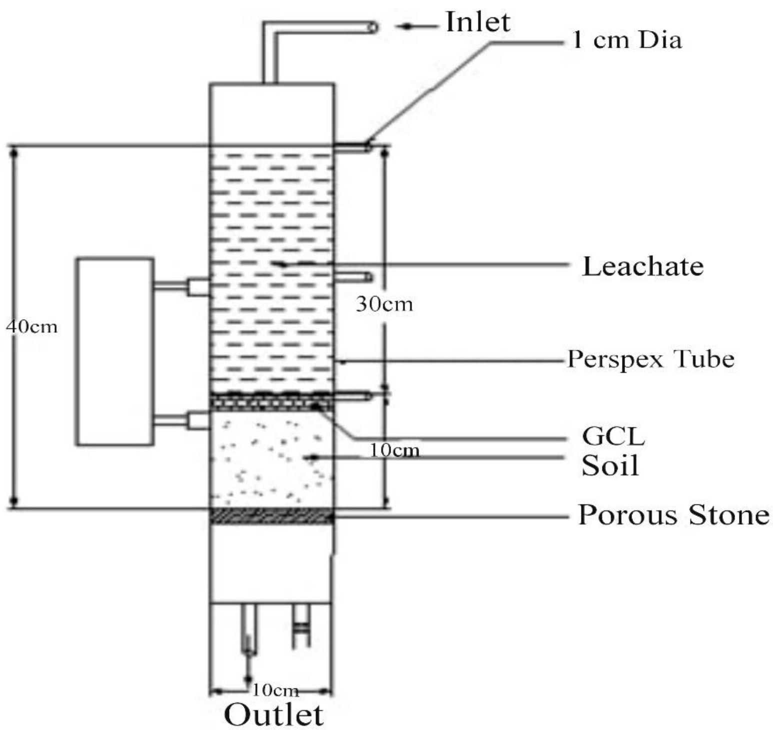

Fig. 1 Column setup for the composite liner system

3. RESULTS AND DISCUSSION

The landfill was assumed to have a soil layer thickness of 1 m and the number of layers was considered as 4. The landfill had the following properties dry density of 0.71 g/cm^3, soil porosity 0.71. The top source concentration of leachate in magnesium taken as 909 g/l (C_o). The predicted concentrations (C_p) at the point of P in the time of interest as 10,50,100 and 200 years. The input parameters Pollute v7 of diffusion column testing of raw clay for Magnesium are distribution coefficient, soil porosity, dry density, soil layer thickness, number of sub-layers, source concentration, base concentration 0.0, times of interest (10,50,100,200 years), Darcy velocity, diffusion coefficient. The model output values for time interval vs concentration for different depth are tabulated (see Table 1) and the numerical values are calculated by using Pollute v7.

Table 1 Model output for raw clay of depth vs Mg^{2+} concentration with time intervals

Time in Years	Depth in m				
	0	0.25	0.5	0.75	1
	Magnesium concentration in mg/l				
10	909	122.9372	2.556957	6.75E-03	4.19E-06
50	909	458.2488	165.0724	41.72428	13.70466
100	909	579.5715	317.5982	158.7519	106.9571
150	909	641.8933	419.0855	273.6422	223.421
200	909	686.3941	498.4452	373.5867	329.9222

The variation of concentration for different depth and time variation is shown (see Fig 2). The output of the model anticipated time interval interest as 0, 50,100,150 and 200 years. The model output result is generated depth of 0 m,0.25 m,0.5 m,0.75 m and 1.0 m underneath the ground surface and corresponding Mg^{2+} concentration shown (see Fig 2). The Well-1, well- 2 and well- 3 groundwater observation bore wells average Mg^{2+} concentration is 403 mg/l, 285 mg/l, and 249 mg/These values were marked (see Fig 2) at time duration of as 50 years since Tiruchirappalli landfill began 50 years. The three well values lie between 0.25 m to 0.5 m. So, the depth of concentration taken as 0.5 m from the ground surface. A similar methodology rehashed miniaturized scale silica-clay composites of 1:20 and 1:10 proportion.

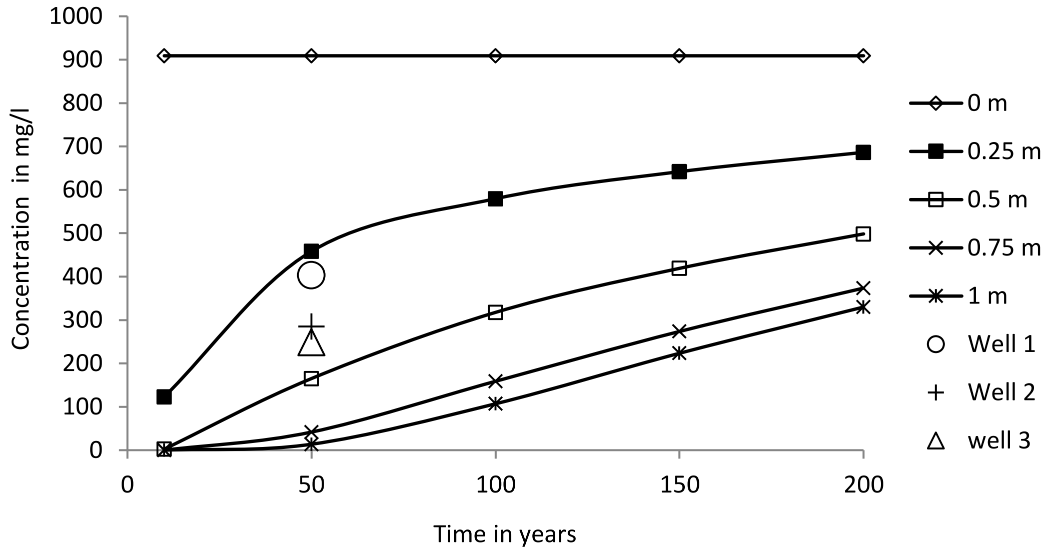

Fig. 2 Mg^{2+} concentration, year and depth profile of raw clay

The input parameters for microsilica-clay composites (1:20 proportion) are given as distribution coefficient, soil porosity, dry density, soil layer thickness, number of sub-layers, source concentration, base concentration 0.0, times of interest (10,50,100,200 years), Darcy velocity, diffusion coefficient that the diffusion column testing of microsilica- clay composites of 1:20 proportion input parameters for magnesium in numerical calculation using Pollute v7. The model output values of (see Table 2) model output for microsilica- clay composites of 1:20 ratio of Depth Vs concentration with time intervals**.**

Table 2 Model output microsilica- clay composites of 1:20 ratio of Depth Vs concentration with time intervals

Time in Years	Depth in m				
	0	0.25	0.5	0.75	1
	Magnesium concentration in mg/l				
10	909	127.2606	2.873857	8.67E-03	6.49E-06
50	909	462.9195	169.9056	44.24375	15.07363
100	909	583.3836	323.3623	164.64	112.6028
150	909	645.5802	425.5056	281.5185	231.7168
200	909	690.2158	505.3983	382.5298	339.5387

The graph between Time, depth and concentration for microsilica-clay composites of 1:20 ratio for predicted up to 0,50,100,150 and 200 years shown (see Fig 3)

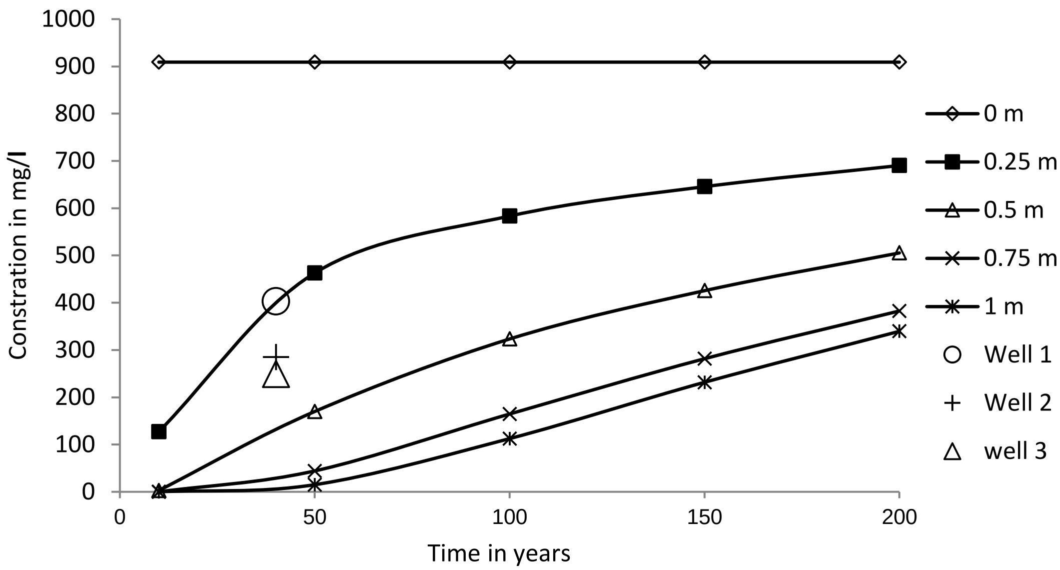

Fig. 3 Time Vs Mg^{2+} concentration at depth profile of 1:20 ratio

The input parameters for microsilica-clay composites 1:10 ratio of numerical calculation using Pollute v7 are given as distribution coefficient, soil porosity, dry density, soil layer thickness, number of sub-layers, source concentration, base concentration 0.0, times of interest (10,50,100,200 years), Darcy velocity, diffusion coefficient that the diffusion column testing of microsilica- clay composites of 1:20 proportion input parameters for magnesium in numerical calculation using Pollute v7. The model output values are tabulated (see Table 3) for model output microsilica- clay composites of 1:10 ratio of Depth Vs concentration with time intervals.

Table 3 Model output microsilica- clay composites of 1:10 ratio of Depth Vs concentration with time intervals

Time in Years	Depth in m				
	0	0.25	0.5	0.75	1
	Magnesium concentration in mg/l				
10	909	72.16944	0.409752	1.29E-04	4.57E-09
50	909	393.3631	106.0323	16.98391	3.092207
100	909	526.4762	243.7075	92.37021	48.16262
150	909	592.7326	337.7606	179.7456	127.3074
200	909	636.7478	410.1876	262.8124	212.0554

The graph between Time, depth and concentration for microsilica- clay composites of 1:10 ratio for predicted up to 0, 50,100,150 and 200 years are shown (see Fig 4).

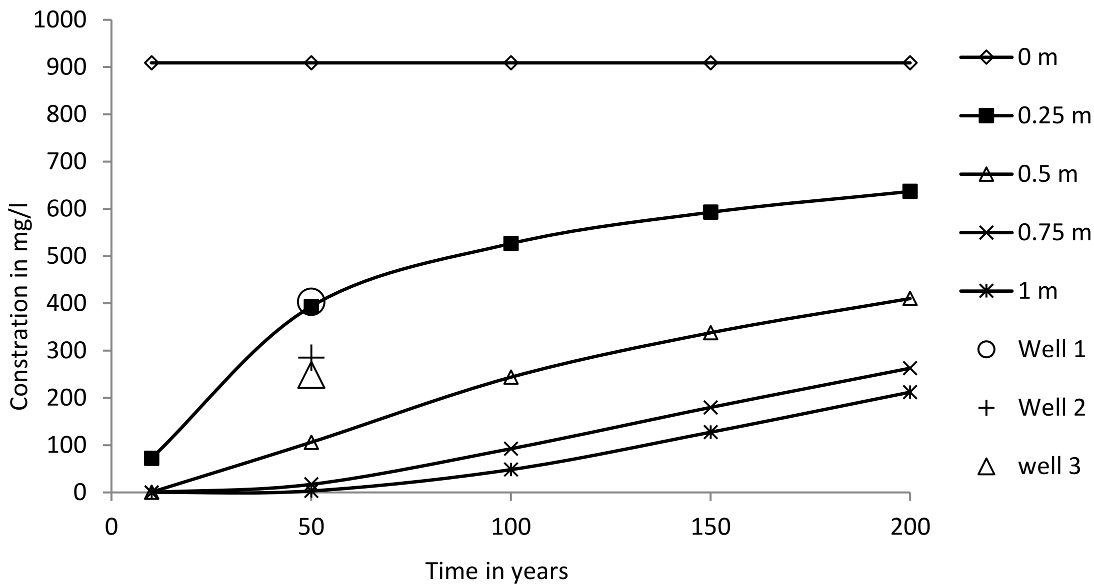

Fig. 4 Mg^{2+} Concentration, year and depth profile of 1:10 ratio

For the past fifty years, solid waste was continuously dumped in the present site. Assuming that the underlying strata as virgin clay, over time, the soil would have undergone metamorphism due to the advective and convective transport of pollutants. The adsorption distribution co-efficient determined by the laboratory studies is used in the Pollute v7 software. The 50 years time period used in the software corresponds to the existing state of metamorphism of the soil matrix due to contaminant transport. The groundwater collected in the vicinity of the solid waste dumpsite can have all the more probability of the contaminants in the store. The Mg^{2+} ion is taken as the respective ion.

4. CONCLUSIONS

A scientific strategy for one-dimensional contaminant diffusion through composite liners was utilized to ascertain the grouping of the natural contaminants at the base of the liner frameworks. New closed-form analytical solutions and graphical solutions for directing the analyses for the diffusion of magnesium through flawless composite liners regarding both fixation and distinctive time interims are introduced in this paper. The graphs are drawn from microsilica and clay composites with 1:10 ratio and 1:20 ratio for concentration, time interval and different depths. The techniques utilized in this paper depend on investigative and graphical answers for diffusion through composite liners. Consequently, predictions of contaminant transport made utilizing strategies portrayed in this paper are constrained by the suppositions, limit conditions and introductory conditions utilized in building up the solutions.

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Impact of Lime on the Behavior of Black Cotton Soil Stabilized with Bagasse Ash

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ABSTRACT
In the present construction practice, industrial wastes are utilized for enhancing the properties of soils to achieve both environmental and economic benefits. Expansive soil, considered as one of the highly problematic soils because of their capacity to interact with the changes in moisture regime. Bagasse ash, the waste material generated from the sugarcane industry poses a serious problem to the health and environment. Studies on stabilization of expansive soil with bagasse ash found to be ineffectual. Hence to enhance the properties of expansive stabilized using bagasse ash, studies were conducted by adding lime to the expansive soil mixed with different percentages of bagasse ash (0%, 5%, 10%, 15%, and 20%). With these proportions, index properties, swell pressure, and shear strength tests were conducted on the stabilized specimens. It is also essential to reduce the effect of cyclic wetting and drying phenomena of expansive soil. Hence, the cyclic wetting and drying cycles test were performed on the expansive soil blended with bagasse ash only and also with bagasse ash and lime. Based on the test results it is found that the lime has a noticeable influence in enhancing the properties of expansive soil stabilized using the bagasse ash. It is concluded that 5% of lime is found to be more effective in modifying the properties of the expansive soil blended with 15% bagasse ash.

Keywords: Expansive soil; Stabilization; Lime; Bagasse ash

1. INTRODUCTION
Black cotton soils so-called as expansive soils tend to expand when they absorb moisture and shrink when moisture evaporates from them (Chen, 1988). Due to these volume change attributes; the expansive soil poses severe threats to the structures constructed on them. The financial loss due to the damage caused by expansive soils is very high than the financial loss caused by any other natural calamities like earthquakes, hurricanes, etc. (Bhuler and Cerato, 2007). Various ground improvement techniques are in use for mitigating the problems posed by the expansive soil. (Shridharan et al, 1986; Cocka, 2001; Al-Rawas, 2005; Ejuni, 2017; Muthukumar and Shukla, 2018). In recent years, researchers focussed on the utilization of wastes to alleviate disposal problems and also to bring the cost benefits in the construction.

Fly ash, which is one of the prime by-products are generated very much in excess than its utilization (Kumar et al 2007). Hence it forced the engineers to utilize fly ash in the construction of civil engineering structures as a substitute to raw. Silica fume, obtained from the silicon industries as a by-product, is also used in the stabilization of clayey as well as expansive soils. Ekrem (2011), noticed that the mixing of 20% to 30% of silica fume to the expansive soil reduces the progressive deformation when subjected to swell-shrink cycles. The reduction was maximum after the first swell-shrink cycles. Lignosulfonate, also a waste by-product generated from the paper manufacturing industries. The annual waste generated is about 50 million tonnes. Successful attempts were made in using this waste in the stabilization of expansive soils (Baharam and Reza, 2017).

Researchers observed that the addition of lime to the soil stabilized with industrial wastes or by-products found to be more effective. Yongzhen cheng et al (2018), identified that mixing of lime and volcanic ash is more effective in escalating the properties of expansive soil. Goodarzi et al (2015) observed from their studies that inclusion of silica fume affects the properties of expansive soils marginally, but adding lime and silica fume to the expansive soil is found to be very effective in improving the behavior of expansive soils. Similar behavior was observed by Ekrem Kalkan (2011).

Bagasse ash is a multi-processed by-product produced from sugarcane industries. Sugarcane is one of the important crops cultivated in India and also all over the world. About 300 million tonnes of sugarcane is produced in India alone, which leads to the generation of 11 million tonnes of bagasse ash as an unutilized waste product (Ganesh et al 2007). This material is fibrous and poses serious problems to the health and environment (Gupta and Ali, 2000). Bagasse ash is a good adsorbent material, but only limited studies are available on its use for stabilization of expansive soils. From the studies, it is observed that the properties of the expansive soil were increased marginally. Hence in the present work, an attempt has been made to study the effectiveness of lime on stabilization of expansive soils mixed with different proportions of bagasse ash.

2. RESEARCH MATERIALS AND SAMPLE PREPARATION

2.1 Expansive soil

The Expansive soil was collected from Mummidivaram village of East Godavari District, Andhra Pradesh, India. The location of the village lies in the deltaic region of the Godavari River. Various index and engineering properties tests were performed and the results have been tabulated in Table 1. From the test results, the soil has been identified as the clay of high plasticity (CH) according to (USCS). According to Chen (1988), based on the value of FSI, the degree of the expansiveness of the soil was classified as very high.

Table 1 Properties of Expansive soil

Property	Value
Specific gravity	2.6
Liquid limit (%)	77
Plastic limit (%)	33
Plasticity index (%)	44
Shrinkage limit (%)	13
OMC (%)	24
Max. dry unit weight (kN/m^3)	18.02
Unconfined Compressive Strength (kPa)	85.38
Free Swell Index (%)	130

2.2 Additives

Hydrated lime and bagasse ash have been used in the present study. Bagasse ash (BA) was collected from Vellore co-operative mill and sugar research institute, Vellore, Tamil Nadu, India. The ash contained some extra waste and 95% of the sample passed through 425-micron sieve. Bagasse ash contains substantial amounts of amorphous silica, aluminum, iron, and calcium oxides, thus indicating the pozzolanic properties. Hydrated lime was used in the present work. The minimum quantity of lime required for stabilization of expansive soil was found to be 3% according to the procedure proposed by Eades and Grim (1966). Hence to enhance the stabilization of BC soil and BA blends, 5% lime content was used for a different proportion of BA blended with BC soil.

3. TESTING METHODS

3.1 Sample preparation

The sample was dried in an oven for 24 hours at a standard temperature of 105°C. After oven drying the sample was sieved according to the requirement of the test standards. Consistency tests were performed for different percentage of lime (1%, 2%, 3%, 5%, and 10%) by dry weight of the soil and for different percentage of BA content (5%, 10%, 15%, and 20%) of the total dry weight of the soil. To study the influence of lime on the expansive soil blended with BA content, different amounts of BA by dry weight of the soil (5%, 10%, 15%, and 20%) and 5% of lime were blended with the prepared dry expansive soil.

3.2 Swell potential and swell-shrink cycle tests

The swell potential is the amount of heave which is expressed in percentage that takes place upon inundation. This test is conducted on the soil sample compacted to the maximum unit weight and the corresponding water content obtained from the compaction test. The samples were then loaded with a seating pressure of 0.7kPa. After applying the seating pressure, the sample was inundated and allowed to heave. The swelling was recorded periodically with the help of displacement transducer until there were no further changes in the swelling.

The important advantage of conducting swelling-shrinkage cycles is better repeatability of the test on the same sample (Guney et al, 2007). The swell-shrink cycle test was carried out to identify the impact of lime on the swelling/heave behavior of BA stabilized expansive soil subjected to swelling-shrinkage cycles. All the samples were flooded and allowed to swell/heave completely. After complete swelling, water was drained out and the saturated specimen along with the consolidation cell was allowed to dry until the water content was close to the initial moisture content. After the specimen has been dried in the consolidation cell, the consolidation cell along with the specimen was again placed in the odometer test setup and then the specimen was allowed to swell by flooding water. This comprises one swell-shrink cycle. Likewise, the specimens were subjected to five swelling and shrinkage cycles. Some researchers reported that there was no appreciable difference in the results after five cycles of swelling and shrinkage (Rao et al, 2001; Ekrem Kalkan, 2011). Hence in the present study, the wetting – drying tests were terminated after 5 wetting-drying cycles.

4.0 RESULTS AND DISCUSSION

4.1 Consistency limits

Liquid limit and plastic limits tests were determined on all soil samples mixed with additives as per ASTM standards. Figure 1 shows the influence of additive content on the plasticity index of the expansive soil. From Figure 1, a decrease in the plasticity index was observed with an increase in the BA content. The plasticity index decreased from 45% to 27.5% with a 20% BA. Similarly, the plasticity index also decreased with an increase in the lime content. But there is a significant reduction in the plasticity index when expansive soil is treated with lime compared to BA. The plasticity index reduced from 45% to 4% when 10% of lime was added to the BC soil. It is also observed that there is a rapid decrease in the plasticity index of expansive soil, as the lime content increased from 0% to 5% and decreased marginally as the lime content increased to 10%. Hence

5% lime was added to study the effect of lime on the expansive soil-bagasse ash blends. In Fig 1, it can be noticed that the plasticity index further reduced by adding 5% of lime to the expansive soil blended with any percentage of BA. The plasticity index of the expansive soil blended with 5% lime and 20% BA content was found to be 5%. The plasticity index reduced nearly 80% when 5% lime of lime was added to the expansive soil blended with 20% BA.

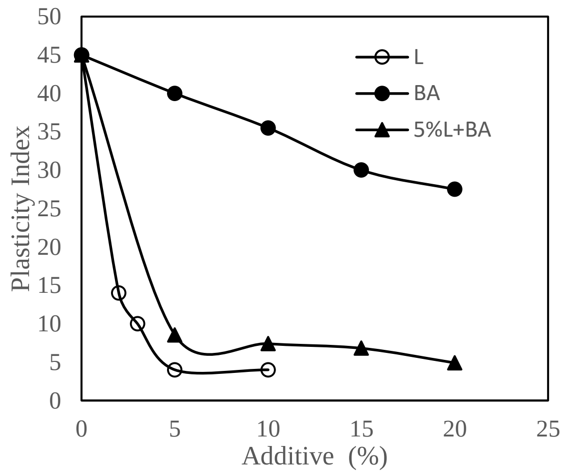


Fig. 1 Variation of plasticity index of expansive soil mixed with Bagasse Ash (BA) and Lime (L)

4.2 Influence of lime on the swell-shrink properties of the expansive soil

The effects of lime on the swell potential of expansive soil blended with different content of BA are reported in Figures 2.

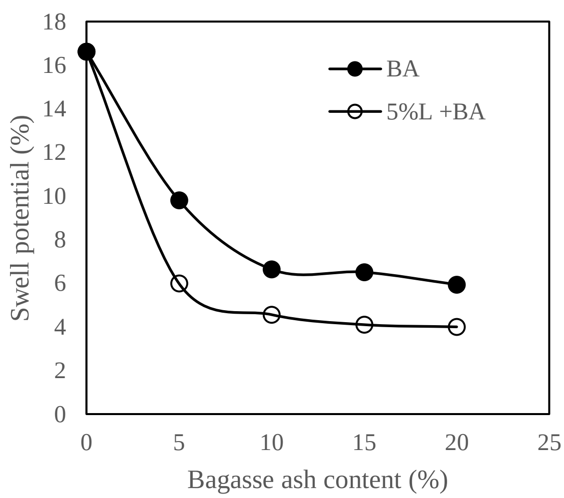


Fig. 2 Impact of lime on the swell potential of expansive soil stabilized using BA

The swell potential (S_p) decreased steadily with an increase in the BA content. The reduction in the swell potential takes place mainly due to the increase in optimum moisture content and the decrease in the maximum density. The higher optimum moisture content and decreased maximum dry density cause a decrease in swell potential (S_p) (Guney et al, 2007; Ekrem Kalkan, 2011). Although the swell potential value of the expansive soil stabilized with BA content decreased with an increase in the ash content, it is noted that the swell potential decreased further, when 5% lime was added to the expansive soil mixed with any percentage of BA content. With the addition of 20% BA content, the swell potential of the expansive soil reduced from 16.62% to 7.94%. The reduction in the swell potential of the expansive soil is also because of the interaction between the ions present in expansive soil, lime and BA. The expansive soil and bagasse ash have a significant amount of silica and alumina ions. These ions interact with the calcium ions present in lime and result in the formation of calcium silicate hydrates (CSH) and calcium aluminum hydrates (CAH). Further new compound magnesium aluminum silicate (MAS) is formed due to the presence of magnesium ions present in the bagasse ash. These hydrates stabilize the soil and in turn, reduces the swell properties of the BC soil. The formation of these hydrates is ensured in the scanning electron microscopic images which are discussed later (section 4.4).

4.3 Swelling- Shrinkage Cycles

Cyclic swelling-shrinkage phenomena of expansive soils cause severe distress to the buildings, pavements, canal linings, waste containment liners and cover systems (Erkem, 2011). The consequence of swelling-shrinkage cycles on the swell potential of the BC soil was conducted by wetting-drying cycles test. The results of swelling-shrinkage cycles are presented in Figure 3. From the Figure, it is apparent that the swell potential of expansive soil decreases marginally with an increase in swelling-shrinkage cycles. The marginal reduction is due to the reorientation and re-adjustment of the structural elements of the micro-aggregates. It is also noted that the reduction in swelling is not prominent even after the 3 cycles of wetting and drying, for the expansive soil blended with BA. With the addition of 5% lime to the expansive soil blended with 20% BA, a prominent reduction in swell potential is noticed after the first swell-shrink cycles. The equilibrium is attained after the first swell-shrink cycles for the stabilized expansive soil containing 15% to 20% BA (For 5% lime and 20%BA was only reported in Figure 3. It is an important observation to note that, with the incorporation of lime to the expansive soil blended with BA, the swell potential decreases after the first swell-shrink cycles. The reason is due to the completion of the ion exchange process and pozzolanic reactions after the first wetting-drying cycles. Hence after the first swelling-shrinkage cycles, the expansive soil becomes inactive to the volume changes when subjected to further wetting-drying cycles.

To identify the microstructural changes, scanning electron microscopy analyses (SEM) were conducted on the soil, soil with 5% lime, 5% lime +10% BA, 5% lime + 15% BA and 5% lime + 20% BA. Fig 4 (a) shows the image of the clay specimen blended with 5% lime. From Fig 4(a) it can be noticed that the blending of 5% lime to the expansive soil, results in the formation of aggregated structure.

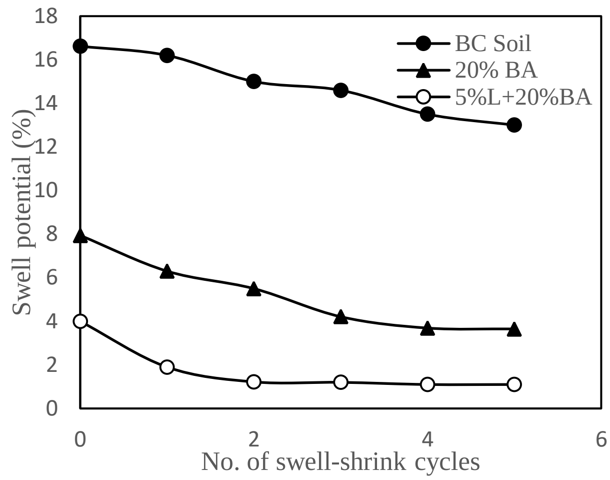
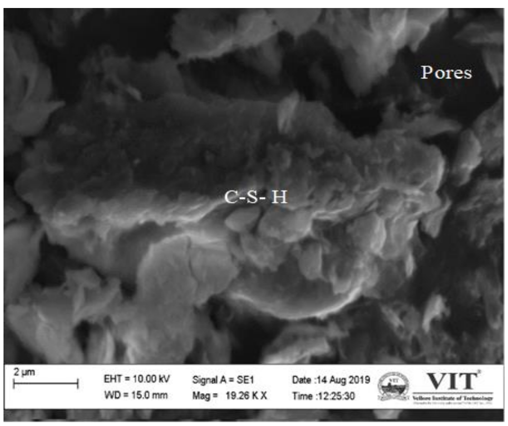
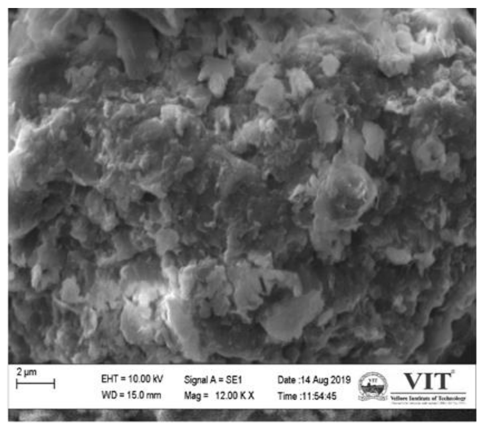


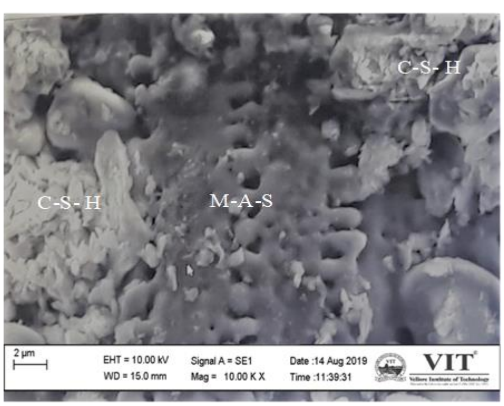
Fig. 3 The swell potential of expansive soil stabilized using admixtures subjected to swell-shrink cycles

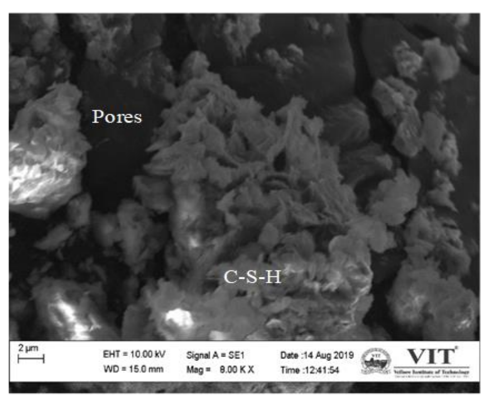




(a) BC soil + 5% L+5%BA

(b) BC + 5% L+ 10%BA





(c) BC soil+5%L+15%BA

(d) BC+5%L+20%BA

Fig. 4 SEM images of Expansive soil for different bagasse ash (BA) content with 5% lime (L)

The addition of 5% lime+ 10% BA content leads to the rearrangement of particles and increased structural integrity (Fig. 4 (b)). The interaction between the clay surface and water reduces due to the agglomeration of the particles, leading to the change in the behavior of the expansive soil. Further incorporation of BA leads to the development of new cementing compounds (CSH, CAH, MAS). These compounds bind the soil particles and also reduces the voids present in the soil. The cementitious products are clearly visible in Fig 4 (c). Due to the formation of cementitious matters at 5% lime + 15% BA, the UCS of the soil was found to increase. Further addition of BA leads to the increase in the voids space among the fine-grained soil and also reduces the bonding between the cementing compounds. This phenomenon is ensured in Figure 4 (d). Hence, the strength of the expansive soil decreased when BA content is increased beyond 15%.

5. CONCLUSIONS

Based on the results discussed, the following important conclusions are arrived:

1. The plasticity index of the expansive soil decreased from 45% to 27.5% with a 20% BA. The plasticity index further reduced when lime is mixed to the expansive soil- bagasse ash mixtures. The plasticity index reduced nearly 80% when 5% lime of lime was added to expansive soil blended with 20% BA.
2. The swell potential and swelling pressure also found to decrease due to the addition of lime to the expansive soil blended with BA. The reduction in the swell potential, as well as swell pressure of the expansive soil, is due to the increase in OMC and decrease in maximum dry unit weight as well as the interaction between the ions present in expansive soil, lime and bagasse ash. The expansive soil has a significant amount of silica and alumina ions. These ions interact with the magnesium and calcium ions present in bagasse ash and form calcium silicate hydrates, calcium aluminate hydrates, and magnesium-aluminum silicates. These compounds act as cementing agents and reduce the swell potential and swell pressure.
3. With the addition of 5% lime, there is a prominent reduction in swell potential is noticed after the first swell-shrinkage cycles. The equilibrium is attained after the first swell-shrink cycles for the stabilized expansive soil containing 15% to 20% BA. The reason is due to the completion of the ion exchange process and pozzolanic reactions after the first swelling-shrinkage cycles. Hence after the first swelling-shrinkage cycles, the expansive soil becomes inactive to the volume changes attributes, when subjected to further wetting-drying cycles.

Finally, it is concluded based on the strength and other aspects, 5% lime, 15% BA found to be beneficial in improving the engineering characteristics of the expansive soil.

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Coimbatore Foundry Sand Waste Material for Road Construction

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ABSTRACT
Different industries are generating different types of waste materials viz. copper slag, zinc slag, steel slag, manganese slag, phosphogypsum slag, cinder, red mud, kimberlite, lime sludge, foundry sand, coal ash, jarofix, jarosite, manganese slag, marble dust, etc. These waste materials have the potential for utilization in road construction. Presently, the utilization of these waste materials is much more crucial and concern in India due to a large amount of production and having very limited applications as per literature available. Foundry sand is one of the waste materials produced from foundry industries spread all over the country. The annual production is about 3 million tons from different foundry industries in India. The unutilized accumulated material is about 25 million tons so far. Foundry waste material was collected from Coimbatore, Tamil Nadu, India, and characterization were carried out to study its application in the construction of embankment, subgrade and shoulder layers of the road. Stability analysis was carried out for phosphogypsum embankment under different water saturation conditions. The paper discusses the laboratory test results and development of design specification of its suitability in the road construction. It is observed that foundry sand is a fine-grained material having silt size particles. It has low free swelling nature and slightly low density which makes it suitable construction material. This material may be used in the construction of embankment/subgrade and shoulder layers.

Keywords: Foundry sand; waste material; construction; road

1. INTRODUCTION

Foundry sand is an industrial waste material generated from the foundry industries spread all over the country. It is natural sand which is used as a molding material in the ferrous and nonferrous metal casting industries. This sand is typically recycled and reused through many production cycles. After several cycles, it becomes unsuitable for the industry and pile up as a waste material, called foundry sand. The total production of this waste sand is about 3 million tons annually.

Fox and Mast (1998) revealed that foundry sand may be used as an embankment construction and its performance is comparable to conventional soil. Kleven et al. (2000) observed that foundry sand can be used in the construction of the pavement sub-base layer (Kirk, 1998; Goodhue et al., 2001). Yucel and Ahmet (2005) advocated that soil-foundry sand mixtures blended with cement/lime can be used in the construction of the highway sub-base layer and as a fill material (Gedik et al., 2008). Luis et al. (2015) used foundry sand blended with clayey soil for application in base and subbase layers construction and observed that foundry sand - soil mixtures have mechanical properties similar to the conventional material. Foundry sand improved the mechanical properties of clayey soil which may be used in the construction of subgrade (Kumar et al. 2014). Different physical, chemical and geotechnical characteristics that were studied included; grain size analysis, Atterberg limit test, free swelling index test, specific gravity test, Proctor compaction test, CBR test, unconfined compressive strength test, consolidation test, permeability test, and direct shear test. The paper discusses the results of laboratory study and different technical specifications for its use in embankment, subgrade, shoulder and GSB layers of the road. Design and stability analysis of foundry sand embankment was also presented under different water saturation conditions with seismic factors.

2. MATERIALS

Foundry sand sample was collected from M/s Bradken India Pvt. Ltd, Coimbatore, Tamil Nadu, India an industry under the Institute of Indian Foundrymen, Kolkata.

3. PHYSICAL AND CHEMICAL CHARACTERISATION

To study the physical characteristics of collected foundry sand, different laboratory experiments were carried out which included: (a) physical appearance (b) surface morphological characteristics (c) mineralogical and crystalline characteristics (d) loss on ignition (e) pH (f) natural moisture content and (g) specific gravity.

3.1 Physical Appearance

Foundry sand sample is a granular material having black color in appearance.

3.2 Surface Morphological Characteristics

The surface morphological and micro- structural texture characteristics of foundry sand particles were studied by scanning electron microscope (SEM) as per the standard procedure. The samples were dried before the test. SEM with emission dispersive spectrometer (EDS) was used to provide detailed imaging information about the morphology and surface texture of individual particles of the powder foundry sand. The spectrum was obtained at 5μm magnification. Figure 1 shows the general morphology and microstructure of foundry sand particles by the SEM spectrum.

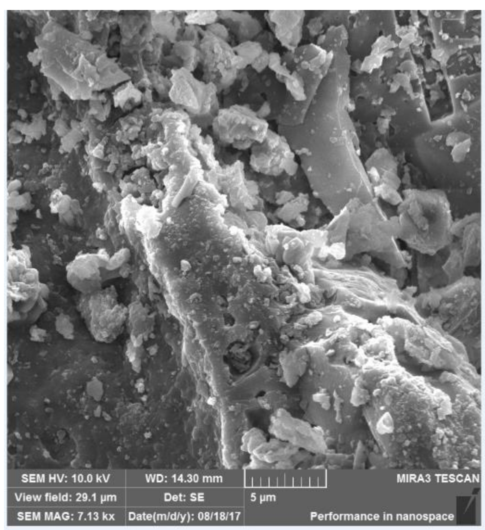

Fig. 1 SEM image of foundry sand

The SEM interpretation is visual and qualitative only. Based on the SEM study, it can be inferred that foundry sand has a closed skeletal, lattice, very porous microstructure. The microstructure shows, it is a silt size material. Figure 2 shows the elements present in the foundry sand. It was observed that foundry sand samples mainly contain carbon (61%), oxygen (31%), silicon (6%), iron (2%) and some other elements in traces.

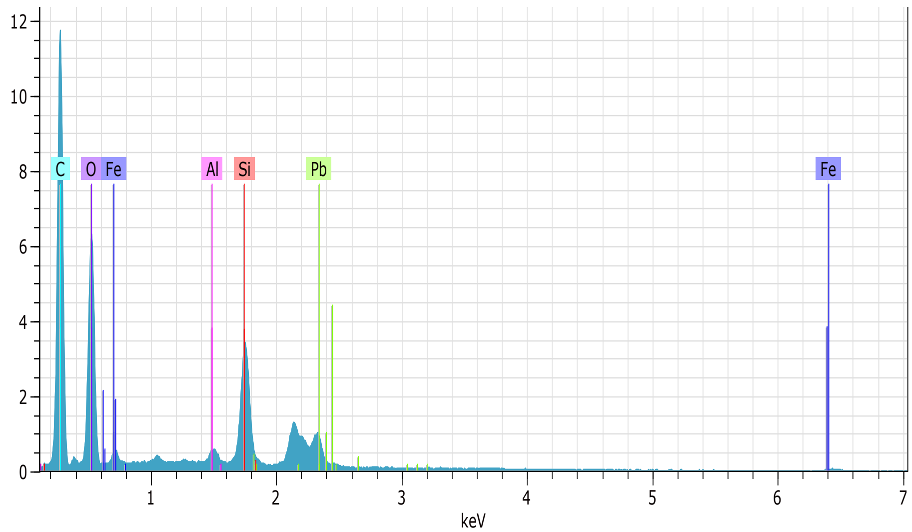

Fig. 2 EDX image of foundry sand sample

3.3 Mineralogical and Crystalline Characteristic

Mineralogical and crystalline nature of foundry sand samples was determined by X-ray diffraction test. Figure 3 shows the XRD pattern and phase constituents present in the foundry samples. Foundry sand sample was used as original or virgin material. The samples were loaded on glass strip and X-ray diffraction pattern was recorded by using X-ray diffractometer. Phase identification was carried out by the diffraction pattern by comparing the database of powder diffraction file (PDF).

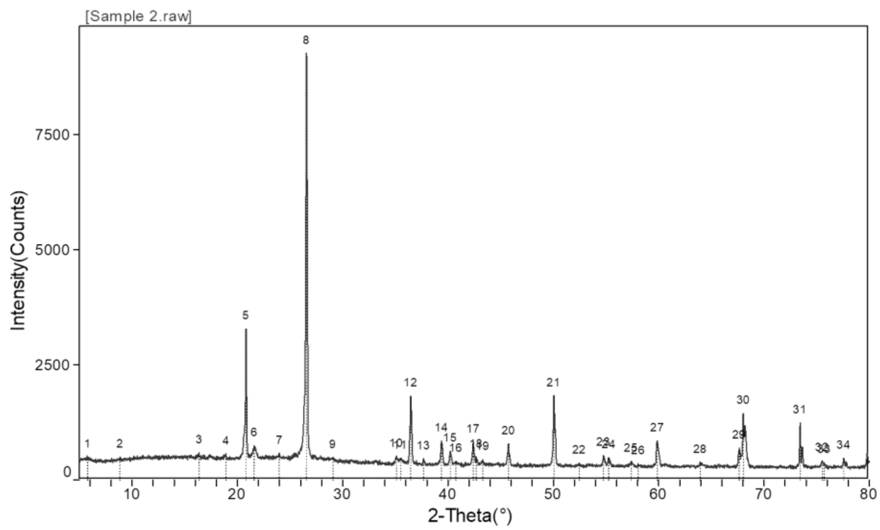

Fig. 3 X-ray diffraction pattern of foundry sand

From the PDF comparing chart, it was observed that foundry sand sample consists of mainly minerals like Andradite Syn, Hydrogen Acetate, Andradite, Syn, Calcium Cilicide, Aluminum Silicate Hydrate and in combination with other elements. From the diffraction pattern, the maximum intensity of peak was observed to be in the range of 34 (8500 Lin, Counts). Details are given in Table 1.

Table 1 Mineral composition in foundry sand sample

Peak No.	Compound	Formula
5	Andradite, Syn	$Ca_3Fe_2(SiO_4)_3$
8	Hydrogen Acetate	$C2H_4O_2$
12	Andradite, Syn	$Ca_3Fe_2(SiO_4)_3$
21	Calcium Cilicide	Ca_2Si
30	Aluminum Silicate Hydrate	$Al_4Si_2O_{10}.H_2O$
31	Akdalaite	$(Al_2O_3)_4.H_2O$
5	Andradite, Syn	$Ca_3Fe_2(SiO_4)_3$
8	Hydrogen Acetate	$C_2H_4O_2$
12	Andradite, Syn	$Ca_3Fe_2(SiO_4)_3$

3.4 Loss on Ignition

Loss on Ignition of foundry sand samples was determined as per ASTM D 2974 (2014). It was observed that foundry sand has a loss on ignition (organic content) of 25 % by weight. The high value indicates the presence of high unburnt carbon content in the sample.

3.5 pH

pH value of selected foundry sand sample was carried out as per IS: 2720 (Part 26, 2002). It was observed that the foundry sample is acidic in nature having a pH value of about 4. Rahman & Nahar (2015) advocated that the shear strength of soil increases with an increase in pH value. Therefore, the foundry sample may be used for the construction of embankment and other layers. In addition to this, foundry sand having a pH value less than 10 should be also used in the reinforced backfill application as per MORTH (2018, clause 3104.1.1).

3.6 Natural Moisture Content

Natural moisture content was carried out as per IS: 2720 (Part 2, 2006) and it was observed to be 1.28 %. This indicates that the sample is in a dry state.

3.7 Specific Gravity

Specific gravity test was carried out as per IS: 2720 (Part 3/ sec 2, 2002). The average value of specific gravity is determined as 2.02. It was observed that the value of the specific gravity of foundry sand is less than conventional soil. This may be due to different mineral compositions in the samples.

4. GEOTECHNICAL CHARACTERISATION

To study the geotechnical characteristics of foundry sand, different laboratory experiments were carried out which include:(a) Grain size analysis (b) Atterberg limit test (c) Free swelling index (d) Proctor compaction test (e) California Bearing Ratio test (f) Unconfined compressive strength test (g) Permeability test (h) Consolidation test and (i) Direct shear test.

4.1 Grain Size Analysis

Sieve analysis was carried out as per IS: 2720 (Part 4-2006) to determine the variation in grain size characteristics. It was observed that it is a fine-grained material. This indicates that foundry sand is having dominantly silt size material. The amount of sand and silt is 43 % and 54% respectively.

The obtained average values of C_u (Coefficient of uniformity) and C_c (Coefficient of curvature) are 8 and 1 respectively.

4.2 Atterberg Limit Test

The plasticity characteristics of foundry sand were determined as per IS: 2720 (Part 5-2006). The liquid limit (LL) was observed to be 36 % and non-plastic in nature. According to IS: 1498 (2002) classification, it is classified as ML.

4.3 Free Swelling Index Test

Free swelling index test was carried out as per IS: 2720 (Part 40 – 2002). The free swelling index was observed to be less than 6 %. It is low free swelling material which makes it suitable for road construction.

4.4 Proctor Compaction Test

Standard and modified Proctor compaction tests were carried out as per IS: 2720 (Parts 7, 2002) & 8, 2006). The compaction curves are flat in nature, indicating the in-sensitiveness of dry density with moisture content. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were observed to be 12.4 kN/m^3 and 25 % respectively for standard Proctor test while 13.8 kN/m^3 and 17 % respectively for modified Proctor test.

4.5 California Bearing Ratio Test

California Bearing Ratio test was carried out as per IS: 2720-Part 16 (2002). Three specimens were prepared by compacting the foundry sand at 100% and 97% of MDD/OMC of standard and modified Proctor tests respectively. The specimens were then soaked for 4 days in potable water before testing. The specimens were sheared at the rate of 1.25 mm/min. The average value of CBR was determined as 8% and 10% at standard and modified Proctor density respectively. This indicates that foundry sand which is cohesionless material has good strength in the confined state similar to conventional sand material.

4.6 Unconfined Compressive Strength Test

Unconfined compressive strength test is carried out as per IS: 2720 (Part 10-2006). Three specimens of size 50 x100 mm were prepared by compacting the sample at their compacted modified density and OMC. The specimens were sheared at the rate of 1.25 mm/min. Average unconfined compressive strength was observed to be 60kN/m^2 while the failure of strain was observed to be 3.3 mm. Though the foundry samples are non-plastic, the determined unconfined compressive strength is due to pseudo cohesion developed by surface tension in a partially saturated condition.

4.7 Permeability Test

Permeability test of selected foundry sand samples was carried out as per IS: 2720 (Part 17-2002). Remolded samples of size 100 mm diameter and 127.3 mm height in cylindrical mold were prepared at 95% of MDD and OMC. Samples were first saturated and water was allowed to flow through the samples. The average permeability was found to be 3.25×10^{-6} m/s. This value indicates that foundry sand is a good permeable material.

4.8 Consolidation Test

Consolidation test was carried out as per IS: 2720 (Part 15-2002). It was carried out on a specimen of 60 mm diameter and 20 mm thickness under double drainage condition. Remolded samples of foundry sand were prepared at 95% of respective MDD and OMC. Samples were saturated for 24 hours at an initial seating stress of 0.025 kN/m^2. The average value of the compression index (C_c) was determined as 0.03. The value of C_c indicates that foundry sand samples are incompressible materials.

4.9 Direct Shear Test

Direct shear test was carried out as per IS: 2720 (Part 13) – 2002. The sample was oven-dried and passed through 4.75 mm sieve. Three specimens of size 60 x 60 x 25 mm were prepared at MDD/OMC and the test was carried out at the rate of 1.25mm/min. The cohesion(c) and angle of internal friction (ϕ) were observed to be 27 kN/m^2 and 29^o respectively. However, cohesion may be due to a partially saturated condition.

5. DESIGN AND STABILITY ANALYSIS OF EMBANKMENT

The design of embankment with foundry sand is similar to an earthen embankment. Foundry sand embankment was designed as a composite structure with foundry sand alone in the core and with a cover of good soil on either side as it is a non-plastic material and to arrest the erosion of slope of the embankment. Accordingly, it was suggested that slope may be covered with good soil having Plasticity Index (PI) less than 6 %. The specifications of cover soil and thickness may be adopted as per IRC SP 58 (2001) or it is proposed to provide 2 m thick soil cover (measured horizontally). This would also add stability to the embankment. In order to evolve a proper construction methodology, it is suggested that a trial embankment of suitable height should be constructed. On the basis of the same, construction methodology may be evolved.

5.1 Stability Analysis

The foundry sand embankment of 3 m height for a two lanes road with a side slope of 2 horizontal to 1 vertical, was analyzed for its slope failure. The shear strength parameters and bulk density of fill material as determined from the laboratory were used for stability analysis while properties of cover soil & subsoil are assumed similar to Delhi silt soil. The embankment was analyzed under partial saturation, fully submerged and sudden drawdown conditions. The traffic and other live loads on the top of the embankment were considered as 24 kN/m^2. The analysis was carried out considering the seismic forces of zone 4, India. The basic seismic coefficients considered in the analysis are α_h = 0.05 (horizontal) and α_v = 0.025 (vertical) as per IRC 6 (2014). The factor of safety was obtained > 1.25 under a critical sudden drawdown with seismic conditions which is as per IRCSP 75 (2015).

6. DEVELOPMENT OF DESIGN SPECIFICATIONS

6.1 As an Embankment, Sub Grade and Shoulder Material

Based on the result of geotechnical characteristics, foundry sand satisfies the plasticity and free swelling characteristics as per MORTH/MORD (2018/2002). It is a low compressible and permeable material that will result in negligible post settlement of the construction of road. However, it has a slightly lower density as compared to soil. Due to this, it may be blended or mechanically stabilized with other suitable material before application in subgrade and shoulder.

As it is a cohesionless material, it should be used in the core of embankment and slope should be covered with soil to stop the erosion of slope (IRC SP 58, 2001). Therefore, it may be used directly in the construction of embankment, subgrade, and shoulder.

6.2 As a Granular Sub Base Material

Foundry sand indicated their potential for use in the sub-base layer of road pavement. However, the sand sample needs to be mixed with conventional aggregate to meet the required design gradation as per MORTH/MORD specifications (2018/2002). Trial and error method of proportioning indicated that about 10 to 30 % of foundry sand may be used as a replacement of fine aggregate in granular sub-base mixes. The mixes were observed to be non-plastic also satisfied the CBR requirement as per MORTH/MORD specifications.

7. CONCLUSIONS

Foundry sand sample was collected and evaluated for their physical, chemical and geotechnical characteristics by detailed laboratory investigations. Technical specifications were developed for its utilization in an embankment, subgrade, shoulder and granular sub-base layers of road pavement. A summary of the conclusions is given below:

- Foundry sand mainly contains unburnt carbon, oxides, and silica with traces of other compounds. Based on the SEM study, it can be inferred that foundry sand has a closed skeletal, lattice and has a very porous microstructure. It has sand-size particles and non-plastic in nature. The specific gravity of foundry sand is less than conventional soil and it is available in dry condition.
- The compaction curves of foundry sand are flat in nature, indicating the in-sensitiveness of dry density with moisture content. This is an added advantage during field construction. However, its density is slightly lower than conventional soil.
- Foundry sand has a high value of CBR similar to good conventional soil and it is a permeable material. It has good shear strength. A low value of the compression index indicated its incompressible nature.
- It is further recommended that an experimental test section of limited length may be constructed after proper design and stability analysis. The performance of the constructed embankment and other layers needs to be monitored over a period of at least two monsoon seasons before recommending the mixes for large scale field applications.
- Utilization of foundry sand in the construction of roads will certainly create value in the form of avoiding the accumulation of waste on fertile land at one end and mining of resources at the other end. This initiative has tremendous value from the environment conservation angle.

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Stabilization of Soil with Lime and Waste Plastic Strips

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ABSTRACT
The disposal of waste plastic in developing countries like India a great challenge as the majority of such waste is currently disposed of by open dumping and burning in open areas. Due to the absence of the appropriate process, the management of waste especially for discarded plastic has become a challenging task. The present study has made an attempt in this direction, whereas the effect of variation of unconfined compressive strength and energy absorption in clayey soil was observed with the addition of 10%, 20% lime and 2%, 3% waste plastic strips having aspect ratio 1 and 2. The results have shown an increase in the unconfined compressive strength of increases with the addition of lime and waste plastic strips. Higher increase in the unconfined compressive strength was observed with the addition of 10% lime content and 2% waste plastic strips having aspect ratio as one. It was observed through the A change in the cracking pattern due to the addition of waste plastic strip was also observed. The author is of the view that the use of waste plastic in the soil mass stabilized with lime can be effectively used for the improvement of the groundmass. The application of the material will be more useful in that area which lies in the seismic prone areas. The disposal of waste plastic in this way will be in an environmentally friendly manner and will solve the disposal related problems associated with waste plastic.

Keywords: Waste plastic strips; energy absorption; unconfined compressive strength

1. INTRODUCTION
Soil stabilization is the process of alteration of soil properties by chemical or physical means to improve the engineering properties of soil. Soil stabilization using lime is one of the most trending methods of stabilization of clayey soils. The main objectives of the soil stabilization are to increase the bearing capacity of the soil, its resistance to weathering process and soil permeability. Unstable soils can create significant problems for pavements or structures, therefore soil stabilization techniques are necessary to ensure the good stability of soil so that it can successfully sustain the load of the superstructure especially in case of soil which is highly active, also it saves a lot of time and millions of money when compared to the method of cutting out and replacing the unstable soil. Ministry of Environment and Forest (MoEF) and Central Pollution Control Board (CPCB) have inducted rules for plastic waste management and suggested recycling of waste plastic as far as possible. Plastic waste management institutes reported about 55% of plastic being recycled effectively. Mixing waste plastic with subgrades may also contribute to the effective recovery of waste plastic. The present study deals with the analysis of variation in unconfined compressive strengths of soil samples of varying proportions of lime and waste plastic strips. The percentage of lime in soil is kept 10% and 20% w/w and the percentage of plastic strip1s is kept 2% and 3% w/w with aspect ratio 1 and 2. Lime is an unparalleled aid in the modification and stabilization of soil beneath the road and similar construction projects. Using lime can substantially increase the stability, impermeability, and load-bearing capacity of the subgrade. Lime is a proven solution, the witness being the more than one million metric tons of lime used annually in the U.S. for soil modification and stabilization.

2. BACKGROUND

The feasibility of reinforcing soil with strips of reclaimed high-density polyethylene (HDPE) was investigated by Choudhary, et al. 2010, Strips of HDPE of different aspect ratios were mixed with local sand and tested to determine CBR values and secant modulus. The tests show that reinforcing sand with waste HDPE strips enhances its resistance to deformation and its strength. Paramkusam. et al. (2013) investigated the dry density and CBR behavior of waste plastic content on stabilized red mud, fly ash and red mud fly ash mixes. For the study pieces of waste plastic bottle size lesser than 20 mm and bigger than 4.75 mm was taken and were mixed in different proportions of 0.5, 1, 2, 3, and 4% by dry weight of red mud, fly ash and red mud fly ash mix. This investigation has shown that the maximum dry density values of the red mud, fly ash and red mud fly ash mix increases with the increase in the waste plastic content up to 2%. However, increment in the proportion of waste plastic beyond 2% induces a decrease in the maximum dry density values.

3. MATERIAL USED AND EXPERIMENTAL PROCEDURE

3.1 Lime

Commercially available lime in the local market was used in the study. Negi et.al. 2013 investigated the use of lime in fine-grained soil and concluded that lime treatment of unstable soil is economical as compared to the replacement of unstable soil.

3.2 Waste Plastic Strips

Waste plastic Strips used in the project were obtained by plastic beverage bottles. Further for the study the waste plastic having two aspect ratios as per detail given below was used.

1) Aspect Ratio = 1 having size 5mm × 5mm.
2) Aspect Ratio = 2 having size 5mm × 10mm.

Fig. 1 shows the photograph of the waste plastic strip having aspect ratio 1 used in the study.

Fig. 1 Photograph of the Waste Plastic Strips having aspect ratio 1

The percentage of plastic strips was kept 2% and 3% of soil by weight. The waste plastic strips were uniformly mixed throughout the soil.

3.3 Sample Preparation

Samples having a size 38 mm × 76 mm, as shown in Fig. 2 and 3 were prepared with the help of a hydraulic sample ejection machine.

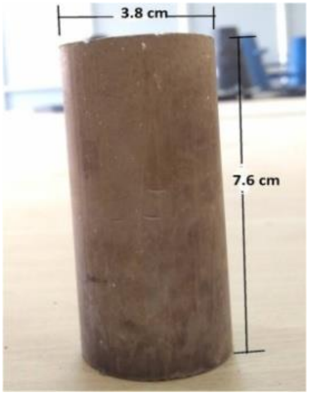

Fig. 2 and 3 showing sample size and samples prepared for testing

3.4 Energy Absorption Capacity

The energy absorption capacity is the area under the stress-strain curve calculated up to point B (area ABC) as shown in Fig. 4. The energy absorption capacity values were calculated using software Graph Pad Prism 7.3.

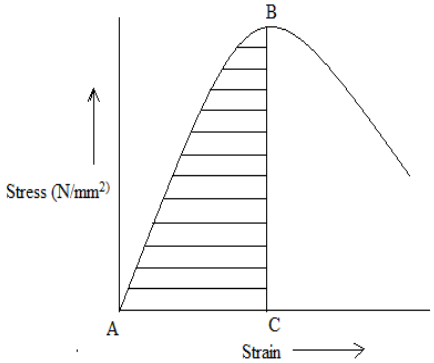

Fig. 4 Schematic diagram for energy absorption capacity

3.5 Codification

For easy reference and identification of specimens, specific codification was used. The specimens were designated by codification, first, second, letters indicate clayey soil and lime, the next two letters indicate percentage addition of lime, fifth and sixth letters indicate plastic and its proportion, whereas seventh and eight letters indicate aspect ratio and last two digits show duration. For example, code CL10P2A1D7 will indicate C as Clayey Soil, L as Lime and "10" as percentage addition of lime, P as waste plastic strips, A as Aspect Ratio of strips, D as the duration for conducting the test. e.g., "D7" here means that the test will be conducted after completion of 7 days.

4. RESULTS

4.1 Compaction studies

Fig. 5 shows the compaction studies carried out on the soil. Fig. 5 reveals that the highest dry density of 1.85 g/cm^3 has been observed corresponding to 26% of water content.

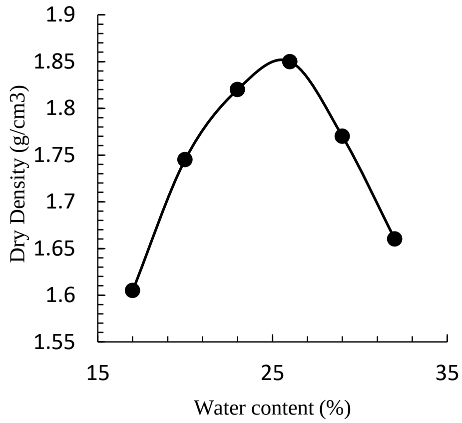

Fig. 5 Results of standard proctor test for Soil

Further, for preparation of sample percentage of water corresponding to maximum dry density is added to the soil along with 10% and 20% of lime and 2% and 3% of waste plastic strips. The contents are thoroughly mixed and compacted in the sample mold and thereby ejected with the help of a sample ejector.

4.2 Unconfined Compressive strength

4.2.1 Variation of Unconfined compressive strength with the increase in the lime content in the soil. Fig. 6 shows the variation of unconfined compressive strength of clayey soil mixed with 10%, 20% lime and 2% addition of plastic strips having aspect ratio as 2.

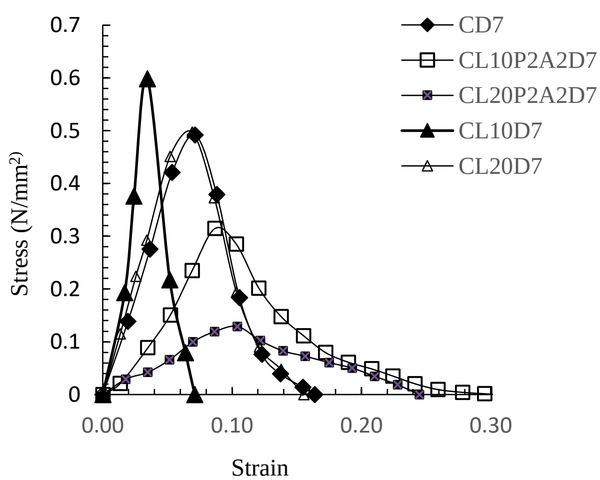

Fig. 6 Variation in UCS with the addition of lime and plastic strips

Further, Table 1 also depicts the values of peak stress along corresponding to energy absorption for soil mixed with 10%, 20% lime and 2% plastic strips having an aspect ratio of 2.

Table 1 Peak Stress and Energy absorption values for variation in lime content

Sample	CD7	CL10D7	CL20D7	CL10P2A2D7	CL20P2A2D7
Peak Stress (N/mm^2)	0.4915	0.5983	0.4903	0.3145	0.1290
Energy Absorption (N-mm)	0.0347	0.0458	0.0321	0.0313	0.01587

A close examination of Fig. 6 and Table 1 shows that peak stress decreases with the increase in the lime content beyond 10% inclusion of lime. For example, a value of peak stress for the reference mix CD7 was 0.4915 N/mm^2, which increases to a value of 0.5983 N/mm^2 with addition of 10% lime, however, with the addition of increased lime content in the soil, a decrease in the peak stress was observed. For example, a value of peak stress of 0.5983 N/mm^2 decreased to a value of 0.4973 N/mm^2 with an increase in the lime content from 10% to 20%. A decrease in peak stress was observed with the inclusion of the plastic strips in the soil-lime mix. The value of peak stress of 0.4903 N/mm^2 was observed to decrease to a value of 0.3145 N/mm^2 with the inclusion of 2% plastic strips in the soil-lime mix. A similar trend as shown in Table 4.1 was also observed for measurement of energy absorption, where, an increase in the energy absorption was observed with the addition of 10% lime in the soil. Studies further reveal that the increased addition of lime contents induces a decrease in energy absorption.

4.2.2 Variation of unconfined compressive strength with an increase in plastic strip content.

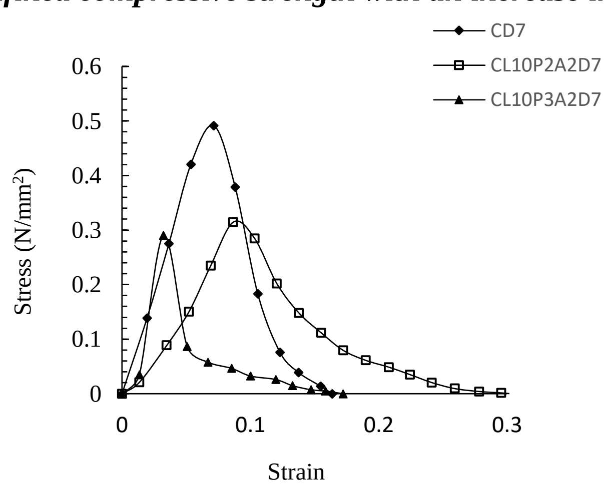

Fig. 7 Variation in UCS with variation in %age of plastic strips

Table 2 Peak Stress and Energy absorption with variation in %age of plastic strips

Sample	CD7	CL10P2A2D7	CL10P3A2D7
Peak Stress (N/mm^2)	0.4915	0.3145	0.2902
Energy Absorption (N-mm)	0.03475	0.03139	0.0105

A close investigation of Fig. 6 and Table 2 reveals that the peak stress decreases with the addition of the plastic strips. For example, a value of 0.4915 N/mm^2 of peak stress corresponding to the reference mix at 7 days was reduced to a value of 0.3145 N/mm^2 and 0.2902 N/mm^2 with the addition of 2% and 3% plastic strips, respectively. Similarly, the energy absorption of the sample was also observed to decrease with the increase in the plastic strips from 2% to 3%. For example, a value of energy absorption of reference mix at 7days was 0.03475 N-mm, which decreases to values of 0.03139 N-mm and 0.0105 N-mm with the addition of 2% and 3% plastic strips, respectively.

4.2.3 Variation of UCS values with an increase in the aspect ratio. Table 3 shows the variation of unconfined compressive strength with the increase in the aspect ratio of the plastic strip in the reference mix.

Table 3 Peak Stress and Energy absorption with variation in Aspect Ratio

Sample	CD7	CL10P2A1D7	CL10P2A2D7
Peak Stress (N/mm^2)	0.4915	0.4133	0.3145
Energy Absorption (N-mm)	0.03475	0.04256	0.03139

A close examination of Table 3 reveals that peak stress decreases with the increase in the aspect ratio from 1 to 2. For example, a value of 0.4133 N/mm^2 of peak stress of samples with the inclusion of plastic strips having aspect ratio 1 was observed to decreases to a value of 0.3145 N/mm^2 with the inclusion of plastic strips of aspect ratio 2 in the sample. Similarly, the energy absorption of samples was also observed to be increased with the change in the aspect ratio from 1 to 2.

4.2.4 Variation in UCS with increased duration of dry curing. Fig. 8 and Table 4 reveals that peak stress and energy absorption increase with the increase in the dry duration for 7 to 14 days. For example, the peak stress value of the samples 7 days was 0.49145 N/mm^2 which increases to value of 0.5686 N/mm^2 when the curing period was increased from 7 to 14 days. A similar trend was also observed with other samples with the inclusion of plastic strips.

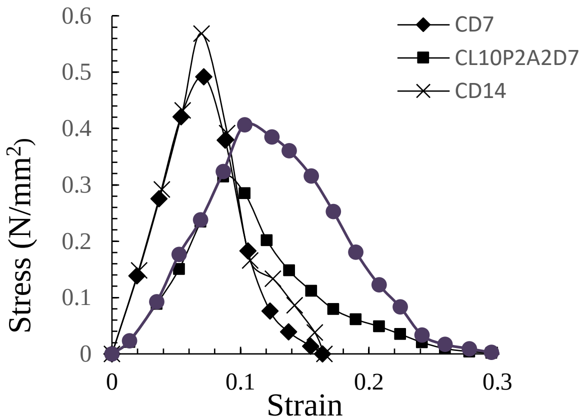

Fig. 8 Variation in UCS with an increase in the duration of sample testing

Table 4 Peak Stress and Energy absorption with variation in the duration of sample testing

Sample	CD7	CD14	CL10P2A2D7	CL10P2A2D14
Peak Stress (N/mm^2)	0.4915	0.5686	0.3145	0.4063
Energy Absorption (N-mm)	0.03475	0.03886	0.03139	0.05233

4.2.5 Cracking Pattern. Fig. 9(a) and 9(b) shows the cracking pattern of the reference sample and with plastic strips, respectively. It can be revealed from Fig. 9(a) that the sample of the reference mix failed with the development of single crack and failure was catastrophic in nature. Whereas, in the sample mixed with plastic strips, a multiple cracking pattern was observed and no catastrophic failure was observed in such specimens.

(a) (b)

Fig. 9 (a) Cracking pattern of reference mix with a development of single crack (b) multiple cracking pattern of reference mix mixed with waste plastic strips.

5. CONCLUSIONS

The following conclusions can be derived from the study:

5.1 Unconfined Compressive Strength (UCS)

1. With the addition of lime in the soil, an increase in the unconfined compressive strength was observed. The increase in the unconfined compressive strength was highest with the addition of 10% lime in the soil, whereas, increased percentage of lime from 10% to 20% induces a decrease in the unconfined compressive strength.
2. The unconfined compressive strength decreases with the addition of the plastic strip to the reference mix.
3. The unconfined compressive strength increases when the aspect of waste plastic in soil mass was changed from 2 to 1.
4. The unconfined compressive strength increases with the increase in the dry duration of the testing of samples. A higher increase in the unconfined compressive strength was observed at 14 days of curing.

5.2 Energy Absorption Behavior

1. The energy absorption increases with the addition of 10% lime in the soil mass, further increase of lime to 20% attributes a decrease in the energy absorption.
2. The energy absorption decreases with the addition of the plastic strip to the reference mix.
3. The energy absorption increases when the aspect ratio of waste plastic in soil mass was changed from 2 to 1.
4. The energy absorption increases with the increase in the dry duration of the testing of samples. A higher increase in energy absorption was observed at 14 days of curing.

5.3 Cracking Pattern

1. A catastrophic failure with a single crack was observed in the sample without the inclusion of waste plastic strips.
2. A multiple cracking pattern was observed in the specimens of soil mixed with waste plastic strips.

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A Preliminary Study on Geotechnical Properties of Bioremediated Oil Contaminated Soil using Bacteria and Organic Manure

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ABSTRACT

Soil contamination is one of the environmental pollutions which is a major threat to the ecosystem. Every day around 2 million tons of oil produced in the world and about 10% of it is percolating into the environment which causes pollution. Mostly the maximum amount of oil-contaminated soil sites had not been rehabilitated, even though these contaminants possess extreme threats to the environment and alter the geotechnical properties since the remediation process is expensive. It is necessary to remediate and reclaim the contaminated soil to improve its properties by suitable methods for the safe and economic construction of structures on it. Bioremediation of these contaminated soil is found to easy, safe and cost-effective and yields promising results with higher efficiencies. It is an eco-friendly technique in which the biological agents are used to transform the contaminated soil into non-toxic forms. The nitrogen sources from the microbes are used to support the microbial biodegradation of the hydrocarbons. In this research, an attempt has been made to remediate the contaminated soil using bacteria, cow-dung and goat manure independently and to study their interaction with the physical and chemical characteristics of the remediated soil. The result obtained confirmed that the oil content has been drastically brought down as these remediation stimulants have been introduced in the contaminated soil.

Keywords: Soil Contamination; Hydrocarbons; Bioremediation; Bacteria; Manure.

1. INTRODUCTION

Soil contamination happens due to the excessive usage of fertilizers, pesticides, petroleum products, chemicals, etc., The percolation of oil into the ground takes place during oil exploration, transportation, buried pipeline leakages, petroleum productions, spillage from vehicles, discharge from the coastal oil wells, etc., The evolution of petroleum fractions has consistently induced and forced various sectors to pollute the adjacent environment bodies with used oils since these don't possess a regulated disposal methodology. The introduction of these vicious materials to the environment discharges huge amounts of hydrocarbon [1] into the environmental bodies and accounts for major pollution sources for the soil in the world, especially in oil-producing countries [2-4]. This menace is found to be very severe in poorly regulated countries since oil spills were not being cared for a longer period of time, which had resulted in continuous accumulation and these turned into an existing problem as the hazards to the environment had been severe lately [5-7]. This soil contamination leads to a cyclic disaster since the oil-contaminated soil leads to loss of vegetation productive soil and groundwater pollutions which ultimately affects the local economic conditions of the people [8]. Remediation of these contaminated soils is basically expensive [12], so as a method to eliminate the toxicity in soil with high efficiencies and low-cost bioremediation techniques are adopted [9-10]. Bioremediation refers to the transformation of the contaminants to potentially less harmful entities with the help of bacteria and microorganisms which infest on the nutrient available as pollutants on the site and thus breaks to degrade the pollutants to potentially less pollutant states. The contaminated sites can be treated using physicochemical methods like soil flushing, soil washing, and electrokinetic remediation and by biological remediation methods. Bioremediation techniques have been observed to be effective techniques that stimulate the biodegradation of contaminated soils [13]. It has been observed that bioremediation of oil-contaminated soil was the most suitable technique for remediation of oil contaminants [14].

According to [15] only two bacteria were able to degrade petroleum oil. In this study, Pseudomonas fluorescence and bacillussublitis, where bacillussublitis is a combination of three bacteria namely (bacilluslicheniformis, bacilluscirculans, and bacillusmegaterium) is used**.** Pseudomonas fluorescence is a rod-shaped bacterium which is gram-negative and it is found everywhere, in virtually all environment on earth that supports life. This type of bacteria has multiple flagella and can survive at room temperature. This bacterium can surpass the other soil micro-organisms by giving a competitive advantage as useable for iron. This bacterium can produce compounds antagonistic to other soil micro-organisms like phenazine and antibiotics of hydrogen cyanide (HCn). The growth of bacteria has more involvement in reducing the oil and grease content from the soil and Bacillus subtilis is a gram-positive, spore-forming bacterial species. It is the best-characterized bacteria and is used as a model organism. It is a rod-shaped bacterium and as it produces endospores it can survive the high-temperature environmental condition. In the soil, the natural environment of bacillus subtilis the bacterium can survive environmental conditions including drastic differences in oxygen tension. Bacillus subtilis is strongly linked to the other bacterium Bacillus licheniformis, Bacillus circulans, Bacillus megatherium. Though many researches are conducted on biodegradation using seven families of bacteria together for efficient results, here an attempt has been made with the above mentioned two families.

A study [16] shows that the bioremediation of oil-contaminated soil can be achieved by the use of cow dung and goat manure, which resulted in the positive degradation of contaminated soil. These animal wastes are mostly used as manure in agricultural fields to enrich the soil nutrients. It is also found that the microbes present in these manures can remove the contaminants. Cowdung is a composite of cellulose, protein, hemicellulose, and minerals like nitrogen, potassium, magnesium, calcium, sulphur, etc., It includes a microbial composition of nearly sixty species of bacteria, fungi and about hundred species of protozoa and yeasts. The bacterial species in cow dung include bacillus, Corynebacterium and lactobacillus [17].Rice husk which is a natural fiber can be used as a bulking agent in bioremediation of hydrocarbon polluted agricultural land [18] The bulking agents will improve the permeability and porosity of the contaminated soil and increases the rate of the remediation process. The hydrocarbon degraders from the rice husk will have enzymes that metabolize hydrocarbon as a source of energy. The rice husk mostly contains fungi due to its lignocellulosic content and results in logarithmic microbial multiplication. The increased microbial activities lower the concentration of hydrocarbon within a maximum of 4 weeks. Goat manure is a good biostimulant that increases the activities of the hydrocarbonoclastic bacteria causes a decrease in the hydrocarbon content in the soil. The nutrients present in the manure stimulates microbial growth and produce enzymes to breakdown the hydrocarbon present in the soil.

However, this study reports on various bioremediation techniques used such as bacterial biodegradation (BA), Cowdung-Rice husk (CR) combination and Goat Manure-Rice husk (GR) combination and to compare the remediation potential for these three different stimulants with respect to the chemical and geotechnical aspects of the remediated soil within standard stipulated time frames.

2. MATERIALS

2.1 Soil collection

The uncontaminated soil samples are collected from Amrita University, Coimbatore, India. The sample is taken from a depth of 15 feet below the ground level to eliminate the interference of organic matter. The sample is collected from an open excavation by core cutter method and sealed to avoid the loss of moisture content.

2.2 Sample preparation

The soil is contaminated artificially by used engine oil. The specific gravity of the oil is 0.79 at 27^0 C with a kinematic viscosity of 67.56 mm^2/s.

The process of bioremediation is done using a hydrocarbon-degrading family of bacteria. Pseudomonas fluorescence and basillussublitis, where basillussublitis is a combination of three bacteria namely basilluslicheniformis, basilluscirculans, and basillusmegaterium.

Organic manure such as cow dung and goat manure with rice husk as a bulking agent. Rice husks are procured from Ettimadai, Coimbatore, India. The bacteria and manure are procured from Tamilnadu Agricultural University, Coimbatore, India.

3. EXPERIMENTAL PROGRAMME

3.1 Soil Preparation and Remediation process

The soil sample was sieved through a 4.75 mm sieve to ensure the removal of coarser particles. The soil was artificially contaminated by 3 % (w/w) with engine oil. The contaminated soil sample was divided into three parts and each part of the soil is treated by a different method. The remediation process was done by adding bacteria (BA), cow dung with rice husk (CR) and goat manure with rice husk (GR). The bacteria mixture of 2 ml was added to the 3 kg soil mass and kept for remediation for 30 days. The ratio of the manure with the bulking agent in the contaminated soil was kept as 1:1:3. The prepared sample was stored in separate labeled containers and maintained at room temperature for 30 days for the development of microorganisms to destroy the oil content.

To analyze the influence of oil content on the strength of the compactive nature of the soil, the density behavior of the contaminated soil was tested for different compositions of oil. The shear strength of the uncontaminated soil and the remediated soil using various methods were obtained to assess the reusability of the remediated soil.

3.2 Tests conducted

***3.2.1 Preliminary Tests*.** Preliminary tests were conducted on the uncontaminated soil samples to determine their physical properties such as sieve analysis, specific gravity, consistency limits, plasticity index in accordance with respective IS standards and the results are shown in Table-1.

Table 1 Properties of Uncontaminated soil

Properties of Uncontaminated Soil	Method	Value
Sand (0.075- 4.75mm)	IS 2720- (Part 4)-1985	53.12%
Silt and Clay (<0.075)	IS 2720- (Part 4)-1985	46.88%
Natural Moisture Content (%)	IS 2720- (Part 2)- 1973	21%
Organic Content (%)	IS 2720- (Part 22)- 1972	3.1%
Specific Gravity	IS 2720- (Part 3)- 1980	2.69
Liquid Limit	IS 2720- (Part 5)- 1985	42%
Plastic Limit	IS 2720- (Part 5)- 1985	20%

3.2.2 Determination of Physiochemical properties of soil. The soil samples were tested for different physiochemical properties such as pH, Moisture content, Total Nitrogen content, Phosphate content, Potassium content, Total organic carbon content, Electrical conductivity, Organic content and Oil and grease content in accordance to IS standards.

3.2.3 Soil Compaction Test. The test was carried out according to IS 2720- Part- 8, where the maximum dry density of the soil and optimum moisture content of the soil was determined by plotting a graph between dry density and water content.

3.2.4 Unconfined Compression Test. This shear strength of the soil was identified using the unconfined compression test in reference to IS 2720-10, where the maximum load on the soil was obtained from the applied load and deformation.

4. RESULTS AND DISCUSSION

4.1 Physiochemical properties of various methods of Bioremediation

The results of the physiochemical properties of the soil samples are given in Table 2, where it is observed that after the following bioremediation techniques adopted has drastically reduced the oil and grease content in minimalistic durations. Also, with a meagre quantity of raw materials for bioremediation of the contaminated soil, where a decrease of 95% and 92% is achieved for Cowdung-Ricehusk (CR) and Goatmanure-Rice husk (GR) combinations respectively. This decrease is majorly due to the presence of pseudomonas and basillus bacteria present in the manure and decaying organic matter, where these microorganisms tend to digest the oil as a possible source of the nutrient. These bioremediation techniques also tend to promote the plant growth in the remediated site due to an increase in the concentration of N, PO4, K, Organic carbon and organic matter.

Table 2 Physiochemical properties of various methods of Bioremediation

Parameters	Units	Method	Contaminated Soil	BA (30 Days)	CR (30 Days)	GR (30 Days)
Oil & Grease	mg/kg	FAO MANUAL	81	32	4	6
Moisture	%	IS 15106:1999	11.2	9.30	8.20	9.21
N	mg/kg	IS 14684:1999	930	1927	916	1502
PO4	mg/kg	IS 10158:1982	238	409	1093	4053
K	mg/kg	USEPA 3050B	183	124	119	125
Total Organic Carbon	%	IS: 2720	7.7	8.9	16.8	14.9
EC@25° C	µmho s/cm	IS: 14767:2000	180	70	120	230
Organic Matter	%	IS:2720	13.3	15.3	28.9	25.6
pH@25° C	-	IS:2720	8.33	9.30	8.23	8.02

BA – Bacterial Remediation Technique
CR – Cow Dung -Rice husk Remediation Technique
GR – Goat Manure - Rice husk Remediation Technique

4.2 Compaction Test

The compaction test results of various composition of oil are shown in Fig. 2.

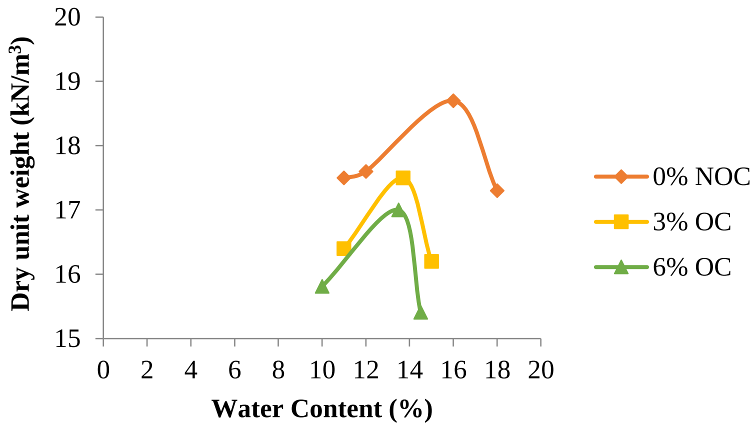

Fig. 2 Compaction test for different concentrations of oil

It is observed that an increase in oil concentrations decreases the optimum moisture content and the maximum dry unit weight of the soil. This behavior is observed since the oil is hydrophobic in nature, which wraps the particles and thus restricts the interaction of water with the clay particles, thus reducing the amount of water required to attain its maximum unit weight and thus decreasing the moisture content. The oil present induces small structural transformations, thus increasing the interlayer expansion within the clay particle. Therefore, using similar compaction effort as used for compacting uncontaminated soil, the soil particles are less packed which leads to the decrease in dry unit weight of the contaminated soil. As oil contamination in soil increases by 3% and 6%, the optimum moisture content of the soil reduces by 14% and 17% respectively. According to Figure-3, the compaction test results for the remediated soils clearly indicate that the optimum moisture content and the maximum dry unit weight of the remediated soil increases by 3.4%, 5.3% and 6.1% for bacterial remediation BA, cow dung-rice husk CR, and goat manure-rice husk GR remediation techniques respectively, due to the decrease in oil content by bacterial digestion.

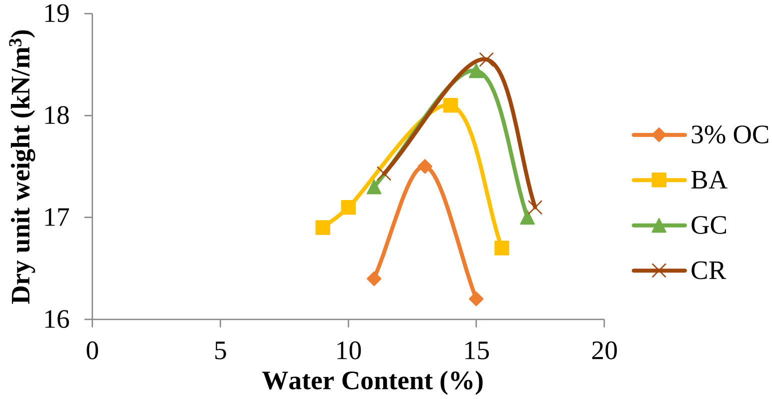

Fig. 3 Compaction tests for Bioremediated soils

4.3 Unconfined Compression Test

Fig. 4 shows the axial stress-strain variation for different oil contents. The unconfined compression strength (UCS) of the soil is found to be decreasing drastically with the increase in oil contamination concentrations. The UCS value of the uncontaminated soil is 130 kN/m^2, whereas the strength of 3% and 6% oil-contaminated soil are 85 kN/m^2 and 70 kN/m^2. The increase in oil content decreases the UCS of the soil, due to a decrease in the compaction of soil which ultimately decreases the UCS of the soil mass. It is also evident that the axial strain increases with the increase in oil content, due to the wrapping of soil particles by oil, which in turn increases the inter-particle sliding effect.

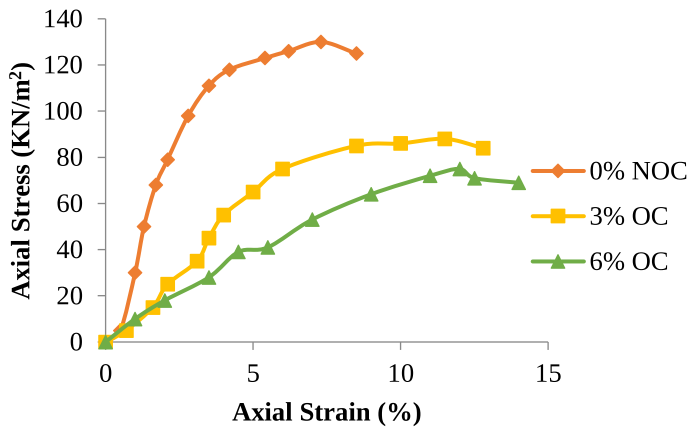

Fig. 4 Variation of axial stress and strain for different oil content

According to Fig. 5 it is evident that the UCS values of the remediated soil had increased drastically due to the reduction of oil content by the remediation methods as listed in Table 3. The remediation using CR and BR has shown an improved shear strength value as the oil content has reduced and due to the presence of the bulking agent. These fibers can influence the improvement of shear strength. But the quantity of materials mixed in these methods is high, they are in the ratio of 1:1:3. Therefore it is difficult to handle for larger quantity remediation.

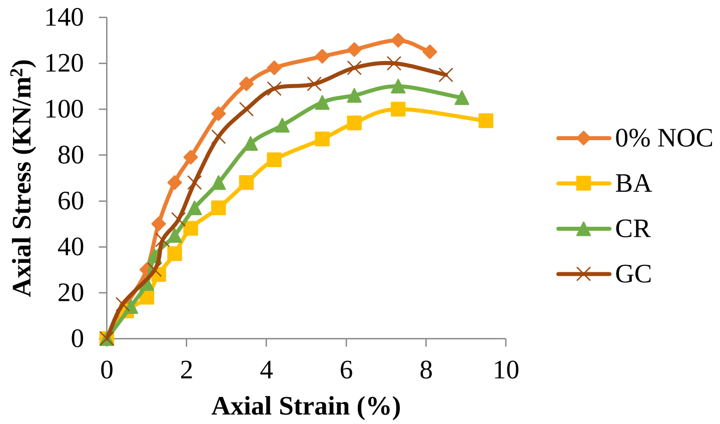

Fig. 5 Variation of axial stress and strain for various bioremediation methods

Table 3 Unconfined Compression Test for various condition

Soil Type	q_u (kN/m^2)	C (kN/m^2)
Uncontaminated Soil	130	65
Contaminated Soil (3% oil)	85	42.5
Contaminated Soil (6% oil)	70	35
Bacterial biodegradation (BA)	98	49
Cowdung-Rice husk (CR)	105	52.5
Goat Manure-Rice husk (GR)	110	55

5. CONCLUSIONS

The present study analysed the amount of oil and grease content in the contaminated soil and the effect of the three different remediation techniques.

The following conclusions are obtained from the study:

- The bioremediation techniques with bacteria and organic manure showed an improved result in the removal of oil contaminants in the soil.
- The oil and grease content in contaminated soil is initially 81mg/kg. The obtained percentage removal of oil contaminants is 60.49%, 92.59% and 95.06% for the remedial combinations Bacteria (BA), Cow Dung-Rice husk (CR) and Goat Manure-Rice husk (GR).
- It is found that bacterial remediation is found to be economical in comparison with the other methods.
- The Unconfined compression strength of the uncontaminated soil has decreased by 34.61% and 46.15% for 3% and 6% oil contamination.
- The UCS value of the bioremediated soil has increased by 15.29%, 23.53% and 29.41% for the remedial combinations Bacteria (BA), Cow Dung-Rice husk (CR) and Goat Manure-Rice husk (GR).

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Utilization of Beach Shells for Soil Stabilization

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ABSTRACT
Soil stabilization is required when the soil available for construction is not suitable for the intended purpose. It can increase the shear strength of soil, control its shrink-swell properties and improve its load-bearing capacity. It can also be used to treat a wide range of sub-grade materials varying from expansive clays to granular soils as well as improve other physical properties of soils. To make deficient soils useful and meet geotechnical engineering design requirements, the present study has focused on the use of potentially cost-effective and locally available material that is obtained from beaches. The present work is aimed at assessing the impact of beach shells powder on the stabilization of weak soil. The soil sample collected was falling under silty gravel type. Different tests were conducted on soil with varying percentages of beach shell powder. From the obtained results, it was observed that the addition of 2% to 10% of beach shells powder showed some improvement over Atterberg's limits, direct shear test parameters, and compaction results. So, the present work concluded that stabilized soil could be utilized for roadways, parking areas, site development projects, airports and many other situations where soils are not suitable for construction.

Keywords: Soil stabilization; Beach Shell; Properties

1. INTRODUCTION
For any land-based structure, the foundation is very important and has to be strong to support the entire structure. To make foundation strong, the soil around it plays a very critical role. So, to work with the soils, proper knowledge about their properties and factors which affect their behavior is essential. The process of soil stabilization helps to achieve the required properties in the soil needed for the construction work. Soil stabilization is the process of improving the engineering properties of the soil and thus making it more stable. It is required when the soil available for construction is not suitable for the intended purpose. In its broadest senses, stabilization includes compaction, pre-consolidation, drainage, and many other such processes. Soil stabilization can be used to treat a wide range of subgrade materials varying from expansive clays to granular soils as well as improve other physical properties of soils such as increasing their resistance to erosion, dust formation or frost heaving. Soil stabilization can be achieved by increasing the density of the soil or by adding admixtures and then applying mechanical work to compact it, which is a more economical solution for improving the performance of problematic soils, by enhancing their cementation and reducing their sensitivity to moisture.

Conventionally, cement, lime and fly ash have been used in stabilizing weak soils for construction purposes like road, building, etc. in order to provide firm bases for all types of paved areas, to improve foundation conditions. The over-dependence on industrially manufactured soil-improving additives (cement, lime, etc.) has kept the cost of construction financially high. In addition to large quantities of carbon dioxide are released during their production which leads to worsening global warming. In order to make deficient soils useful and meet geotechnical engineering design requirements, researchers have focused more on the use of potentially cost-effective materials that are locally available from industrial and agricultural waste in order to improve the industrial properties of deficient soils. Some of such studies are discussed here.

Babu and Vasudevan (2008), studied the strength and stiffness response of coir fiber-reinforced tropical soil. They found coir retains much of its tensile strength when wet. It has low tenacity but the elongation is much higher. The degradation of coir depends on the medium of embedment, the climatic conditions and is found to retain 80% of its tensile strength after 6 months of embedment in clay. Mounika et al. (2014), studied the influence of seashells powder on black cotton soil during stabilization. In this research, the admixture sea shell powder is added at a proportion of 12% to 18% with an increment of 2%. It was concluded that with the addition of admixtures, the UCS of the black cotton soil has been increased. For sea shell powders it was 273 kN/m^2 at 16%, when compared to natural black cotton soil it was 38.63 kN/m^2. The CBR values have also been increased by adding the seashells powder as admixture at a proportion of 5% to 45% with an increment of 5% with the black cotton soil. It attains a maximum CBR value of 7.8% at 20%, as for black cotton soil without adding the admixture attains a value of 1%. Their study concluded u beach shells powder can be used as a stabilizing agent. Gupta and Sharma (2016), has presented an approach on the way of improvement in the various geotechnical properties of black cotton soil properties, by blending it with waste materials such as river sand, fly ash and marble dust. Hence, from these approaches, the impacting effect of waste materials on the environment reduced due to the optimum utilization of these waste materials in the improvement in various properties of black cotton soil. Prasanna and Kumar (2017) carried out research on soil reinforcement using coconut shell ash as waste material for Indian soil. They observed by comparing all the results of Atterberg's limits, maximum plasticity index, the liquid limit was achieved at 2% and also maximum plastic limit was at 10% coconut shell ash reinforcement. Then regarding compaction, they concluded at 0.8% ash achieved a maximum improvement of MDD and OMC. From direct shear test results, they concluded that the angle of internal friction and cohesion was achieved at the range of 0.4 to 0.8%. Prasanna (2018) utilized waste plastic shreds for the stabilization of soil. In that research paper, the author added waste plastic shreds in varying percentages like 2, 4, 6, 8, and 10% to the soil samples as a reinforcement material. For the first soil sample, there was a decrease in MDD, OMC, and cohesion and a slight increase in friction with an increase in the percentage of reinforcement. For the second sample also, almost the same results were obtained which means a decrease in MDD, OMC, and cohesion and a slight increase in friction with an increase in the percentage of reinforcement. The decrease in the maximum dry density of soil must be due to the low specific gravity of plastic shreds. Also, it has been observed that adding beyond 10% of plastic waste would not vary much in MDD value. The author concluded that the stabilized soil could be utilized for roadways, parking areas, site development projects, airports, and many other situations where subsoils are not suitable for construction.

In this research paper author is aimed at assessing the impact of beach shell powder on the stabilization of weak soil. This present research paper provides data regarding stabilization of soils using beach shells powder (BSP) as a stabilizer and explains how the value of soil data can be increased by the use of BSP. The main objectives of this study are to:

- To carry out physical tests on soil without reinforcement.
- To carry out physical tests on soil with reinforcement (beach shells powder) in varying percentages.
- To compare the results of the test conducted on ordinary soil and soil with beach shells powder.

2. MATERIALS AND METHODOLOGY

The soil samples used in this study were obtained as undistributed samples from Margao city. The study area falls under the district of South Goa. All samples were taken at three different locations. The shells were obtained from Colva beach in South Goa. The beach shell powder was made by putting the shells in the Los Angeles testing machine. The beach shell powder retained on IS75 micron sieve was used for this experiment. In this project work, an experimental study on the effect of beach shell powder to increase the strength of the soil was studied. Different tests were conducted on soil samples with varying percentages of beach shell powder. The samples were subjected to different laboratory tests such as particle size distribution (wet sieve analysis), Atterberg's limits, shear and compaction tests.

2.1 Beach shell powder (BSP)

Beach shells are naturally available materials on the seashores. They are hard exoskeleton of molluscs. They contain about 90% of calcium carbonate which is a major component in lime and the remaining 10% contains dust and impurities.

Fig. 1 Beach shells and powder

3. RESULTS AND DISCUSSION

Undisturbed samples were collected from the field and different laboratory tests were conducted. Moisture content and the specific gravity of the sample were found to be 20.02% and 2.43 respectively. From particle size distribution analysis soil was found as silty-gravel soil. Then Atterberg 's limit (Liquid limit and Plastic limit) test was performed on an unreinforced sample. The values of liquid limit (LL), plastic limit (PL) and plasticity index (PI) obtained were 49%, 23.58% and 25.42 respectively. At 2% addition of beach shell powder on the soil sample, the following LL, PL and PI values like 47%, 28.33% and 18.67 respectively were obtained. By adding 4% of beach shell powder on the soil sample, LL, PL, and PI obtained were 45.42%, 29.09% and 16.33 respectively. At 6% of beach shell powder, LL, PL, and PI were 45.21%, 29.14% and 16.07 respectively. At 8% of beach shell powder, LL, PL, and PI were 47%, 24.93% and 22.07 respectively. From results obtained it was observed that the liquid limit decreased with the addition of beach shell powder and plastic limit slightly increased till the addition of 6% but after that slightly decreased. Plasticity index decreased at 2%, 4% and 6% addition of beach shell powder but at 8% then a slight increment was observed. The results were shown in Fig. 2.1

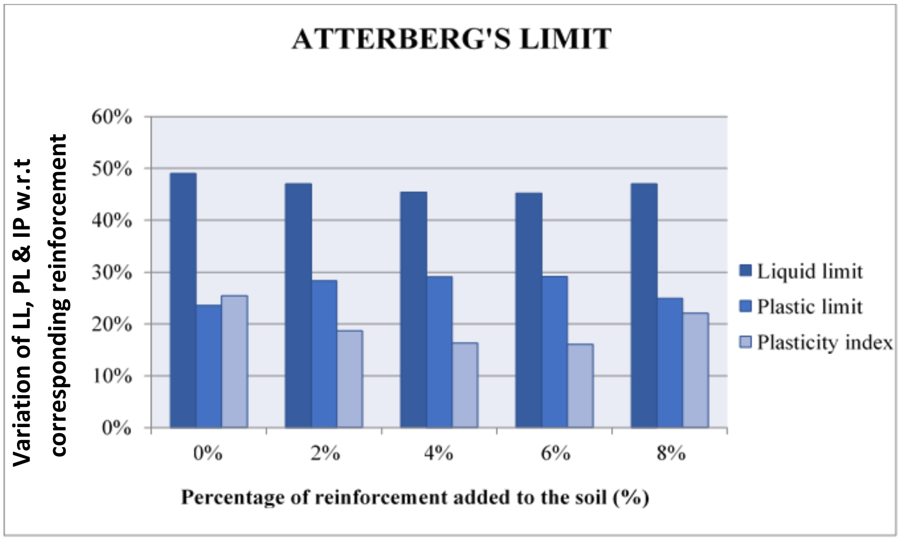
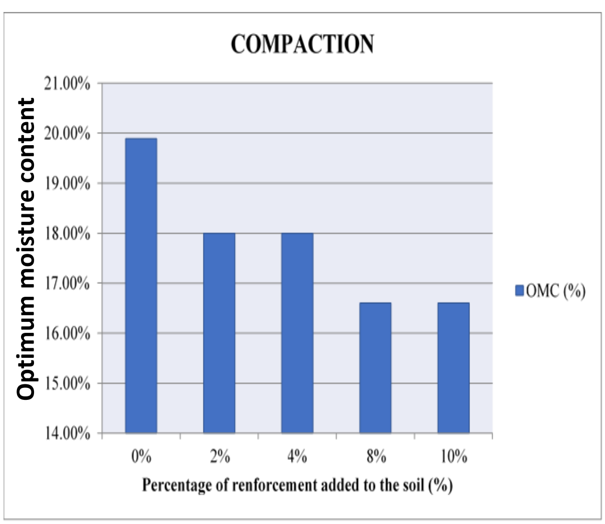


Fig. 2.1 Comparison of Atterberg's limits with different percentages of beach shell powder

After that compaction test was done and found optimum moisture content (OMC) and maximum dry density (MDD). The following results were observed. OMC was found to be 19.89% and MDD was 17.2 kN/m^3 without the addition of beach shell powder. After the addition of beach shell powder as a stabilizer in various percentages, the following changes were obtained. With the addition of 2% of beach shell powder, OMC and MDD were decreased to 18% and 17.0 kN/m^3 respectively. Again, with the addition of another 2% that is a total of 4% beach shell powder, OMC and MDD were 18% and 17.5 kN/m^3 respectively. For 8% of beach shell powder, OMC and MDD were 16.6% and 18.0 kN/m^3 respectively. At 10%, OMC and MDD were 16.6% and 18.2 kN/m^3 respectively. From this, it was observed that with the addition of beach shell powder as a stabilizer, optimum moisture content was decreased and maximum dry density values were increased.



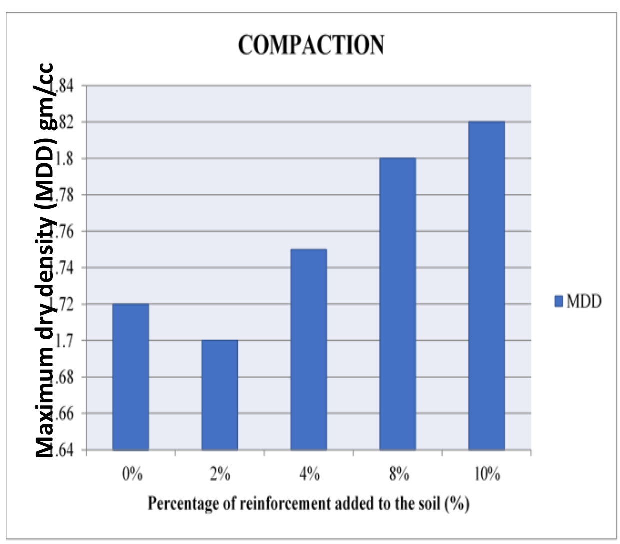


Fig. 2.2 Comparison of OMC and MDD with different percentages of seashell powder

The next direct shear test was conducted to determine the shear strength parameters of soil, which is cohesion (c) and angle of friction (ϕ). A direct shear test without beach shell powder was conducted. The following $c = 0.2 g/cm^2$ and $\phi = 31°$ values were obtained. Generally, the higher the friction and cohesion value better the shear strength of the soil and also the stability of the soil. Then soil was stabilized with beach shell powder in different percentages. With 2% of beach shell powder as a stabilizer, the following $c = 0.19 g/cm^2$ and $\phi = 37°$ values were obtained. At 4%, $c = 0.12 g/cm^2$ and $\phi = 50°$. Here cohesion value decreased and friction value increased. At 6%, $c = 0.14 g/cm^2$ and $\phi = 51°$. At 8% $c = 0.14 g/cm^2$ and $\phi = 42°$. Here it was observed that the angle of internal friction increased from 31° to 42° and cohesion decreased from 0.2 to 0.14 g/cm^2. The angle of internal friction increases as the percentage of beach shell powder increases. Fig. 2.3 shows the comparison of friction and cohesion values with different percentages of beach shell powder.

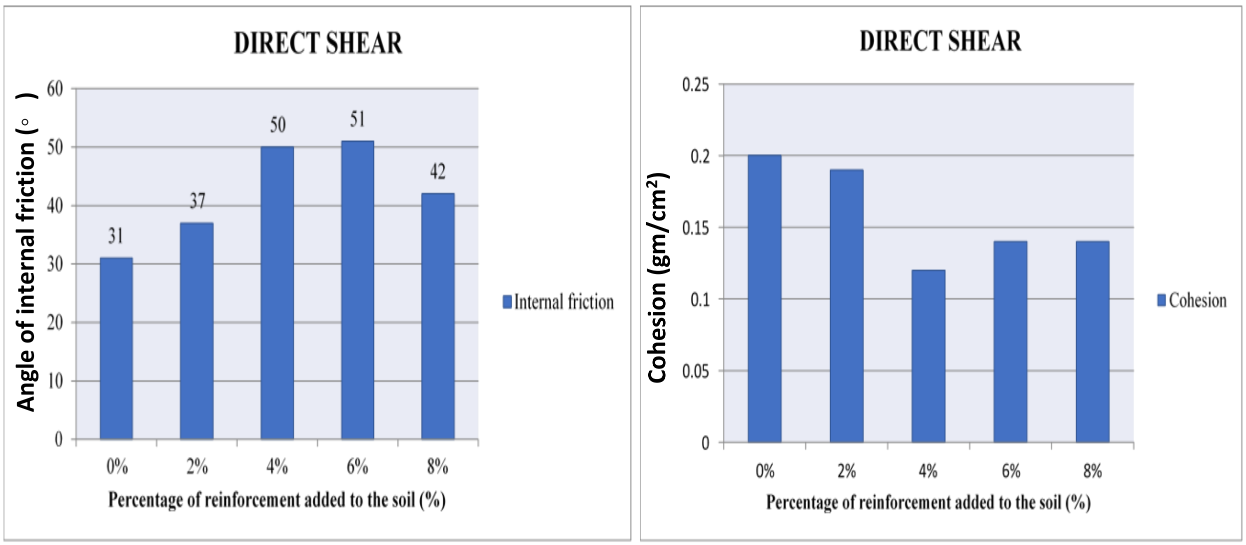


Fig 2.3 Comparison of friction and cohesion with different percentages of seashell powder for soil sample

4. CONCLUSIONS

In this paper, the effect of various percentages of beach shell powder on the soil sample was studied. From results obtained from Atterberg's limits, it was observed that the liquid limit decreased with the addition of beach shell powder and the plastic limit slightly increased. Plasticity index decreased at 2%, 4% and 6% addition of beach shell powder but at 8% then a slight increment could be observed. Compaction test on soil sample with varying percentages of beach shell powder indicates that the beach shell powder increases the maximum dry density and decreases the optimum moisture content. This point can be beneficial in the construction of embankments of lightweight materials. The angle of internal friction (ϕ) increases and cohesion (c) decreases considerably with the inclusion of different percentages of beach shell powder on the soil sample. The variation of the friction angle of soil with the percentage of beach shell powder is a non-linear variation. From the results obtained it could be concluded that beach shell powder can be used as one of the stabilizing materials for soil stabilization in the region under consideration.

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Mechanically Stabilized Earth Walls with Alternate Backfills for Highway Structures

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ABSTRACT

Ideally, freely draining granular materials such as sand is used as the backfill material in Mechanically Stabilized Earth (MSE) wall applications. But the scarcity of ideal granular material necessitated the researchers to think about other alternatives. A large quantity of construction and demolition waste (CDW) is being generated in India. In this study, the feasibility of utilizing CDW as a backfill for MSE walls constructed for the approach way of a flyover at a site in Kerala was studied. The geotechnical properties of CDW were determined in order to ascertain whether the properties comply with existing specifications. Further, the numerical studies were conducted to study the deformation behavior of the MSE wall with CDW backfill at the end of construction and at failure. The present study highlights the potential use of processed CDW as an alternative backfill material for MSE walls constructed for highway structures.

Keywords: MSE walls; Marginal backfills; Construction and demolition waste; Reinforced soil

1. INTRODUCTION

Mechanically stabilized earth (MSE) walls or reinforced soil walls are very well-recognized alternatives to conventional retaining walls. Reinforced soil walls are considered beneficial and cost-effective in congested urban areas due to right-of-way restrictions. They have been increasingly used as approach structures to vehicular and pedestrian bridges and for support of railway embankments. MSE walls are comprised of backfill soil, reinforcements and facing. One of the key components which govern the performance of the MSE wall is the backfill. For the satisfactory performance of MSE walls, the backfill material should possess good frictional and freely draining characteristics. Various agencies such as Federal highway authority (FHWA), National Concrete Masonry Association (NCMA), British standards (BS 8006), etc. specify guidelines for the selection of ideal backfill material. An ideal backfill material ensures proper drainage and good interaction between the reinforcements.

Back-to-back walls are generally used for highway ramps and flyover approach ways. For walls that are built back-to-back, a modified value of lateral earth pressure influences external stability (FHWA Guidelines). However, if the distance between the reinforced zone (D) is greater than H x tan (45- ϕ/2); where H is the height of the wall, the walls can be designed independently. A typical cross-section of the back-to-back MSE wall is shown in Fig. 1.

The availability of ideal backfill soil is very limited, in recent years. Also, the cost of transporting ideal soil in bulk will be prohibitive, if such soil has to be transported from faraway places. The cost of backfill constitutes about 50-75% of the total cost of the wall (Koerner & Koerner, 2011). The scarcity of ideal backfill material necessitates the use of other alternative materials.

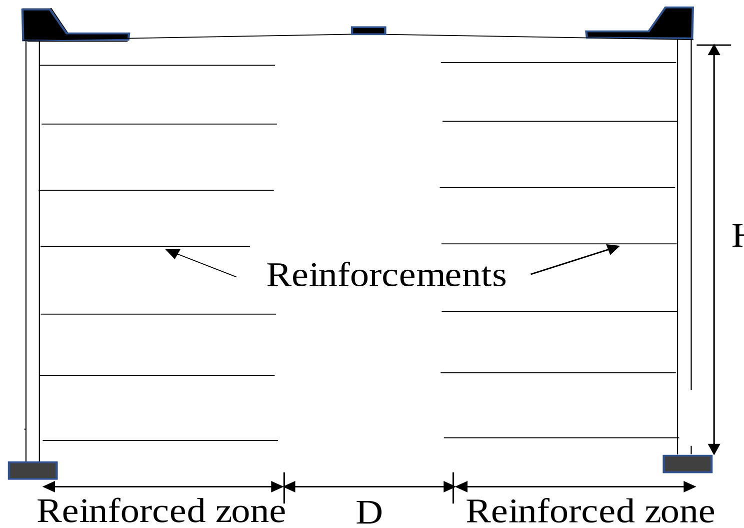

Fig. 1 Typical cross-section of back-to-back MSE wall

A large quantity of construction and demolition waste (CDW) is being generated in India as well in other parts of the world. Ministry of urban development in India reported that about 25-30 million tonnes of CDW are generated annually. Figure.2 shows the picture of CDW dumped along the roadside. Very little effort is taken for the segregation and processing of CDW. The recent controlled demolition of Maradu apartment in Cochin, Kerala is an example of bulk generation of construction and demolition waste.

Fig. 2 Construction and demolition waste dumped along the roadsides

Studies conducted by Xiao et al (2013) highlight the feasibility of using an alternative backfill composed of lightweight aggregates and recycled tired shreds. Studies conducted by Santhos et al (2013), Vieira and Pereira (2016) and Soleimanbeigi et al. (2018) highlight the use of recycled concrete aggregates as an alternative to granular materials in geotechnical applications. Neethu and Divya (2013) reported the application of geosynthetic encased crushed construction debris columns as an alternative to conventional geosynthetic encased stone columns. However, systematic studies on the characterization of CDW in the Indian scenario and potential use of processed CDW as an alternative backfill material are very limited in the literature. Thus, in the present study, the feasibility of using processed CDW as a backfill for the MSE wall has been explored. Further, numerical studies are conducted to study the deformation behavior and failure mechanism of the MSE wall with processed CDW as backfill.

2. MATERIALS

A comprehensive summary of the properties required for ideal backfill material, specified by various agencies and standards is reported by Prasad and Ramana (2016). The geotechnical, physical and chemical properties of processed CDW were evaluated to check the feasibility of using CDW as backfill for MSE walls. For the present study, CDW was collected from a waste processing plant operational in Delhi. The Kerala State Pollution Control Board (KSPCB) is in the process of setting up a facility for recycling construction and demolition waste in Cochin. The processed CDW used in the present study is shown in Fig. 3.

Fig. 3 Processed CDW used in the present study.

The grain size distribution of processed CDW was obtained by conducting sieve analysis according to ASTM-D6913-04 (2009). Figure. 4 shows the grain size distribution of processed CDW samples. The coefficient of uniformity (Cu) was found to be 5.9 and the co-efficient of curvature (Cc) was found to be 0.792. For ideal backfill soil, the percentage of fines should be less than 15%. It is important to note from Fig. 4 that the fine content i.e, the percentage of particles passing 75μ sieve is less than 10% for all the samples. The plasticity index for an ideal backfill soil should be less than 6%, however, the processed CDW was found to be non-plastic. According to the Unified Soil Classification System (USCS), the processed CDW was classified as poorly graded sand (SP). The chemical properties such as pH and total soluble solids determine the durability of reinforcements used in reinforced soil applications. Thus, the chemical properties (pH and total soluble solids) of CDW were evaluated. FHWA guidelines specify that the pH of ideal backfill soil should be between 3 - 9 and total soluble solids should be less than 1%. The pH of processed CDW was evaluated according to ASTM G51- 95 (2012) and the pH was found to be 8.88. The total soluble solids were evaluated as per IS-2720-Part 21, the total soluble solids were found to be 0.2%.

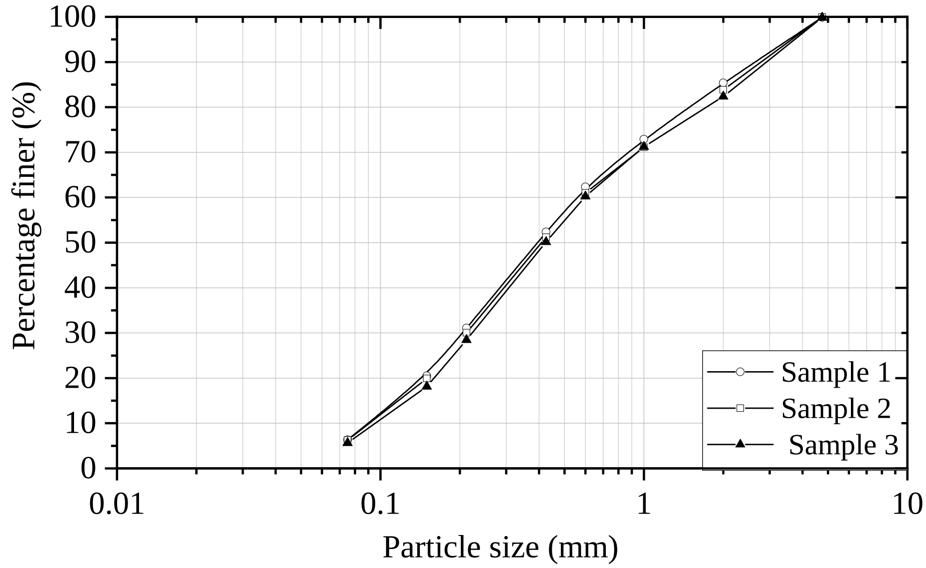

Fig. 4 Particle size distribution curve of CDW used in the present study.

The maximum dry density and optimum moisture content were evaluated as per ASTM D698-12 (2012). The compaction curves of processed CDW are shown in Fig. 5. The maximum dry density and optimum moisture content were observed to be 16.6 kN/m^3 and 15.1%. It can be observed from Fig. 5 that the compaction curve is similar to the compaction curve of coarse-grained soils.

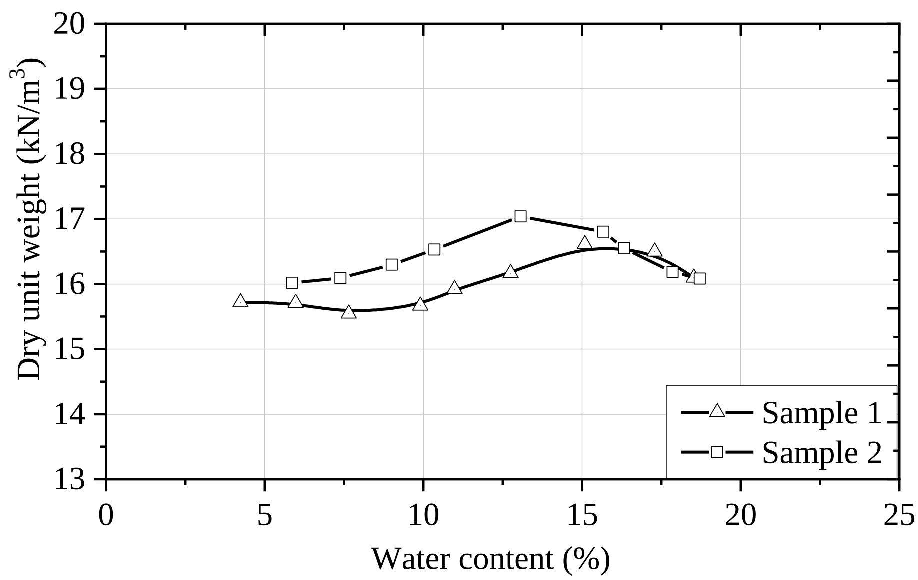

Fig. 5 Compaction curve of processed CDW

The shear strength characteristics of processed CDW were evaluated by conducting the direct shear test in accordance with ASTM-D-6528, 2000. The sample was prepared at maximum dry density. The strain rate of 1.25 mm/min was maintained during shearing. The cohesion intercept was found to be 5 kPa and friction angle was observed to be 35°. Further, the susceptibility of the crushing of processed CDW particles under a stress of 500 kPa was evaluated. The percentage of particles passing each sieve before and after being subjected to the stress is shown in Table.1. It can be observed from Table.1 that the particle size does not change significantly when subjected to a stress of 500 kPa. Also, it is important to note that the particles passing 75 microns have not increased beyond 15% even after being subjected to a stress of 500 kPa.

Table1 Percentage of particles passing each sieve before and after crushing

Particle size (in mm)	% passing	
	Before the application of stress	After the application of stress
4.75	99.89	99.89
2.00	83.29	83.74
1.00	68.96	70.01
0.30	42.55	43.46
0.15	19.30	19.99
0.075	6.25	6.76

From the above geotechnical, physical and chemical properties, it can be observed that the CDW meets the requirements of ideal backfill material mandated by various agencies. Further, numerical studies were conducted to study the deformation behavior of MSE walls with construction and demolition as backfill.

3. DEFORMATION BEHAVIOUR OF MSE WALLS WITH CDW BACKFILL

The numerical studies of MSE with CDW as backfill was carried out using a finite element software - Plaxis 2D. Deformation behavior at the end of the construction stage and the failure mechanism of MSE walls with CDW as backfill were studied. A back-to-back MSE wall of height 9 m was adopted in the study. The details of the geometry of the back-to-back MSE wall are shown in Fig. 6.

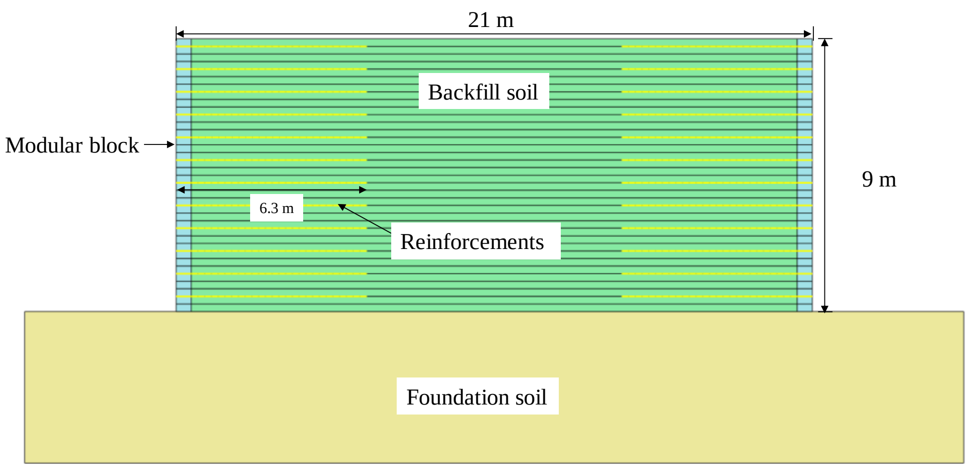

Fig. 6 Geometry of back-to-back MSE wall adopted in the present study

MSE wall with modular block wall facing which is commonly used for flyover approach ways is adopted in the present study. Mohr-Coulomb model was adopted to define the backfill and foundation soil. The reinforcements were modeled as linearly elastic elements. Geogrid reinforcements of the ultimate strength of 160 kN/m were adopted in the present study. The reinforcements were placed at a vertical spacing of 750 mm. The properties obtained from the geotechnical characterization of processed CDW were used to define the backfill properties. The modular block and foundation were considered to be rigid. To simulate the field conditions, the staged construction was adopted in the present numerical study. The deformed mesh at the end of construction is shown in Fig.7. The shear strain distribution at the end of the construction stage was used to study the state of the MSE wall under working stress conditions.

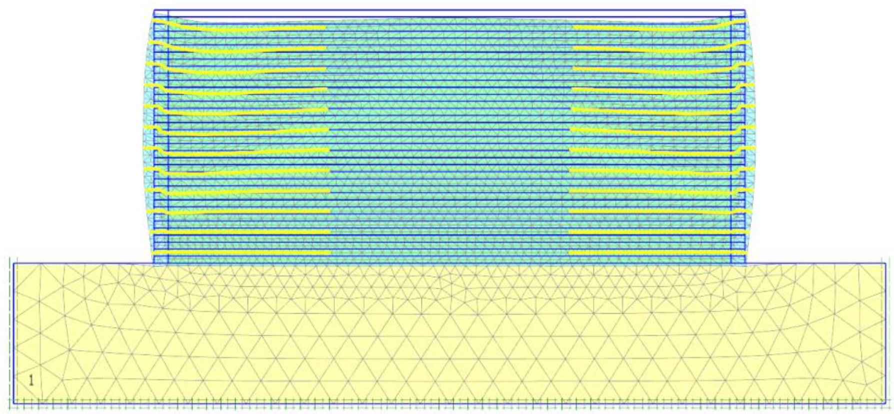

Fig. 7 Deformed mesh at the end of construction

Figure 8 shows the shear strain distribution at the end of the construction stage. It indicates the location of potential failure planes. The inclination of the potential failure plane observed (55º) was in reasonable agreement with the failure planes assumed (62.5º) by the limit equilibrium analysis methods. Along with the shear strain distribution in soil, the location of maximum tensile force in each reinforcement was also plotted in Fig.8. It can be observed that the location of maximum tensile force in reinforcement and the location of maximum shear strain in the soil are co-incident at the end of the construction stage. This implies that the shear strain in soil and tension in reinforcement reaches its peak values at identical locations.

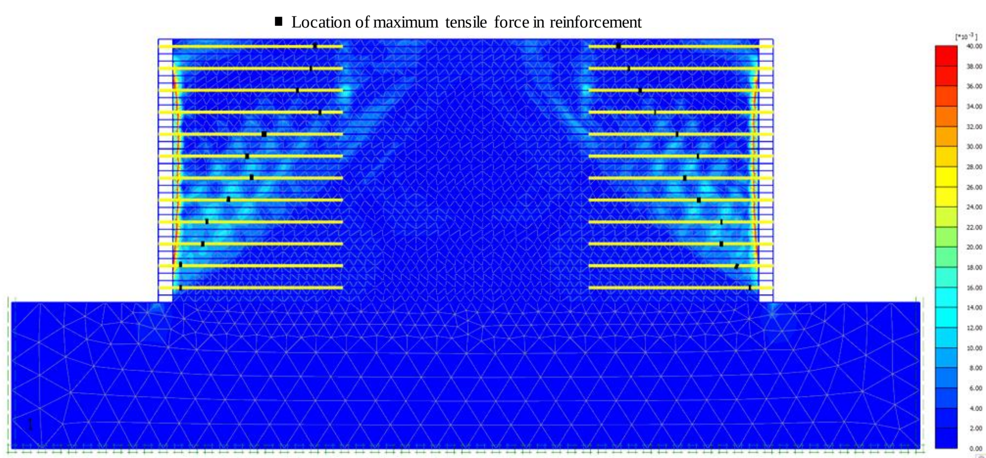

Fig. 8 Shear strain distribution at the end of construction

Further to study the failure mechanism, the safety analysis was carried out. Safety analysis uses c-φ reduction technique, in which the shear strength parameters (c and φ) are reduced by a reduction factor until the failure takes place. The factor of safety was found to be 1.91. The shear strain distribution at the end of safety analysis indicates the failure mechanism. The shear strain distribution at the end of the safety analysis is shown in Fig. 9. From Fig. 9, the formation of the bi-linear wedge can be observed. This indicates that when the design loads are exceeded, the failure mechanism is governed by external sliding.

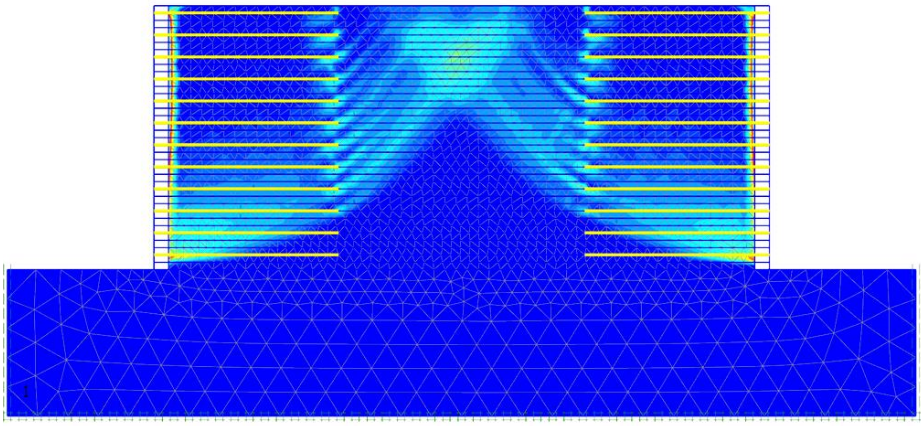

Fig. 9 Shear strain distribution at the end of c-φ reduction

4. CONCLUSIONS

Based on the present study, the following conclusions can be drawn:

- The geotechnical, physical and chemical properties of processed CDW meet the requirements of ideal backfill material for MSE walls, mandated by various standards and guidelines. Hence, there is a potential for construction and demolition waste to be used as an alternate backfill for MSE walls. However, further studies are warranted to ensure the interaction between geosynthetic reinforcements and the CDW.
- At the end of construction, the location of maximum tensile force in reinforcement and location of maximum shear strain in the soil coincide. The potential failure plane observed (55º) was in reasonable agreement with the failure planes assumed (62.5º) by the limit equilibrium analysis methods.
- From the safety analysis, it was observed that when the design loads are exceeded, the formation of a bilinear failure plane was observed and the failure mechanism is governed by external sliding.

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Landfill Mining Potential of Legacy Waste and its Associated Challenges

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ABSTRACT

We characterize dumped waste from Deonar, dumpsite located in Mumbai, India, to identify different recovery routes for this legacy waste. The study also ascertains possible challenges related to landfill mining in India. The waste characteristics for the entire dumpsite were estimated by conducting sampling using a stratified random sampling design. The dumpsite was divided into three strata and a total of 32 samples were collected. Manual sieving into different particle size categories (>20 mm, 20–4 mm and <4 mm) and further sorting into different streams (paper/cardboard, plastic, textile, wood, metal, and glass) of the excavated waste was carried out. The results show that the fine fraction (<4 mm) was accounted highest in the dumpsite. The waste older than 20 years had ~57% fine fraction while the average was 44.4% in the dumpsite. The plastic fraction was ~11.4% and showed a decreasing trend with the age of the waste. Since plastic is non-biodegradable in nature, the finding suggests that the consumption of plastic has increased in recent decades. Furthermore, metal and glass contents were very low in the dumpsite. The recyclable fraction (plastic, metal, and glass) in the dumpsite was of poor-quality suggesting recycling challenges. The combustible fraction was found to be ~23% and hence could be used to prepare refuse-derived fuel. Also, we looked at the strengths and limitations of landfill mining for Indian dumps. The strength of landfill mining lies within the goal of reaching a circular economy while putting a check on environmental pollution caused due to old dumpsites. The landfill mining projects can create revenue from recovered fractions and generate employment. However, the market for the recovered fraction needs to be identified. Most of the international studies cited that the metal fraction can generate great revenue, which is lacking in the case of Indian dumpsites.

Keywords: Landfill mining; legacy waste; physical characterization; Indian dumpsite; waste valorization.

1. INTRODUCTION

Landfilling and open dumping have been a popular municipal waste disposal choice in the past. Subsequently, these old dumps have become a heterogeneous pool of vast quantities of waste, which have various environmental and health implications for the nearby ecosystem (Dubey et al., 2016; Mor et al., 2006). Methane is generated during the decomposition of waste which is highly combustible in nature leading to landfill fires. The leachate generated from waste contains various heavy metal which contaminates the water resources if not handled carefully. Improper management of leachate can cause severe groundwater contamination and pollute the water system of nearby cities. A study in Nagpur, India, showed that the leachate from landfills has traversed to deeper layers through fractures polluting the aquifer below the landfill (Pujari and Deshpande, 2005). Similarly, a study was performed near Ghazipur landfill and its neighboring area to investigate the impact of leachate percolation on groundwater quality (Mor et al., 2006). The moderately high concentrations of chemical oxygen demand (COD), phenol, Fe, Zn, Cl^-, NO^{3-}, SO_4^{2-}, and NH_4^+ in groundwater, implicated the possibility of leachate percolation in groundwater.

Landfill mining is the recovery of the resource buried in the landfill with up-gradation of the existing landfill to mitigate the environmental problems associated with them (Johansson et al., 2013; Jones et al., 2013; Quaghebeur et al., 2013). Through landfill mining, the old landfills can be excavated and equipped with sanitary measures to control environmental threats. Also, the recovered space could be used to develop an integrated solid waste management facility to deal with the old and incoming fresh waste. The excavated waste from the dumpsite could be recycled to monetize some benefits.

The previous studies conducted on landfill mining indicate that the objective and potential valorization routes change from landfill to landfill due to difference in composition of the landfilled waste (Kaartinen et al., 2013; Kurian et al., 2003; Quaghebeur et al., 2013; Singh and Chandel, 2020). The landfill content will depend on the waste management practices that are being followed by a government or similar authority. The cultural and economic lifestyle of a country also has a specific dynamic on the waste accumulated at a landfill. The following points can be inferred from literature: a) the old landfills are more heterogeneous in nature b) they have a higher concentration of components which get recycled nowadays like plastics, metal, paper.

The recovery of secondary resources from the piled-up stocks in dumpsites/landfills requires in-depth knowledge and data of dumped/landfilled material. The objective of the current study is to apprehend the physical characteristics of deposited waste in the Deonar dumpsite. The study would also identify the strengths and limitations of landfill mining in India by carrying SWOT (strengths, weaknesses, opportunities, and limitations) analysis.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

Deonar dumpsite was selected as the study area to understand the physical characteristics of waste for its possible valorization (Fig. 1). It is one of the oldest dumpsites in India and has no buffer zone between the dumpsite and neighboring residential areas. As the site predates the formation of solid waste management rules, all kinds of commingled MSW are deposited in the dumpsite. The height of waste mounds in the Deonar dumpsite is reported to be from 30–40 m and is located adjacent to Vashi creek.

2.2 Sampling and Analysis Procedure

Information regarding the landfilling practices and waste disposal was gathered using a reconnaissance survey with officials and operators working at the site. Different sampling techniques were studied to meet the objective of estimating waste characteristics in the dumpsite. Stratified random sampling (based on component) was selected as the sampling design to apprehend characteristics of the dumpsite. The dumpsite was divided into three strata (Stratum 1: where old waste is located; Stratum 2: where waste gets dumped during monsoon season; Stratum 3: where dumping was going on). The number of samples to be collected from the dumpsite according to sampling design was 40. Samples were collected with the help of the excavator. Since an excavator can reach up to a depth of 5 m only, waste was collected by digging horizontal (at flat surfaces) as well as lateral trenches/pit (from the periphery). From one sampling point, two samples were collected (one denoting middle layer and another denoting bottom layer). The sampling points in different stratum were located in different areas of 5–10 acres. Due to inaccessibility at some location, which could not be foreseen, a total of 32 samples were collected from 16 locations.

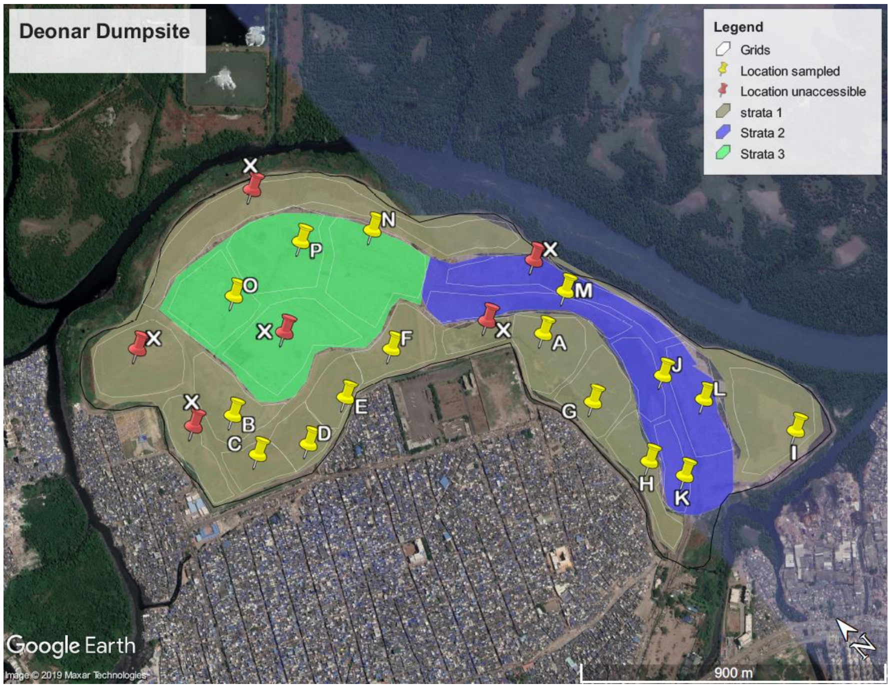

Fig. 1 Map of the study area (Deonar dumpsite, India) with marked sampling locations. (Stratum 1: where old waste is located; Stratum 2: where waste gets dumped during monsoon season; Stratum 3: where currently dumping was going on). Satellite image from Google Earth Pro 7.3.2.5776 (2019)

The excavated waste was dried in a hot air oven at a temperature of 80 °C for the analysis. For physical characterization, the dried waste was first screened into different size fractions manually using sieves of size 20 mm and 4 mm into categories of >20 mm, 20–4 mm and <4 mm. Subsequently, the screened fractions were further manually segregated into seven categories (plastic, paper/cardboard, metal, glass, textile, wood, and stone). The fine fraction (<4 mm) was not segregated into different streams since it was mostly composed of degraded organic matter and cannot be separated manually.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

The >20 mm fraction in stratum 1 (26.7±7.8%) is low compared to stratum 2 (43.9±7.1%) and stratum 3 (51.1±9.3%), which is expected as with time the waste would degrade and result in particle size reduction (Fig. 2). In addition to this, <4 mm fraction (fine fraction) has a decreasing trend from stratum 1 to stratum 3, indicating a decrease with age. For stratum 1, the <4 mm fraction varied from 40–67% with a mean of 54% and a coefficient of variation <13%. For stratum 3, the <4 mm fraction varied from 14–34%, with a coefficient of variation 35% indicating ongoing degradation. The 20–4 mm fraction was almost similar in most locations of stratum 1 and was 19.7±3.2% with a coefficient of variation less than 16%. It increased in stratum 2 and stratum 3 and was 20.4±5.2% and 23.4±4.2%, respectively.

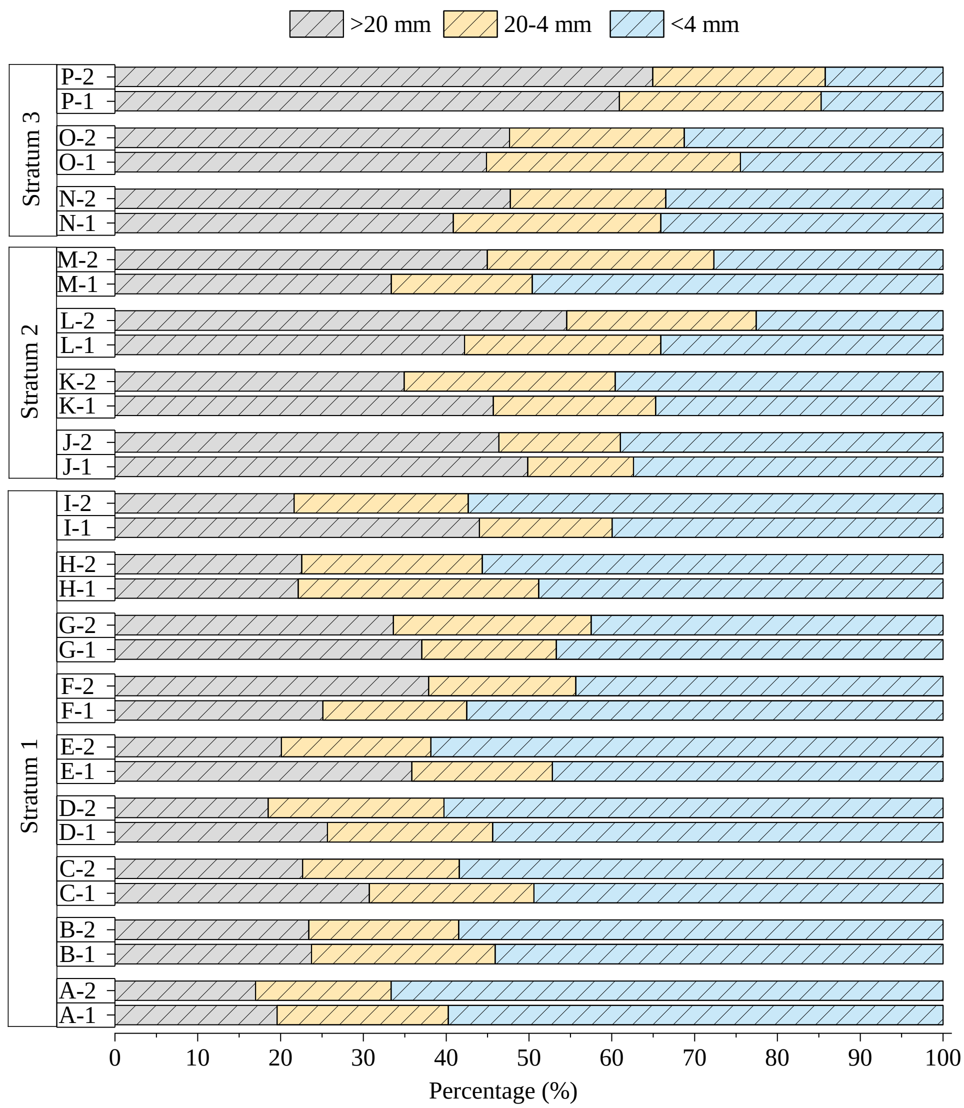

Fig. 2 Particle size distribution of excavated waste from Deonar dumpsite

3.2 Physical Characteristics

The stone fraction was accounted second-highest, i.e., 31±5%, 28±6% and 39±14% for stratum 1, stratum 2 and stratum 3, respectively (Table 1). Furthermore, the plastic fraction was the third most dominant fraction with 8±3%, 17±3% and 14±5% for stratum 1, stratum 2 and stratum 3, respectively. For stratum 1, the plastic content is almost similar for sampling location A to E which belongs to the period below 2000 and has comparatively increased for location F to H above the year 2000 indicating an increase in plastic use with the time. It could be seen that the plastic content in stratum 2 and stratum 3 is almost double compared to stratum 1. Since stratum 1 had the most aged waste, it could be said that plastic consumption has increased in recent decades. The paper fraction in stratum 1 is negligent (0.01%) and is absent for all locations except location D and F.

Table 1 Composition of excavated municipal solid waste from different stratum of Deonar dumpsite.

	Location	Plastic	Paper	Wood	Textile	Metal	Glass	Stones	<4 mm
Stratum 1	A–1	7.5	0.0	1.9	4.2	0.0	0.0	26.7	59.7
	A–2	4.5	0.0	3.4	2.5	0.0	0.7	22.2	66.6
	B–1	6.2	0.0	1.0	3.3	0.3	0.1	35.0	54.1
	B–2	6.3	0.0	3.2	5.8	0.9	0.5	24.8	58.5
	C–1	7.7	0.0	3.3	4.7	0.0	0.3	34.5	49.4
	C–2	7.4	0.0	3.7	2.7	1.2	0.5	26.1	58.4
	D–1	6.2	0.2	0.7	9.2	0.0	0.0	29.3	54.4
	D–2	5.0	0.0	3.1	6.0	0.3	0.8	24.6	60.3
	E–1	8.5	0.0	0.0	11.5	0.0	0.3	32.6	47.2
	E–2	3.4	0.0	0.1	1.9	0.0	0.1	32.7	61.8
	F–1	11.5	0.0	0.4	5.5	0.1	0.4	24.7	57.5
	F–2	13.8	0.1	1.6	5.8	0.0	1.5	32.7	44.4
	G–1	6.9	0.0	0.8	4.9	0.1	3.6	37.1	46.7
	G–2	13.8	0.0	2.5	1.7	0.0	1.8	37.7	42.5
	H–1	16.8	0.0	2.0	3.8	0.0	0.7	36.7	40.0
	H–2	3.7	0.0	0.6	2.3	0.1	0.6	35.4	57.3
	I–1	7.2	0.0	1.3	7.2	0.2	0.3	34.9	48.8
	I–2	10.7	0.0	0.4	0.6	0.0	0.5	32.1	55.6
Stratum 2	J–1	15.3	0.0	0.5	21.5	1.3	0.0	24.0	37.4
	J–2	21.2	0.2	1.8	7.7	0.9	2.0	27.4	39.0
	K–1	21.8	0.6	4.7	3.0	0.4	4.2	30.6	34.7
	K–2	19.9	6.2	5.0	2.5	0.0	1.0	25.7	39.6
	L–1	12.7	0.3	5.6	17.1	0.0	2.7	27.6	34.1
	L–2	19.7	1.7	9.7	16.0	0.7	1.3	28.5	22.6
	M–1	12.4	0.9	10.6	3.2	0.3	3.3	19.8	49.6
	M–2	13.5	4.8	8.0	4.8	0.0	0.0	41.3	27.7
Stratum 3	N–1	8.7	1.5	7.5	2.4	0.0	2.9	42.9	34.1
	N–2	17.9	1.0	2.0	6.6	0.0	1.1	37.9	33.5
	O–1	7.3	5.5	2.3	0.9	0.1	0.6	58.9	24.5
	O–2	17.3	10.1	18.3	4.7	0.6	1.0	16.7	31.2
	P–1	16.0	4.4	10.6	4.1	0.0	1.2	48.9	14.7
	P–2	18.7	5.0	16.2	12.6	0.0	1.6	31.8	14.2

The paper is more evident in stratum 3, i.e., 5±3% compared to stratum 2, i.e., 2±2%. The wood fraction also increased from stratum 1 to stratum 3 with a mean value of 1.6±1.2%, 5.7±3.5%, and 9.4±6.8% in stratum 1, stratum 2 and stratum 3 respectively. The metal and glass content in all strata were very low. The recyclable fraction like plastic, textile, metal, and glass were found to be higher in the case of stratum 2 then stratum 3. This could be due to the inefficient recycling by informal sectors during the monsoon season leading to disposal of recyclables in the dumpsite.

The overall distribution of the sorted streams in the fine fraction was calculated using the method suggested for stratified random sampling (Fig. 3). The fine fraction was accounted in the highest amount in the dumpsite ~44.4%. Stones and pebble-like material were the second-highest components in the dumpsite. Plastic was the third dominant fraction and was ~11% in the dumpsite. The metal and glass fraction were <1% in the dumpsite. The result of the physical composition for excavated waste is similar to our previous study for Mulund dumpsite (Singh and Chandel, 2020). It should be noted that the sample collected in this study could not go beyond certain depth due to equipment constraints. Hence, although the analysis is done as far as accurate as could be performed. Nevertheless, there may be some variation in the overall concentration deposited in the Deonar dumpsite.

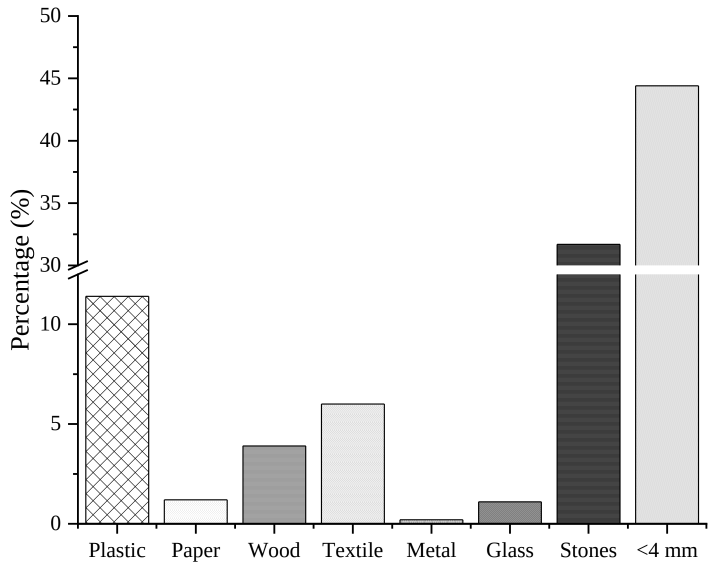

Fig. 3 Overall distribution of mass into different waste fractions in the Deonar dumpsite.

3.3 SWOT Analysis of Landfill Mining

The SWOT (strengths, weaknesses, opportunities, and threats) analysis for landfill mining was carried out in this study (Table 2). Even though various steps are being taken worldwide for reaching a circular economy, a recent report has shown that the circularity of the global economy has gone down from 9.1% to 8.6% in the last two years (Circle Economy, 2020). The main reason for this is the high extraction rate of resources, low level of processing and recycling and finally, stock build-up. It should be noted that the strength of landfill mining lies in the fact that it is a step towards sustainable development. By realizing the mining of landfills and dumpsites, we can change the linear approach of waste disposal sites to a circular approach, which is a necessary step for the coming era. Besides, the government of India necessitates analyzing the reclamation potential of the old and operational dumpsite. Furthermore, most of the old dumps in India were made before municipal solid waste rules were imposed and lacked necessary sanitary measures towards the environment. Carrying out landfill mining projects will ensure not only secondary resource extraction but also remediation of the old landfills to prevent further pollution. In addition, according to MSW rules 2016, after the closure of the landfill site, care and monitoring should be carried out for at least 15 years before considering human settlement. This adds extra economic burden in the event of landfill capping. However, the reclamation of the landfill will avoid post-closure costs (MoEFCC, 2016).

As discussed above, India is formulating many policies for tackling waste and resource management in the country. However, the implementation of such policies lacks in India due to various reasons. The first hurdle is convincing the stakeholders to bring landfill mining projects which require the support of local authority. Further nearby community's non-willingness due to NIMBY (not in my backyard) attitude can also act as a barrier.

The benefits of landfill mining lie with the extraction of secondary resources from the dumpsites. The study has shown that ~11% of dumped waste is plastic, which can be recycled after some pretreatment. Also, ~22% of dumped waste in Deonar is combustible in nature, suggesting the development of refuse-derived fuel which can be supplied to local markets like cement industries. The fine fraction, after some pretreatment to meet standards, can be applied as cover material or compost for non-edible crops. Reclaimed waste fractions from dumpsites/landfills can generate revenue while creating employment.

Table 2 SWOT (strengths, weaknesses, opportunities, and threats) analysis for landfill mining.

Strength	- Step towards a circular economy - Government policies towards clean India - Check on environmental pollution due to landfills - Zero post-closure and maintenance cost
Weakness	- Convincing the stakeholders - Public perception
Opportunities	- Possible revenue from the recovered fraction - Generation of employment
Threat	- Low cost in dumping waste - Activities associated with landfill mining - Immature market for recycled fraction - Funding for pilot projects and research

Most of the international studies have shown that the benefits of landfill mining are associated with recycling metallic fractions. However, in Indian dumpsite, the metal fraction for most of the studies are found to be very low (Kurian et al., 2003, Singh and Chandel, 2020). Furthermore, the recycling market in India is very immature and needs some exploration. In addition, funding is required to carry out and demonstrate the feasibility of the project on a large scale. Few success stories are available for small dumpsite in India for landfill mining (Patel, 2015). However, details for such projects are not available in the research domain. Furthermore, activities related to landfill mining would require safety and hazard assessment for workers. There are also chances of opposition from locals since landfill mining activities may cause the release of volatile organic compounds and other gases during excavation. This study provides a detailed physical characterization of the Deonar dumpsite which can be used to explore different valorization routes for the dumped waste. Further assessment of valorization options based on the waste characteristics and its economic study needs to be carried out to evaluate the full potential of dumped waste.

4. CONCLUSIONS

- The overall combustible fraction in the Deonar dumpsite, Mumbai was ~22.5%. The assessment of combustibles retrieved from landfills needs to be carried out for the identification of best-suited valorization routes.
- The recyclable fraction (metal and glass) is very low in Deonar dumpsite, while fine fraction (<4 mm) is accounted highest (~44%) suggesting the importance of fine fraction valorization for successful landfill mining. Furthermore, low recyclable content can change economic dynamics for landfill mining in India.

- The biodegradable fraction (paper/cardboard and wood) is significantly lower in stratum 1 and increased from stratum 1 to stratum 3 in the Deonar dumpsite.
- SWOT (strengths, weaknesses, opportunities, and threats) analysis shows that the government is forming policies for landfill reclamation. However, there is a lack of implementation due to incomplete knowledge on recycling the dumped waste in the Indian context; further leading to an immature market for reclaimed resources.

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Identification of Soil Properties using Integrated Remote Sensing and Statistical technique for Effective Agricultural Practices at Pollachi in Tamilnadu, India

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ABSTRACT

Sustained profitable agriculture productivity solves many socio-economic issues in the country. The important two natural resources that play a major role in farm productivity are the land and water resources. Though water availability is unpredictable and relies on natural resources, the soil fertility of the agricultural land can be easily and continuously predictable. Cropping pattern or multiple cropping depends on both the water demand and soil fertility of the land. Hence, the knowledge of the water supply and soil fertility is needed. This supports the farmers to choose the cropping pattern to maximize the profit. Hence this study on soil properties of the agricultural land is very imperative which determines the key factors in raising the crops. The frequent analysis of soil reports after each cropping season helps them to go for choosing proper organic manure and suitable crops. Hence accurate digital database about all soil parameters of agricultural land is needed for the farmers to choose their crops to increase the agricultural profit. Remote sensing is becoming an effective tool in monitoring local, regional and global environmental issues. The remote sensing and Geographical Information System (GIS) technologies play a vital role in mapping and characterizing soils at various scales. Spatial soil information is one of the most essential for agricultural risk assessment and decision making. The degree of accuracy and the justification for using remote sensing technology alternatives to manual soil testing will be proven by statistical models. The two statistical prediction models such as Multiple Linear Regression (MLR), Support Vector Machine (SVM) will be validated against an independent set of samples that clearly gives pattern of soil properties. All the solutions and outcomes of this study will be a boon for the policymakers and local farmers to overcome their drought problems through proper usage of information from satellite data.

Keywords: soil properties; Remote sensing; Geographical Information System (GIS); Multiple Liner Regression (MLR); Support Vector Machine (SVM).

1. INTRODUCTION

The soil is a natural resource that covers the uppermost of the earth’s surface and act as a medium for plant roots to grow. The soil consists of minerals, organic matter (OM), living organisms, air and water for life support to the plants. Furthermore, the plant roots absorb the required amount of water and necessary minerals for growth from the soil. Soil fertility measurement is important to determine the availability of nutrients and necessary solute in the soil to ensure better quality and quantity of the crops. The fertility level of the soil can be obtained by measuring the soil nutrients such as nitrogen (N), phosphorus (P), potassium (K), soil moisture, soil minerals and soil OM which are the important elements needed for plant growth. Plant nutrient level is one of the most important factors affecting forage quality. Increased nitrogen applications have positive effects on yield, dry matter (DM), and crude protein (CP). It was reported that the positive effect of nitrogen

(N) increased with P (phosphorus) and K (potassium). Macro nutrient elements such as N, P and K account for plant growth and health and affect yield and quality of forage plants that are used in animal feeding. Determination of nutrient element levels provides information about nutrient conditions and quality in plants. Conventional chemical analysis is usually made to determine nutrient element status of plants using laboratory techniques. Analysis of leaf samples in crop plants is usually undertaken with the objectives of diagnosing nutrient deficiencies and imbalances, and evaluating the effectiveness of the current nutrient management programs. But conventional laboratory techniques are expensive, laborious, and time consuming. Furthermore, in many cases, the results of the laboratory analyses are sent to the livestock growers after the pastures have been grazed, hence, significantly reducing any benefit to the farmer in terms of feed management and budgeting for the grower's animals. The reflectance spectrum of green leaves is considerably affected by their biochemical and biophysical properties. It is possible to extract biochemical information from a continuous vegetation spectrum produced using hyperspectral sensors. Investigation of the Pollachi soil quality with remote sensing systems is an important method to improve its efficiency. Determination of leaf biochemical content by remote sensing could be used as an alternative method and could reduce the problems of laboratory analyses. Remote sensing is the acquisition of information about an object without making physical contact with the object. In recent years, remote sensing systems have been used in a variety of applications including agriculture and forestry. Remote sensing systems provide a measure of light energy reflectance in one or more wavelengths. Ground based systems play an important role in remote sensing. The reflectance spectroscopy has become popular in ecophysiological studies depending on introduction of portable, sensitive, and reliable spectrometers. Because these systems have simplicity, rapidity, and nondestructive nature, they could be effectively used to determine spectral features of objects. Vegetation status could be easily determined with the use of the remote sensing systems, which have several advantages over the conventional laboratory techniques. Ground based remote sensing systems could be used quickly and inexpensively in determination of nutrient status of vegetations. Objectives of the present study include: (i) determination of N, P, and K concentrations and (ii) investigating which wavelengths are more important for N, P, and K levels of plants using the ground based remote sensing systems**.**

2. MATERIALS AND METHODS

The experiments were carried out in Paramikulam Aliyar irrigation Project (PAP) which supports an agricultural land of 20536 Ha at Pollachi [10.662°N 77.00650°E], located 40 km to the south of Coimbatore. Reflectance measurements were made using a portable spectroradiometer capable of measuring the wavelengths of 325-1,075 nm of the electromagnetic spectrum. However, due to the observed low signal-to-noise ratio at wavelengths shorter than 400 nm and longer than 900 nm, measurements were evaluated for the wavelengths ranging from 400 nm to 900 nm. Also, all obtained spectrums were visually evaluated using the RS3 software.

Canopy reflectance measurements were made during clear days between 10.00 am and 11.30 am in 49 distinct parts of the Pollachi. During the measurements, fiber optic cable and portable computer were connected to the spectroradiometer and reflectance measurements were made for calibration with white reference panel (spectralon). The reference panel has reflective features of almost the entire light that come to the surface. The optical sensor of the spectroradiometer was mounted at 1.5 m above vegetation surface in the plots and measurements were made with a 10° field of view. Five independent measurements at each part were taken to obtain an averaged value. To decrease the measurement errors white reference panel measurement was made in every three measurements. Plants in each measurement area were clipped after the reflectance measurements and samples were dried at 65°C for 48 hours. While the total N content of the samples was analyzed according to a modified Kjeldahl method, the dry ashing method was used for P and K analysis. ViewSpecTM Pro software was used to view and average the five reflectances. All statistical analyses were conducted using stepwise regression analysis implemented in MINITAB statistical program. In this method, wavelengths associated with plant N, P, and K levels were determined and regression equations were developed using the selected wavelengths.

3. RESULTS

According to the results, the concentrations of N, P, and K varied among the measured areas of the rangeland. While the minimum, maximum, and mean values of N concentrations were determined as 0.616, 3.668, and 1.51%, respectively, the same values were determined for phosphorus as 0.039, 0.257, and 0.10%. Also, K concentrations of samples ranged between 0.355 and 2.214 %. Regression equations composed of wavelengths related to the N, P, and K levels and the corresponding R^2 values are shown in Table 1.

Table 1 Regression equations and R^2 values for N, P, and K levels in rangeland conditions **:P<0.01, [a] Root Mean Square Errors. [b]Nitrogen, [c] Phosphorus, [d] Potassium

	Equations	R^2	RSME[a]
N[b]	$N= - 0.426 + (-630xR_{647}) + (296xR_{680}) + (517xR_{651}) + (-569xR_{675}) + (244xR_{654}) + (66.4xR_{609}) + (44.5xR_{760}) + (-141xR_{727}) + (-280xR_{669}) + (86.4xR_{721}) + (381xR_{676})$	0.85**	0.0774
P[c]	$P= 0.0316+ (42.5xR_{680}) + (-42.6xR_{675})$	0.43**	0.0010
K[d]	$K= 0.759+ (-417xR_{646}) + (410xR_{651}) + (-458xR_{669}) + (147xR_{682}) + (140xR_{417}) + (-423xR_{410}) + (334xR_{670}) + (1059xR_{460}) + (-716xR_{468}) + (-410xR_{674}) + (225xR_{658}) + (-480xR_{463}) + (164xR_{422}) + (178xR_{676}) + (256xR_{411})$	0.84**	0.0550

As a result of stepwise regression analysis, 11 wavelengths (R609, R647, R651, R654, R669, R675, R676, R680, R721, R727, R760) for N, 2 wavelengths (R675, R680) for P, and 15 wavelengths (R410, R411, R417, R422, R460, R463, R468, R646, R651, R658, R669, R670, R674, R676, R682) for K levels were determined Regression analyses showed that 11 wavelengths were associated with N level (Table 1). Among these wavelengths, 8 were in red regions [601-700 nm (R609, R647, R651, R654, R669, R675, R676, R680)] of the spectrum, while 3 were in NIR (Near Infrared Reflectance) regions [701-900 nm (R721, R727, R760)]. The coefficient of determination (R2) of the equation composed of these wavelengths was 0.85 and *RMSE* (root mean square error) was 0.0774. Also, 2 wavelengths (675 nm, 680 nm) from the red region of the spectrum were associated with P, with *R2* of the calculated equation as 0.43 and *RMSE* of 0.0010

(Table 1). Fifteen wavelengths were selected for potassium. While 7 of these wavelengths (R410, R411, R417, R422, R460, R463, R468) were in the blue region (400-500 nm) of the spectrum, 8 wavelengths (R646, R651, R658, R669, R670, R674, R676, R682) were placed in the red region. R^2 and RMSE values of the equation were calculated as 0.84 and 0.0550, respectively. Regression analysis of canopy reflectance measurements is shown in Figures 1, for N, P, and K, respectively.

4. DISCUSSION

Vegetation reflectance values are successfully used for different purposes such as determination of biomass productivity, leaf area index, vegetation cover, and species identification, plant pigment identification studies and other plant components, the health status of vegetation and green herbage yield. Also, in many studies, remote sensing systems have been used to determine the nutrient content of plants and successful results have been acquired. According to this study results, significant relationships were determined between NPK levels and reflectance values in spectral reflectance measurements of Pollachi. Equations with high R^2 value were found for nitrogen (0.85) and potassium (0.84). Also, red region wavelengths, which were included in the regression equations, had a significant role in the determination of nitrogen and potassium levels. According to the results of this study, RMSE values of the models obtained for the prediction of N, P, and K were close to zero. Low RMSE values verified the reliability of the models.

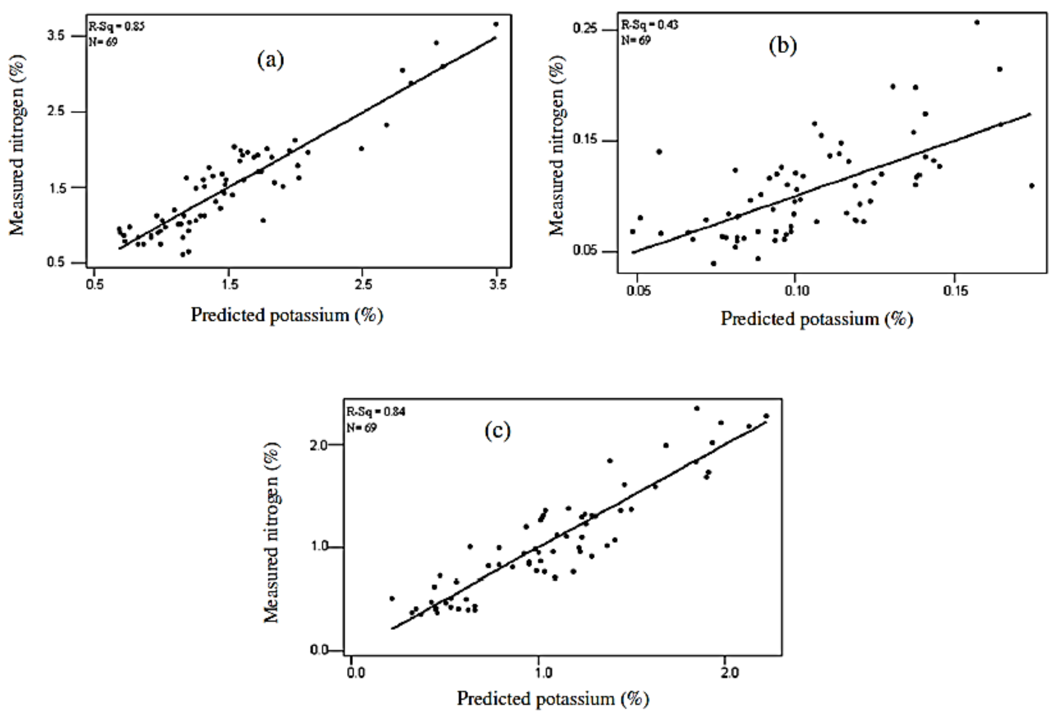

Fig. 1 Relationship between laboratory-measured N concentrations (a) P concentrations (b) K concentrations (c) and the predicted values based on the reflectance data

In this study, significant relationships were determined between nitrogen levels and reflectance values in red and NIR wavelength regions of the spectrum. Several studies on different plant species have indicated that two-waveband reflectance ratios of plant leave correlated more closely with leaf chlorophyll and leaf N concentration, compared with leaf reflectance in a single narrow waveband. Plant canopy reflectance in the visible (400–700 nm) and NIR (700–900 nm) wavelengths of spectrum are primarily influenced by chlorophyll content and leaf cell structure, respectively. Chlorophyll absorbs light in the red region of the visible spectrum; therefore, low reflection occurs in this region. Chlorophyll concentration decreases in the case of nitrogen deficiency while reflections increase in the red region of the spectrum. The leaf reflectance in the red-edge range of wavelengths (690–740 nm) could be used to predict leaf nitrogen concentration and total nitrogen content. This shows that red region reflections change due to the nitrogen content of plants. The crude protein content (thereby nitrogen content) closely correlated with the red and NIR regions. In the present study, it was found that significant relationships existed between phosphorus levels and red region wavelengths, while potassium levels correlated with the blue and red region. The bands in the visible and SWIR (small wavelength infrared reflectance) regions were more sensitive to phosphorus levels (R^2= 0.63) in grass rich pasture. The spatial variation in actual and predicted maps of phosphorus variability could be represented using diffuse reflectance spectroscopy in the UV, VIS, and NIR regions. Canopy light reflectance properties based mainly on the absorption of light at a specific wavelength are associated with specific plant characteristics. The spectral reflectance in the visible (VIS) wavelengths (400–700 nm) depends on the absorption of light by leaf chlorophyll and associated pigments such as carotenoid and anthocyanins. Using the visible region of the spectrum i.e., red (500–600nm) to green (600–700 nm) reflectance ratio, the prediction of anthocyanins content was possible. The phosphorus level of plants is one of the most important factors that affect anthocyanin content. Phosphorus deficiency may lead to high anthocyanin levels and, consequently, purple discoloration appears in the leaf margins of plants. The anthocyanin absorbs energy in the green region while reflecting in the red and blue regions of the spectrum. Also, chlorophyll concentrations and content change due to potassium levels in plants. As a result of this situation, while hexose, sucrose and starch contents increased in leaves, sucrose and starch contents of stems and floral buds decreased. This caused lower chlorophyll concentration and the poor development of leaf anatomy and chloroplast ultrastructure. These alterations cause changes in reflectance features in plants.

5. CONCLUSIONS

This study was conducted to investigate whether nitrogen, phosphorus and potassium content could be determined by the use of spectral reflectance values. According to the result of the study, significant relationships existed between red (R609, R647, R651, R654, R669, R675, R676, R680) and NIR (R721, R727, R760) regions and nitrogen level. Also, results showed that spectral reflectance values in R675 and R680 wavelengths were associated with phosphorus levels and reflectance values in blue (R410, R411, R417, R422, R460, R463, R468) and red (R646, R651, R658, R669, R670, R674, R676, R682) region of spectrum were useful to identify potassium levels. The results indicated that differences in nutrient concentration largely influence spectral reflectance and, thus, revealed that the remote sensing and statistical technique could be used to estimate the nitrogen, phosphorus, and potassium concentration in the Pollachi region for the best agricultural practices.

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Study on Non-Linear Displacement Characteristics of Recycled C & D Waste for RE Wall using Composite Reinforcements

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ABSTRACT

Properties of reinforced soil play a crucial role in the performance of reinforced soil structures. The cost of this structure is also dependent on the properties of reinforced soil. It is important to give preference to the non-plastic fill which meets gradation and plasticity requirements for reinforced soil structure. It is emphasized that the material having free draining, good shear strength and compaction properties which is preferred as backfill material. There is a scarcity of sound backfill material due to high demand and low availability because of various construction activities, so it is better to find the replacement of these materials. On the other hand, generation and dumping of construction & demolition waste are one of the big issues now a day as the rapid development of the construction industry. A developing country like India generates millions of tons of that C & D waste material which is increasing haphazardly day by day. Initial investigation shows C & D waste has high internal friction and alkaline behavior. From proper gradation of C & D waste, we shall make it a good option for backfilling in reinforced soil structure. The main objective of this study is to evaluate suitability and feasibility through load displacement and settlement characteristics of C & D waste available after the recycling process as fill material for reinforced earth wall with and without geosynthetics. Tests were performed on different compositions of C & D waste using composite reinforcement to observe nonlinear displacement characteristics from load displacements and load settlements of these compositions. In these tests, the performance of the composition of backfill such as C & D waste with and without reinforcement, sandwich technique in which 20 mm thick layer of fly ash sandwiched between recycled C & D waste was evaluated. The vertical pressure distribution at the base of the RE wall, vertical stress distribution on the horizontal and vertical plane, active earth pressure corresponding to displacement were calculated according to Laba and Kennedy (1986) theory for experimental results. From the results, it demonstrates good characteristics of load-displacement and settlement behavior. It is concluded that recycled C & D waste material is likely to be preferred backfill material in the RE wall due to the added advantage of environmental friendliness and cost-effectiveness.

Keywords: Recycled C & D waste; RE wall; Backfill material; Sandwich technique

1. INTRODUCTION

Reinforced soil structure is very popular for construction method which was introduced by Henri Vidal (1966). Generally, granular material having free draining and good strength is used as backfill with geosynthetics. Several materials were proposed for backfilling in reinforced structure as there is a scarcity of sound backfill material due to high demand and low availability because of various construction activities. Kumar (2012) and Mandal et al. (2012) respectively said that Pond ash and fly ash could be used as an alternative to conventional earth as a backfill material.

Construction and demolition waste are permeable material Shiva Bhushan et al. (2016), It has good shear strength as high internal friction angle and also has non-alkali behavior Santos and

Viera (2008). The handling of Construction and demolition waste is a very difficult task in India. According to CPWD (2017), India has been generating over 25-30MT which is increasing at a rate of 5%. This study is based on performance evaluation of C & D waste as backfill material in the RE wall to check its feasibility and suitability as sound backfill material.

2. MATERIALS

2.1 Recycled C & D Waste

The recycled C & D waste was collected from the recycling plant Ahmedabad Enviro Project Pvt. Ltd. Located at Ahmedabad, Gujarat, India. Two samples were taken according to E.C. Santos at al. (2007) fresh and stored material which was mixed to determine its geotechnical properties. The value obtains from the various test was shown in Table 1.

Table 1 Geotechnical properties of recycled C & D waste

Test	IS code	Symbol	Value
Grain size analysis	IS: 2720-4:1985	C_u	7.39
		C_c	0.726
Soil classification	IS: 1498-1970		Similar to SP
Specific gravity	IS: 2720-3:1980	G	2.60
Standard Proctor test	IS: 2720-7:1980	OMC	14%
		MDD (kN/m^3)	17.26
Relative density	IS: 2720-14:1983	γ_{max} (kN/m^3)	17.13
		γ_{min} (kN/m^3)	13.24
Direct box shear	IS 2720-13:1986	c (kN/m^2)	0
		ϕ	40^o
pH test	IS 2720-26:1987	pH	8.62

2.2 Reinforcements

A galvanized sheet having a thickness of 0.2mm cut into 60mm wide and 600mm long strip for reinforcement also biaxial geogrid having tensile strength 40kN/m was used as reinforcement with different backfill composition of recycled C & D waste.

2.3 Fly Ash

F class fly ash procured from a power plant located in Ahmedabad for the composition of backfill with recycled C & D waste.

3. TEST SETUP

To simulate the field condition a model tank of size 700 mm x 990 mm x 750 mm was fabricated using channel sections. A 30 mm thick 8 Nos. of 300 mm x 175 mm and 4 Nos. of 150 mm x 175 mm size wooden blocks is fixed at the front face of the tank. Geogrids and metallic strip were secured to the facing panel by means of 20 pairs of clamps. According to BS 8006:2010, geogrids of length 525 mm and a metallic strip of length 600 mm having width 60mm were positioned in five layers. Backfill composition was compacted to achieve the relative density of 80% as per IRC SP 102:2014. To observe the displacement of facing panel, 4 dial gauges (L.C. = 0.01 mm) viz. D1, D2, D3, D4 were fixed in a diagonal pattern and 2 dial gauge were fixed to the top of plat for measure settlement.

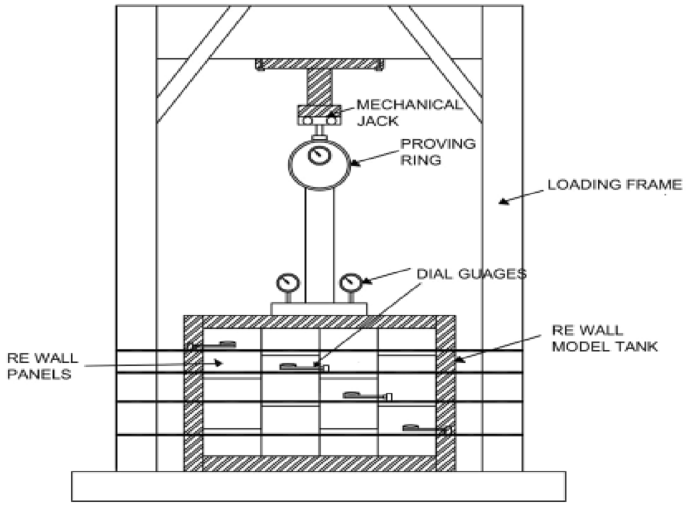

Fig. 1 Schematic diagram of the model tank

Fig. 2 Fitting of geogrid with facing panel

Fig. 3 Test set-up with dial gauge arrangement

3.1 Sandwich Technique

As Sridharan et al. (1991) low friction angle can be used backfill material by providing a layer of high internal strength material immediately adjacent to the reinforcement. A 20 mm thick fly ash layer sandwich between recycled C & D waste securing metal strip and geogrid as reinforcement for respective tests.

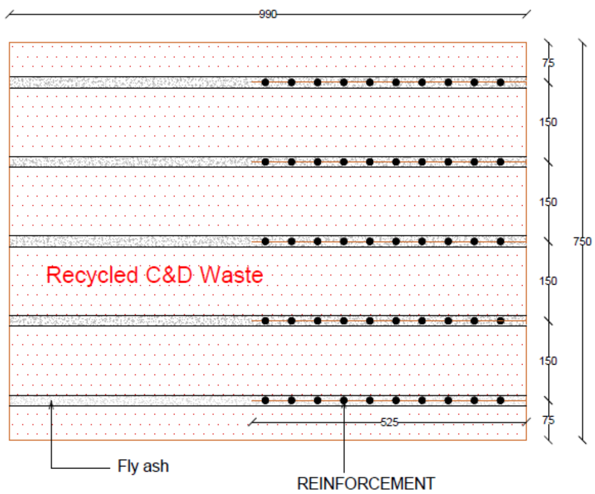

Fig. 4 C/S diagram of the sandwich

Fig. 5 Fly ash layer for the sandwich

4. TEST PROCEDURE

The tank was filled with different backfill compositions as recycled C & D waste with and without composite reinforcements for respective tests. The tank was also filled with a layer of 20mm thick fly ash is sandwich between recycled C & D waste was make Backfill material fill in five layers using a surface vibrator to achieve 80% relative density as per IRC SP 102-2006. Geogrid and metallic strip of galvanized steel were used as reinforcement for respective tests. A plate of size 250mm x 250mm having 25mm thickness was placed top of the tank with firm contact with backfill material to transfer uniform load. The load was applied into the active zone which is inclined at ($45 + \Phi/2$) from horizontal. The load is applied with an equal increment of 1.66 kN the dial gauge readings were noted, when the deformation rate became nearly constant and there was no perceptible increase in settlement or when the rate of settlement reduced to 0.02 mm per minute, in accordance with IS 1888:1982.

The load vs displacement and load vs settlement curves for different compositions with different reinforcement were plotted to study nonlinear behavior of recycled C & D waste.

The vertical stress distribution on the face of the RE wall panel at all dial gauge locations calculated using Boussinesq's theory. The active earth pressure at different dial gauge D1, D2, D3, D4 were calculate using Laba and Kennedy's theory for lateral displacement of 2.5mm and 0.48 mm at the center portion of the RE wall.

5. RESULTS AND DISCUSSION

The test was performed on a model of RE wall with recycled C & D waste and sand as backfill with composite reinforcement. The result obtains from displacement and settlement at a particular location of dial gauge is shown in the various plots.

5.1 Load vs Displacement Curve

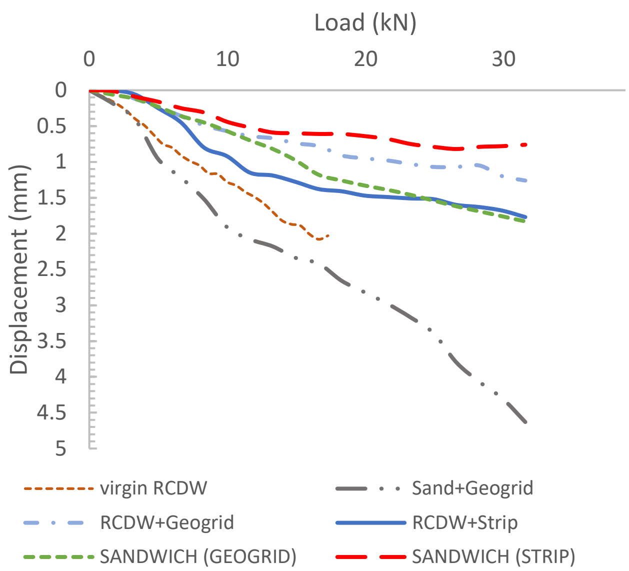

Fig. 6 Load vs Displacement at D1(85,60)

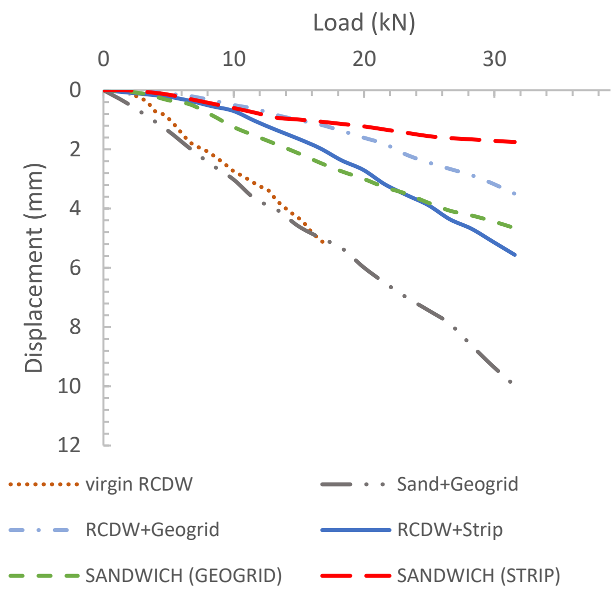

Fig. 7 Load vs Displacement at D2 (260,210)

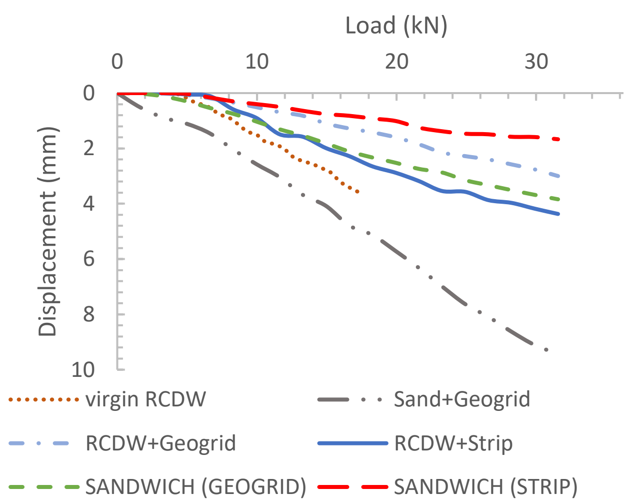

Fig. 8 Load vs Displacement at D3(435,360)

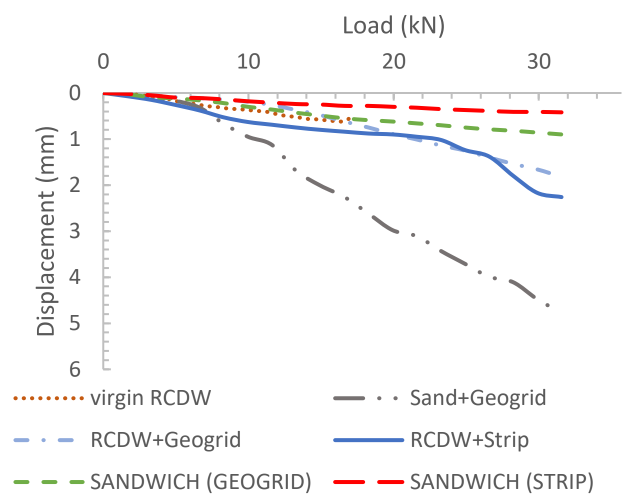

Fig. 9 Load vs Displacement at D4 (610,690)

Referring Fig. 7&8, reflecting the behavior of material stresses transformed as discrete particle deformations, shown through dial gauge D1, D2, D3 and D4 for a different composition, it is observed that C & D waste shows non-linear nature of stress distribution at the geogrid-waste interface, but with more efficiency in sandwich case using strip reinforcement. As the aperture size of geogrid is offering more resistance with respect to tensile stresses, the vertical stress is predominant in the case of sandwich material compare to the non-sandwich case. The strip having high lateral and linear tensile stresses, the skin friction offered by C & D waste is getting more mobilized compare to granular material sand. Though C & D offers a higher angle of internal friction, the discrete particle deformation capacity being low at certain locations, it demonstrates lesser strain value in lateral directions which once again reflects in the above plots. The basic interaction mechanism between waste-reinforcement is similar to sand-reinforcement, except the limit of lateral displacement prescribed by BS8006, the sandwich case with strip offers more mobilization of in-plane stress distribution compare to other cases were vertical stress i.e. vertical settlement is playing a major role in inducing lateral earth pressure.

5.2 Load vs Settlement Curve

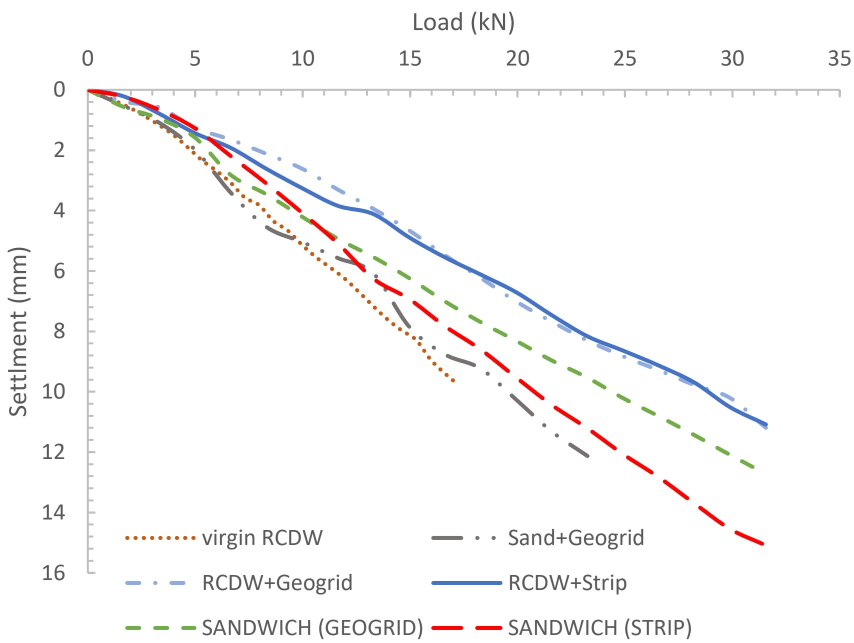

Fig. 10 Load vs Settlement characteristics for recycled c & waste with different compositions

The settlement behavior for different backfill compositions with composite reinforcement is shown in the above plot. Sandwich having strip as reinforcement gives maximum settlement comparing all other compositions. Recycled C & D waste shows an equal amount of settlement with geogrid and metal strip.

5.3 Vertical Stress Distribution on Face of RE Wall

The vertical stress distribution on the face of the RE wall panel at all dial gauge locations calculated using Boussinesq's theory. Here the load is taken corresponding to the vertical settlement of 9.7mm in all the backfill composition.

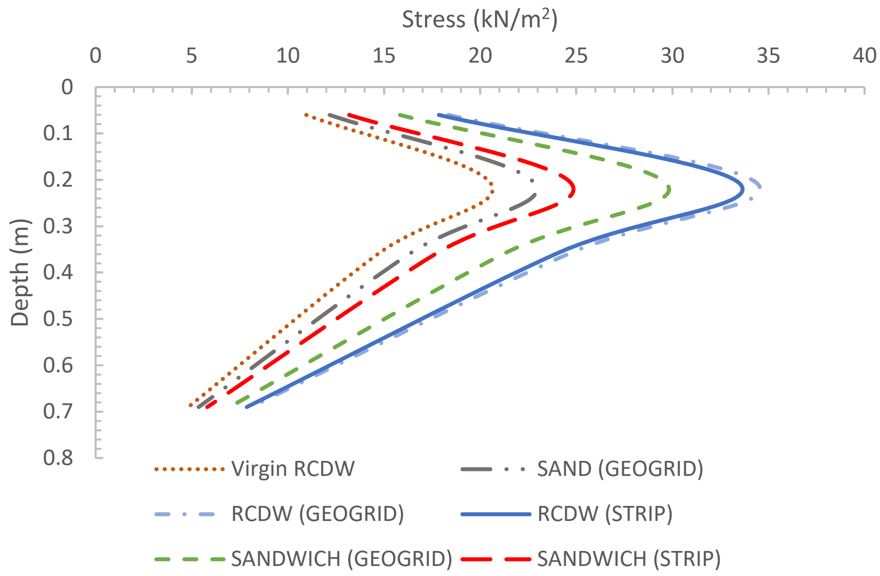

Fig.11 Vertical stress distribution on the face of RE wall

5.4 Active Earth Pressure on RE Wall

Earth pressure corresponding to 2.5 mm and 0.48 mm displacement were calculated using Laba and Kennedy theory (1986) by considering the unit value of factor M which depends on the height of the wall and distance of application of load from the wall. From the table, it describes that sandwich with metal strip and recycled C & D waste with geogrid shows maximum pressure at lesser displacement.

Table 2 Active Earth pressure for displacement 2.5mm

Backfill Composition	Active Earth Pressure (kN/m^2)			
	D1	D2	D3	D4
Sand (Geogrid)	37.55	50.12	30.33	11.77
RCDW without Reinforcement	55.37	73.51	43.80	15.30
RCDW(Geogrid)	104.54	138.0	80.80	24.90
RCDW (Metal Strip)	75.00	99.33	58.73	19.52
Sandwich (Geogrid)	71.20	94.33	55.84	18.70
Sandwich (Metal Strip)	164.88	217.24	127.24	38.84

Table 3 Active earth pressure for displacement 0.48mm

Backfill Composition	Active Earth Pressure (kN/m^2)			
	D1	D2	D3	D4
Sand (Geogrid)	8.17	11.47	7.95	5.45
RCDW without Reinforcement	12.45	17.04	11.06	6.07
RCDW(Geogrid)	33.13	44.06	26.38	9.55
RCDW (Metal Strip)	28.41	38.03	23.23	9.5
Sandwich (Geogrid)	20.55	27.70	17.24	7.81
Sandwich (Metal Strip)	34.73	46.35	28.05	10.86

6. CONCLUSIONS

- The nonlinear behavior of recycled C & D waste is much similar to the linear behavior of standard granular backfill with limited settlements and displacement characteristics according to BS 8006-1:2010.
- Approximately 60% less lateral displacement was observed in recycled C & D waste compared to sand with geogrid.
- Stress distribution ability is improved in recycled C & D waste as compared to granular material.
- Reinforcing recycled C & D waste shows capacity improvement about twice to thrice times with respect to strip and geogrid.
- Geogrid shows finer interaction than metal strip as recycled C & D waste bear 40% more earth pressure with geogrid than metal strip at 2.5 mm displacement having a similar amount of settlement.
- Sandwich (strip) shows higher settlement and less displacement as metal strips have a high tensile capacity with higher strain capacity.
- It is concluded that recycled C & D waste can be recommended as sound backfill material with added advantage of environmental friendliness and cost-effectiveness.

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Utilization of Waste Hair Fibers and Shredded Tyre Chips in Geoengineering Applications

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ABSTRACT
Management of solid waste is a serious concern faced by the world for which large area of land is required for its disposal. Since the last decade, the feasibility of using and/or recycling waste materials in civil/geotechnical engineering applications has been explored by several researchers to meet the challenges of environmental pollution resulting from the increase in waste at landfill sites. The waste hair fibers and tyre-derived materials are not easily biodegradable even after a long period. Therefore, it is needed to find out the alternative for consumption or disposal of these waste materials. Recently, the use of waste materials such as human hair fibers and rubber tyre-derived materials in different geoengineering applications is also being explored. In the present study, an attempt is made to review the recent works carried out at IIT Delhi for understanding the human hair fiber interaction with sand and various research advances on the utilization of waste rubber tyres.

Keywords: Hair fibers; Tyre-derived materials; Geoengineering Applications.

1. INTRODUCTION
Fibers are used to reinforce the soil provide resistance against the shearing of soil due to the high tensile strength of fibers and thus improve the properties of the soil to withstand the load. There are various types of natural fibers (i.e. coir fiber, sisal fiber, palm fiber, jute fiber, flax fiber, barely fiber, cane fiber, bamboo) and Synthetic fibers (i.e. Polypropylene fiber, Polyester fiber, Polyethylene fiber, Glass fiber, Nylon fiber, Steel fiber, Polyvinyl alcohol fiber) have been used to reinforce the soils in various civil engineering applications (Hejazi et al. 2012). Beukering and Jansen (2001) have stated that approximately 800 million tyres are discarded annually. Almost 20% are re-used in the fields of fuel, roads, rubber-modified asphalt, etc., and the remaining 80% is stockpiled or illegally dumped. India generates nearly 7% of the global scrap tyres. Hair fibers and waste tyre are not biodegradable and can only really be disposed of (in an economical fashion) by consigning them to landfills, and as such, they are relatively environmentally unfriendly. Therefore, the different waste/natural waste materials such as tyre-derived materials (Soumya and Ayothiraman 2015; Mazumder et al. 2016, 2018, 2019; Reddy and Krishna 2015; Hazarika and Yasuhara 2007; Upendra et al. 2018) and human hair fibers (Akhtar et al. 2008; Pillai and Ayothiraman 2012; Ayothiraman et al. 2011, 2014; Butt et al. 2016, Sahu et al. 2016, 2018, 2019) are being tested as possible materials for using in different geoengineering applications. The shredded scrap tyre materials may be classified into three categories as specified by ASTM D6270: granulated rubber (maximum size of 12 mm), tire chips (generally between 12 and 50 mm) and tire shreds are generally between 50 and 305 mm (Reddy et al. 2018).

2. SOIL REINFORCEMENT USING HAIR FIBERS

The use of hair fibers as reinforcement to improve the engineering properties of sand as well as clay soils were investigated by the research group of IIT Delhi (Pillai and Ayothiraman 2012a&b; Ayothiraman et al. 2014; Sahu et al. 2016, 2018a&b; 2019; Basson and Ayothiraman 2020). Direct shear tests are conducted by Sahu et al. (2016) on sand reinforced with human hair fibers (HFR sand) and polypropylene mixed with sand (PFR sand) fiber on under saturated conditions. The experiments were conducted by varying the fiber content, viz., 0.25%, 0.50%, 0.75%, and 1.0%. Fig. 1 shows the waste of hair fibers collected from barbershops. Fig. 2 shows the variation of the angle of shearing resistance with fiber content for both hair fiber and PP fiber-reinforced sand. The Direct Shear test results show that the performance of HFR sand is similar to the Behaviour of PFR sand fiber. The Angle of shearing resistance for HFR sand increases with increases in the percentage of hair fiber up to 0.5% for 10 mm fiber length and then decreases (Sahu et al. 2016).

Fig. 1 Random human hair fibers (Sahu et al. 2016)

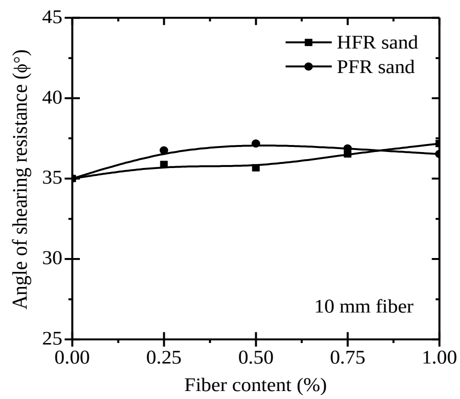

Fig. 2 Fiber content (%) Vs Angle of shearing resistance (Φ’) for PFR sand HFR sand. (Sahu et al. 2016)

Pillai and Ayothiraman (2012) studied the influence of hair fiber (0.5%, 1.0%, 1.5%, 2.0% and 2.5% by weight of soil) on Kaolinite clay through a series of laboratory tests such as consistency limit tests, compaction tests, and unconfined compression tests. With the addition of 2.0% fibers by weight, the unconfined compressive strength increased up to 2 times that of unreinforced soil. Table 1 shows the results of unconfined compression test results (Pillai and Ayothiraman 2012).

Table 4 Unconfined compression test results (Pillai and Ayothiraman, 2012)

Percent of the Hair fiber	Average UCS (kg/cm2)	Peak Axial Strain (%)	Avg. Cohesion, c (kg/cm2)	Increase in strength (%)
0.0	1.18	7.56	0.59	NA
0.5	1.59	9.87	0.79	34.83
1.0	1.77	10.09	0.89	50.35
1.5	2.09	9.87	1.05	77.55
2.0	2.35	9.65	1.18	99.79
2.5	2.23	11.18	1.12	89.45

Basson and Ayothiraman (2020) carried out an experimental investigation to study the shrinkage cracking behavior of clay soil under natural and reinforced conditions. Waste human hair fibers are used as reinforcement along with other natural/synthetic fibers such as coir fibers and polypropylene fibers. It is found that polypropylene fibers are most efficient in controlling the cracking potential, and human hair fibers are also found to perform practically comparable with polypropylene fibers and the percentage reduction in cracking with coir fibers is relatively less. Figs. 3 and 4 show that human hair fiber–reinforced soil can be considered an efficient method to resist desiccation cracking of waste containment barriers of an engineered landfill (Basson and Ayothiraman, 2020).

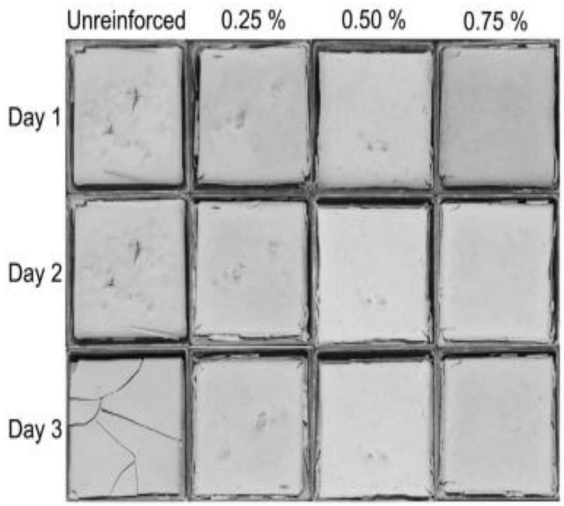

Fig. 3 Evolution of cracks for unreinforced soil and human hair–reinforced soil (Basson and Ayothiraman, 2020).

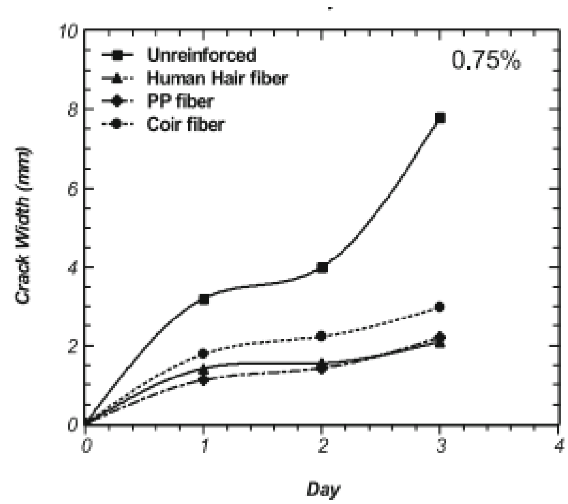

Fig. 4 Comparison of maximum crack width (Basson and Ayothiraman, 2020).

3. USE OF WASTE TYRE-DERIVED MATERIALS

3.1 Asphalt Mixtures

Waste tyre rubber can be used as substitutes for natural aggregates or as bitumen modifiers in asphalt mixtures. The use of waste tyre rubber in asphalt mixtures reduces fatigue cracking, requiring less maintenance compared to conventional mixtures. Rubberized asphalt mixtures show better performance at high temperatures. They can be used in a variety of climate conditions and they are more flexible at low and sub-under zero temperatures. Rubberized asphalt mixtures also reduce noise levels. A stretch of almost 100000 km of Indian roads had been laid with asphalt blended with recycled rubber, and more than 500000 tons of crumb rubber modified bitumen (CRMB) is used annually in road construction by 2016. (http://www.thehindu.com/business/Turning-waste-tyre-into-%E2%80%98green steel%E2%80%99/article14518524.ece).

3.2 Aggregates in Stone Column

In depletion of natural resources and the need for reuse of waste materials in civil construction, research is needed to replace stone aggregates in stone columns. Waste tyre rubber chips can be used as an alternative to aggregates in stone columns. Laboratory studies have been conducted on a single stone column by Soumya and Ayothiraman (2015), Mazumder et al. (2016, 2018) and Mazumder (2019). The size, specific gravity, Maximum dry density of Tyre Chips is 10mm × 10 mm, 1.10, 780 kg/m^3 respectively. The size, specific gravity, Maximum dry density of stone aggregates is 10 mm, 2.78, 1840 kg/m^3 respectively. Laboratory model tests on the stone column of 100 mm diameter and 450 mm length is constructed in a cylindrical tank (550 mm diameter, 750 mm length) filled with Kaolinite corresponding to 7.5 kPa in shear strength are conducted by (Mazumder, 2019). The results of the model tests on ordinary and encased stone columns are summarized in Table 2. The results indicated that partial replacement of about 30% to 50% of the stone aggregates with shredded tyre chips can safely possible in conventional stone columns. However, full-scale field tests are required.

Table 5 Comparison of load-carrying capacities under quick and slow loading (Mazumder, 2019)

Stone Column type	Ordinary Column Capacity (N)		Geonet Encased Column Capacity (N)	
	Quick Loading	Slow Loading	Quick Loading	Slow Loading
100% Stones	1087	1425	1466	1770
70% Stones + 30% Rubber chips	948	1287	1300	1610
50% Stones + 50% Rubber chips	751	1021	1041	1458
30% Stones + 70% Rubber chips	662	928	1048	1257
100% Rubber chips	527	696	1031	938

3.3 Retaining walls

3.3.1 Backfill to Retaining wall. Performances of retaining walls under static and seismic loading conditions depend upon the type of backfill soil. Generally, clean granular cohesionless backfill materials are preferred but due to the non-availability of suitable soil and to utilize the waste materials like shredded tire chips [Cecich et al., 1996; Tweedie et al., 1998; Hazarika et al., 2008; Ravichandran 2014; Reddy and Krishna 2015] are used as alternative backfill materials. Lightweight materials are beneficial in reducing earth pressures and lateral displacements of the retaining walls. Small-scale physical model tests were performed by Reddy and Krishna (2015) on a rigid retaining wall model of 600 mm height with different Sand Tire Chips (STC) mixtures. Size of Tire Chips, 10 × 10 mm size and about 20 mm. STC mixtures with different tire chips proportions, 10, 20, 30, 40, and 50 % along with pure sand were considered as backfill materials. Fig. 5 shows the shredded tyres used for the study and Fig. 6 shows the variation of earth pressure with the percentage of tyre chips (Reddy and Krishna, 2015).

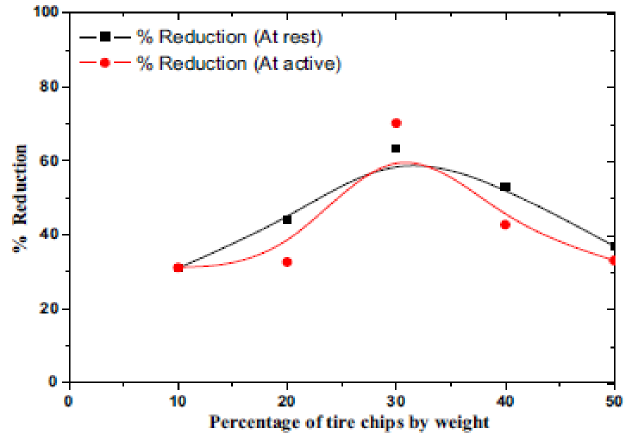

Fig. 5 Tyre shreds used as retaining wall fill (Reddy and Krishna, 2015)

Fig. 6 Percentage reduction of measured maximum earth pressures with %Tire Chips (Reddy and Krishna, 2015)

The results indicated that the horizontal displacements and lateral earth pressures are reduced to about 50–60 % of that of the control case by using STC mixtures which functioned as lightweight backfill materials (Reddy and Krishna 2015).

3.3.2. Back-panel to Retaining wall. The use of tyre-derived materials as vertical compressible layers placed against rigid soil retaining wall structures to reduce lateral static earth pressures (Reddy and Krishna 2019). Shake table tests on cantilever retaining wall with the inclusion of waste tire fibers shown in Fig. 7a (19 mm length and 4.5 mm width i.e., the aspect ratio of L/B equals to 4.22) back panel to the wall was done by Upendra et al. (2018). The tyre fibers of varying width 0 mm (No fiber), 50 mm, 75 mm, 100 mm back paneled to the wall and tested for wall deflection at various motor frequency 5 Hz, 10 Hz, 15 Hz, 20Hz of shake table and the typical test result is shown in Fig. 8.

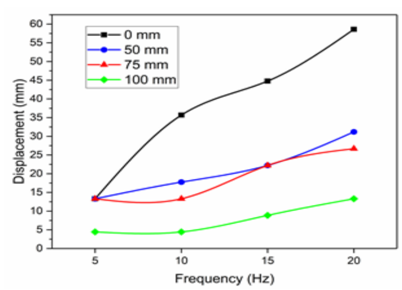

Fig. 7 Tyre shreds back-panelled to retaining wall (Upendra et al. 2018)

Fig. 8. Frequency vs displacement of the wall for different fiber panel width (Upendra et al. 2018)

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The results indicated that, a decrease of 47%, 54%, 77% deflection of Retaining wall back paneled by 50 mm,75 mm, 100 mm width fiber respectively at a maximum frequency of 20Hz. The lateral deflection of the cantilever retaining wall reduced with the inclusion of tire fibers panel back to the wall due to the absorption of inertial force in fibers during the dynamic phase.

3.4 Seismic Base Isolation

Sand–rubber tyre shreds mixture finds its application in seismic base isolation (Anastasiadis 2011, Madhusudhan et al., 2019). Fig. 9 shows rubber tyre shreds and Fig. 10 shows the result of cyclic triaxial tests carried out by Madhusudhan et al., 2019 with different sand–rubber tyre shreds mix. Madhusudhan et al. (2109) concluded that 10% of rubber content possesses satisfactory shear moduli and damping ratios at large strain levels and may be effectively used as a material for seismic base isolation applications. Very recently, field test results were presented by Mahdavisefat et al. (2018) on using the sand-rubber mixtures as infill materials in open trenches for vibration isolation.

Fig. 9 Rubber tyre shreds, size of 2 mm and down. (Madhusudhan et al. 2019)

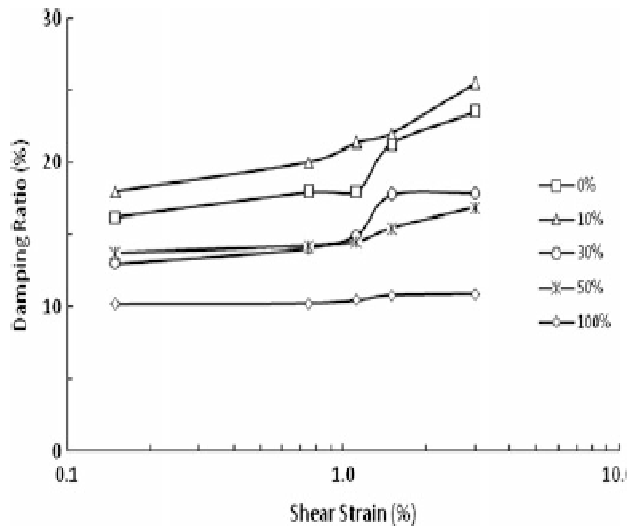

Fig. 10 Plot of damping ratio versus shear strain for sand–rubber tyre shreds mixtures (Madhusudhan et al. 2019)

4. CONCLUSIONS

From various numerical and experimental studies, by various researchers, it can be concluded that hair fibers and waste tyre-derived materials can be effectively used in different geotechnical applications. Tensile property of hair fiber makes it suitable to be used as a reinforcing agent. Reinforcement by human hair fiber can be used in clay to handle the desiccation of cracking. Waste tyre rubber chips due to its low density and high shear strength find various geotechnical applications. Waste tire utilization would not only be economical but may also help to protect the environment. Although hair fibers and rubber tyre-derived materials provide one of the environmentally friendly and economically viable products still there is a lack of awareness in society. Field studies using these materials are limited. Hence, there is a need to study the real-time response of these materials in the field.

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Laboratory Investigation of MSW for use as a Filler Material in embankments

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ABSTRACT

In the recent times, the rate of generation of MSW has depicted an increasing trend owing to the increase in population, urbanization, and standard of living. As per the statistical report of CPCB (2017), Maharashtra is generating 21,867.27 Mt of MSW daily, out of which only 31% is being treated while the remaining 69% is disposed of unscientifically. After treating and recycling the waste, a large quantity of waste still remains to be disposed, which is applying a heavy load on the existing landfill facilities. To reduce the load over the landfill, the potential of utilizing the aged MSW which has already decomposed in the landfill due to physical and biological processes needs to be found out and this will also minimize the scarcity of filling material. In the present study, geotechnical characterization of MSW from Mulund dump yard, Mumbai was done. All the experimental investigations were done using the conventional instruments used for the soil. The low value of MDD of MSW compared to soil is advantageous because as a filler material MSW will generate less stress on the embankment foundation. Further low permeability of MSW is also good in reducing the leachate production.

Keywords: MSW; Compression characteristics; compression ratio,

1. INTRODUCTION

In the present state, waste generation rate is increasing in a way that its collection, segregation, treatment and disposal has become a matter of prime concern. In a developing country like India, people are moving towards the metro cities and with an increase in urbanization, waste generation rate is also increasing. There are various treatments and processes available for waste volume reuse and reduction but even after all the processing, there is always a large volume of waste that remains to be disposed of. Out of all the available techniques, landfilling is the most widely used technique for waste disposal in India. Landfill requires a large amount of area to operate and function properly. In the major cities of India availability of land is very difficult and most of the landfills available in these cities have almost reached their full capacity or are going to reach their capacity within a few decades. To dispose of MSW, new landfills are required in future or landfills that are holding the aged MSW need to be emptied so that the space for the new MSW could be provided. Due to the increase in population, there is also a decrease in the availability of land. To construct new landfills, big piece of land far from the society is required, which is very challenging in major cities of India. In order to overcome these problems, a study on the potential of utilizing the aged MSW buried in the landfill as a filling material in geotechnical projects like embankments needs to be probed. This will also minimize the scarcity of filling material. But using aged MSW as a structural fill may lead to excessive settlement due to primary and secondary compression. Expected deformation in embankments constructed using ages MSW are shown in Fig. 1 and Fig. 2. Total settlement due to primary compression could be up to 20-30% of initial thickness of MSW layer [Landva and Clark (1990)]. Therefore, before constructing the embankment it is necessary to properly analyze the geotechnical characteristics of the MSW. This will help in proper designing of the embankments.

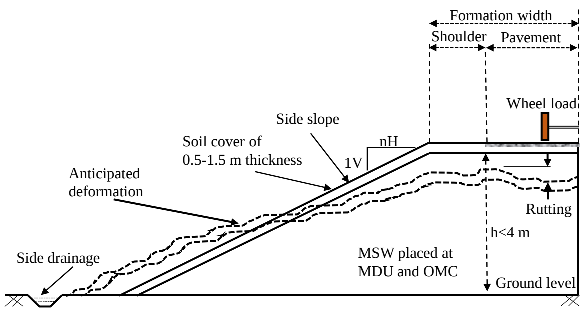


Fig. 1 Embankment (h < 4 m) constructed using aged waste as a filling material

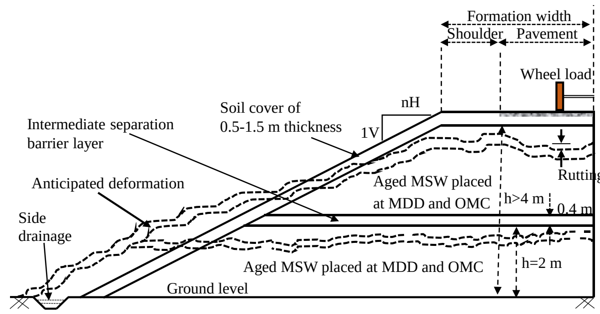


Fig. 2 Embankment (height > 4 m) constructed using aged waste as a filling material

2. PROPERTIES OF MSW USED IN PRESENT STUDY

From the geotechnical point of view, MSW can be characterized based on age i.e. fresh/young, average age and old age/aged MSW. Aged MSW is the waste which was dumped some years ago and most of the organic matter has been stabilized by biological degradation. This MSW has low compressibility and low hazardous material as compared to fresh and average age waste. Therefore, aged MSW was selected for the study so that the waste could find its utilization with or without minimum modifications. MSW generated in Mumbai goes to three main dump yards i,e., Kanjurmarg, Mulund and Deonar. MSW was collected from Mulund dump yard from one of the heaps which was receiving waste since 2012. MSW was collected from 3 m depth below the top level of dump. Leachate was present 20 cm below the top surface of the dump. Product packaging wrappers obtained from the collected waste show the manufacturing date of product in between 2012 to 2013, which indicates that the waste was around 5 to 6 years old. MSW collected from the Mulund dump yard is shown in Fig. 3

2.1 Processing of MSW for further studies

As the MSW dumped in the landfill contains very large size components like cardboard, clothes, wood etc., this MSW cannot be used directly in the laboratory due to the small size of all apparatus. Therefore, MSW that was collected from the Mulund dump yard was first shredded to achieve a size lesser than 4.75 mm and then experimental investigations were performed. The collected MSW was then sundried for 7 days so that all the moisture evaporated. MSW is segregated by hand picking. The major components found in the waste during segregation are soil, polythene, cloth, wood, stone, ceramic, glass, plastic, paper, metal, geo-foam, coconut shell and fibre as presented in Table 1. After segregation, waste is then cut down into small pieces less than 2 cm with the help of a butcher knife, which is further crushed using the jaw crusher and cut down using a plastic cutter. This shredded waste is then mixed thoroughly for 90 minutes by hand to get a uniform composition of the waste as shown in Fig. 4. The properties determined for the characterisation of MSW are presented in following sections.

Fig. 3 MSW from Mulund dump yard

Fig. 4 MSW after shredding and mixing

Table 1 Composition of MSW

Sr. No.	Components	Fraction by weight (%)
1	Soil and other material	65.60
2	Ceramics and stones	13.56
3	Cloth	3.57
4	Metal	0.90
5	Glass	0.90
6	Coconut shell and fibres	0.88
7	Geo-foam	0.15
8	Polythene	9.47
9	Paper	0.78
10	Wood	3.91
11	Plastic	0.70

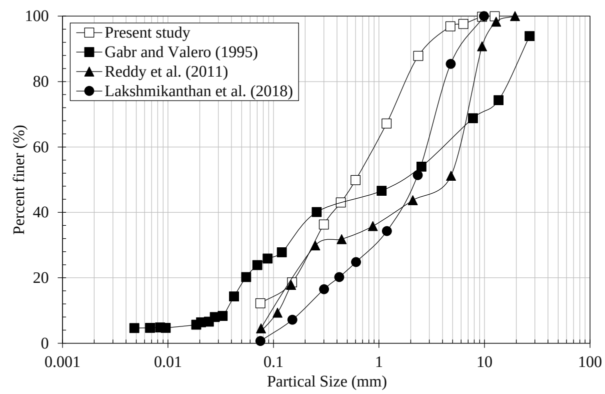


Fig. 5 Grain size distribution of shredded MSW

2.2 Specific gravity

The range of specific gravity for soils lies between 2.6 to 2.9 but MSW contains particles of different materials with some particles that are lighter than water which lowers the value of the specific gravity of MSW as compared to soil. The specific gravity of soil is determined with the help of water pycnometer but in MSW, various components are lighter than water which leads to floating of the lighter materials. Therefore, turpentine oil having specific gravity of 0.78 was used in place of water. A set of 3 tests were performed and an average value of specific gravity of the waste was found out to be 2.073. Gabr and Valero (1995) report the average value of specific gravity 2.0 for 15-30 years old waste. Yesiller et al. (2014) report value of specific gravity as 1.162, 2.161, 2.235, and 2.237 with a degree of degradation as 0%, 83%, 94% and 95% respectively. Ramaiah et al. (2017) reported a range of specific gravity values from different pits from the Ghazipur and Okhla dumps at Delhi to be 1.90 to 2.55.

2.3 Grain size distribution

The grain size distribution of the shredded waste is further shown in Fig. 5. Sample was first oven dried at 45^{o}C for 3 days. 100 g of oven dried sample was mixed with 2 g of sodium hexametaphosphate and 1 litre of water. This mix was thoroughly stirred and left for soaking. After

4 hours of soaking, sample was washed over a 0.075 mm sieve and the particles retained on it was again oven dried. After oven drying, the sample was then sieved through 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.425 mm, 0.3 mm, 0.15 mm and 0.075 mm. In the shredded MSW, percentage of particles finer than 0.075 mm was more than 10% but as MSW contains particles which have a specific gravity less than that of water, therefore, hydrometer analysis was not performed for further classifications. Figure 5 compares the results of particle size distribution curve from other researchers. Gabr and Valero (1995) used particles that are passing through 9.5 mm sieve and used both dry sieving and hydrometer analysis for particle size distribution analysis. Sample was oven dried at 60 ^{o}C and hydrometer analysis was done on the waste passing 0.075 mm sieve. Reddy et al. (2011) show the particle size distribution of synthetic waste. Lakshmikanthan et al. (2018) took waste passing through 10 mm. The curve obtained after shredding the MSW is comparable to the results of previous literature.

2.4 Compaction characteristics

Standard Proctor test was used for the determination of compaction characteristics of the MSW. Compaction characterization is of prime importance for geotechnical properties of MSW. Unit weight of MSW depends on its age and composition. Standard proctor test is conducted on MSW and maximum dry unit weight (MDD) obtained was 11.90 kN/m^3 with optimum moisture content (OMC) of 28.12% as shown in Fig. 6. Establishment of zero air void line shows that at an OMC value of 28.12%, maximum density that can be achieved with zero air voids is 12.85 kN/m^3. Gabr and Valero (1995) did the compaction characterization of 15-30 years old waste and found an MDD value of 9.3 kN/m^3 and the OMC value as 31%. The low value of MDD of MSW compared to soil is advantageous because as a filler material MSW will generate less stress on the embankment foundation.

2.5 Compression characteristics

Settlement of MSW takes place due to immediate settlement, primary compression, biological degradation and secondary compression. Primary and secondary compression are the major causes of settlement in landfills. Study of compression characteristics helps in gaining a better understanding about designing an embankment and estimating the settlement expected after construction. Compression characteristics were determined in this study using 1-D consolidation method using 75 mm diameter and 20 mm thickness oedometer cell. The main parameters obtained from this study were primary compression ratio, secondary compression index, coefficient of consolidation, and coefficient of permeability. Increase in settlement with time for different loading stages is shown in Fig 7. It can be seen from the Fig. 7 that there is a sudden compression that takes place followed by a gradual reduction in the rate of settlement. From Fig. 7 maximum settlement after the end of primary consolidation at increasing loads up to 400 kPa was found to be 22.21%. Coefficient of compression ratio C_{ce} was calculated as the ratio of percentage settlement to the change in the log of vertical stresses at base 10. Value of C_{ce} calculated from the slope of the curve of Fig. 7 is 0.11. Figure 8 shows the change in void ratio with the increase in vertical stress. Figure 9 shows the variation of the coefficient of consolidation with vertical stress for MSW. Coefficient of consolidation gives information about rates of settlement of MSW that takes place for different vertical stresses. The average value of C_v obtained from the test is 1.12 x 10^{-6} m^2/s.

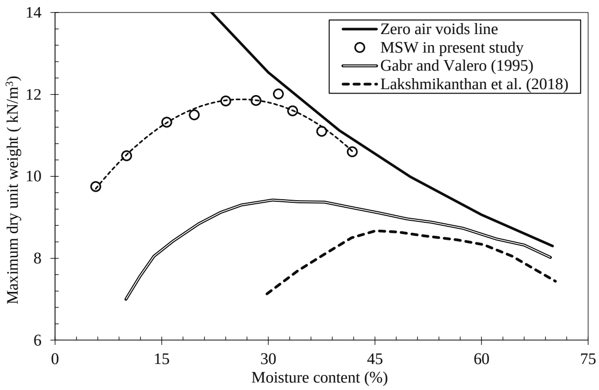


Fig. 6 Compaction curve of MSW [Standard Proctor compaction]

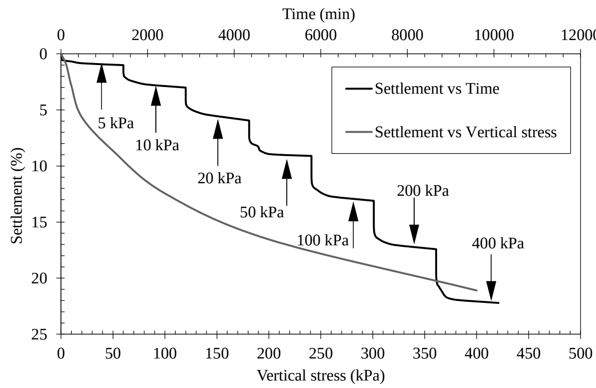


Fig. 7 1-D compression on MSW

Table 2 Compression ratio reported in literatures

References	C_{ce}	Remarks	
Thusyanthan et al. (2006)	0.25	Waste was synthesized in the laboratory	
Landva et al. (2000)	0.17	3 years old	
	0.22	6 years old	
Gabr and Valero (1995)	0.18	15-30 years old	From 14.6 m depth
	0.18		From 19.2 m depth
	0.22		From 11.6 m depth
Reddy et al. (2011)	0.35	Degree of degradation = 0%	
	0.26	Degree of degradation = 50%	
	0.15	Degree of degradation = 82%	
Vilar and Carvalhod (2004)	0.22	Degradable organic 14% 15 years old	
Present study MSW	0.11	Waste collected at 3 m depth; 5 years old	

Table 3 Secondary compression index reported in literature

References	C_{α}
Reddy et al. (2011)	0.015-0.010
Wall and Zeiss (1995)	0.033-.0056
Present study	0.0326

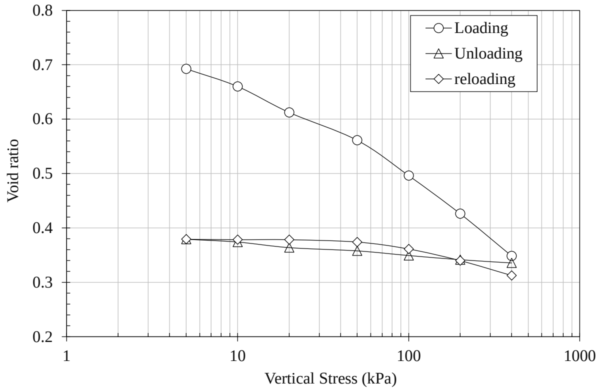


Fig. 8 Effect of vertical stress on void ratio of MSW

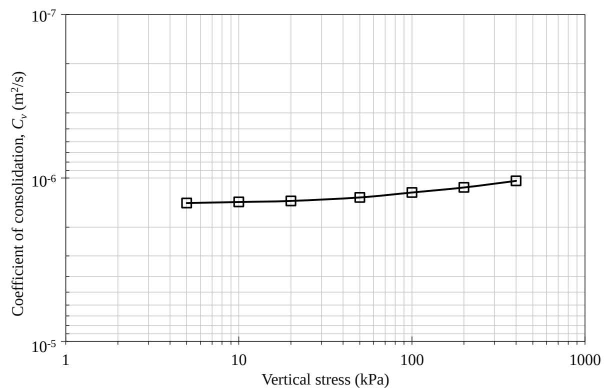


Fig. 9 Variation coefficient of consolidation with vertical stress for MSW

2.6 Coefficient of permeability

Leachate generation is one of the main issues with MSW. Leachate creates the problem of generation of pore water pressure and seeps through the side of landfills which causes instability to the landfill. Fresh MSW shows more permeability as compared to the old waste. Coefficient of permeability (*k*) can be calculated from the oedometer test. Average *k* value obtained from the oedometer test is 2.4 x 10^{-8} m/s. Fig 10 shows the variation of the coefficient of permeability with vertical stress. As vertical stress increases pore water dissipation and rearrangement of particles takes place and void ratio decreases. This reduction in void ratio leads to a decrease in the coefficient of permeability. This value shows that MSW used in this study lies in the category of old age waste.

2.7 Coefficient of secondary compression

After the end of primary compression, additional settlement starts to occur due to readjustment of particles of MSW. This settlement which occurs at a constant stress level with an increase in time is known as creep or secondary compression. In the case of MSW settlement, creep comes along with biological decomposition and continues to take place until entire MSW has stabilized. After the end of primary compression, sample was kept at a constant effective stress of 400 kPa for 5 weeks and the dial gauge readings were taken regularly to observe the settlement with time. The plot of change in void ratio with time at constant stress levels of 400 kPa is shown in Fig 11. Secondary compression ratio, C_α is calculated using Equation 1.

$$C_\alpha = \frac{\Delta e}{\log_{10}(t_2/t_1)} \tag{1}$$

Value of secondary compression obtained in the present study is 0.0326. Gabr and Valero (1995) give the range of secondary compression for old waste as being in between 0.03 to 0.09. Value of secondary compression given by other researchers is shown in Table 3.

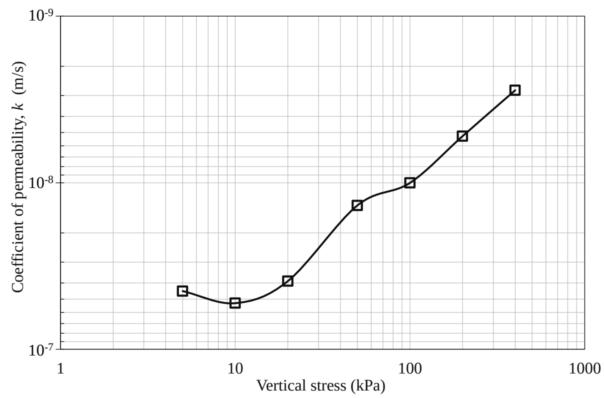


Fig. 10 Variation of coefficient of permeability of MSW with vertical stress

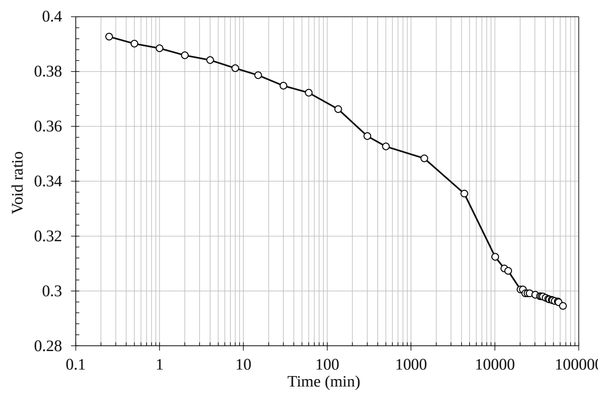
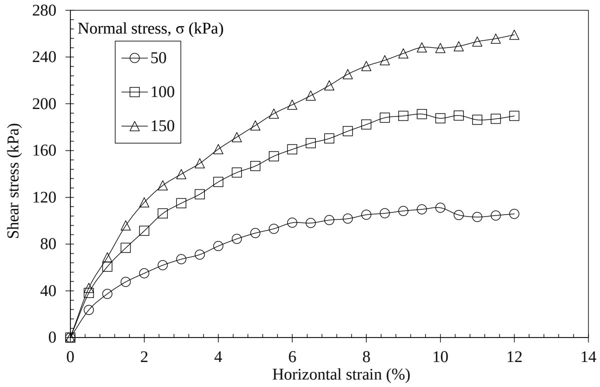


Fig. 11 Secondary compression of MSW at 400 kPa vertical stress

2.8 Shear strength parameters

Shear strength characterization is very important for the stability study of landfill or any geotechnical structure if constructed using MSW as a filling material. Shear strength of the waste majorly depends on its composition. Presence of a high percentage of fibrous materials like polythene, cloth, plastic and coconut fibre gives it the reinforcement effect which leads to higher friction angle. The direct shear test is a direct method to determine the friction angle of MSW. 10 cm x 10 cm direct shear box with 3 cm thickness was used to determine the friction angle of the MSW. The unsaturated-undrained direct shear test was done at a constant horizontal displacement rate of 0.625 mm/min while the saturated-drained test was done at a constant horizontal displacement rate of 0.025 mm/min. The sample was compacted at MDD and OMC. For the saturated shear test, sample was kept submerged in water for two days under same normal stress at which shearing of sample was done. Figure 12 shows the change in shear stress with shear strain at different normal stresses for unsaturated test. Shear stress peak is not visible up to 12% of shear strain, so failure stress was taken corresponding to 10% of shear strain. Figure 13 shows the shear stress vs shear strain graph for the saturated sample. The value obtained for the saturated sample was less than the unsaturated sample. Figure 3.22 shows the value of shear stress for different normal stresses at the saturated condition and the values of friction angle and cohesion obtained were 25.9^{o} and 46.3 kPa respectively. Figure 14 shows the value of shear stress corresponding to 10% shear strain at different normal stresses for both unsaturated and saturated tests. Values of frictional angle and cohesion obtained from the tests are 53^{o} and 46.1 kPa for unsaturated test and 26^{o} and 46.6 kPa for saturated tests. For designing embankment with MSW as filling material the use of shear strength parameters obtained from saturated tests are recommended. Values for friction angle and cohesion reported by previous researchers were then compared with the values obtained in the present study in Table 4. From this table, it could be seen that the value of shear strength parameters varies to a large extent and it depends on the age and composition of the MSW.

UCS test was conducted in order to determine the unconfined strength of MSW. Test was conducted on the MSW sample of 15 cm height and 7.5 cm diameter at a displacement rate of 1.2 mm/min and the maximum dry unit weight of 11.9 kN/m^3 at the optimum moisture content of 28.12%. Failure of sample occurred at a strain value of 18% by bulging with unconfined compressive strength (q_u) of 196.56 as shown in Fig. 15. All the properties of MSW are presented in Table 5.



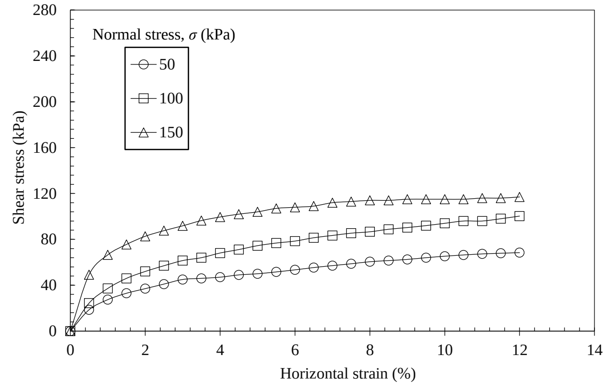


Fig. 12 Direct shear test stress-strain response of unsaturated MSW

Fig. 13 Direct shear test stress-strain response of saturated MSW

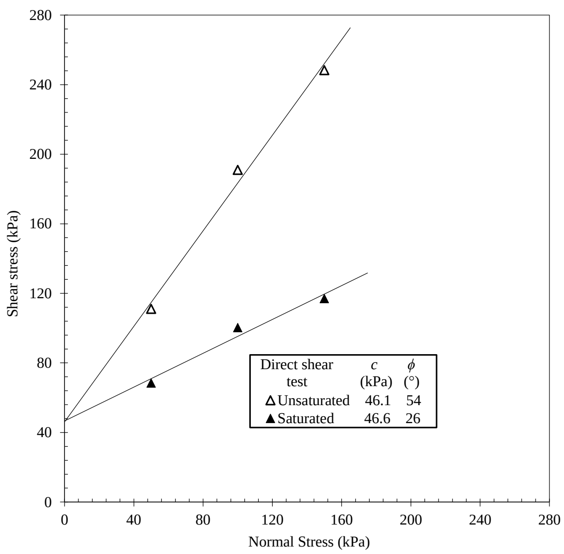


Fig. 14 Shear strength parameters of MSW

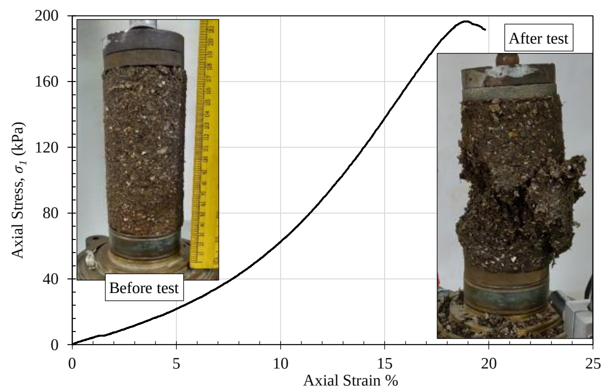


Fig. 15 UCS test results on MSW

Table 4 Comparison of shear strength parameters obtained in present study with literature

Sr. No.	References	ϕ (°)	c (kPa)
1	Landva and Clark (1990)	0-39	15-41
2	Gabr and Valero (1995); effective stress parameter	34	16.8
3	Reddy et al. (2011)	12-30	29- 65
4	Pulat and Yukselen-Aksoy (2017); fresh MSW	21-27	32-50
5	Pulat and Yukselen-Aksoy (2017); aged MSW	29-36	32-36
6	Ramaiah et al. (2017); effective stress parameter	35-40	11-28
7	Present study	53 and 25	46.1 and 46.6

Table 5 Properties of shredded MSW

Property	G_s	MDD (kN/m^3)	OMC (%)	k (m/s)		C_{ce}	C_v (m^2/s)	C_α	c (kPa)		ϕ (°)		q_u (kPa)
Values	2.07	11.9	28.1	1.1 x 10^{-7}	2.4 x 10^{-8}	0.11	1.12 x 10^{-6}	0.033	46.1	46.6	54	26	196.6

3. CONCLUSIONS

The present study was intended to investigate the characteristics of MSW from Mulund dump ward in Mumbai for possible use as a filler material in embankment construction. However, this can be accomplished by constructing trial embankments with MSW having properties identical to those in Mulund dump yard and monitor for settlement and lateral movements, etc. However, these embankments with MSW as fill material shall have adequate soil cover. All the properties ascertained suggest that the MSW is suitable for use embankment. Further studies are also required to explore the possibilities to improve the characteristics of MSW further.

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