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Geoenvironment-2020

International Seminar on

Contaminated Sites

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Organized by
Geotechnical and Geoenvironmental Group
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Preface

Geoenvironment-2020:

a unique 3-in-1 event

Geoenvironment-2020 has been organized from 17th to 21st 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 12th & 13th July 2018. Geoenvironment-2020 is the second major activity under the umbrella of NERCS.

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Direct Push Methods for Environmental Sampling & Logging in Soils & Unconsolidated Formations

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EXTENDED ABSTRACT

Direct push (DP) methods are used extensively for subsurface investigations at contaminated sites around the world. The DP methods provide advantages when compared to traditional rotary drilling methods for the investigation of unconsolidated formations. The DP method almost eliminates the generation of contaminated drill cuttings and also reduces the generation of decontamination fluids. This reduces worker exposure to hazardous contaminants during fieldwork. Contaminated drill cuttings may need to be contained and stored until sampling and analysis confirm the level of contamination. If contaminated, the stored cuttings may require disposal at a hazardous waste landfill. At many sites in the US, the handling and disposal of waste cuttings often increased the investigation budget by as much as 50 percent. The elimination of potentially hazardous waste cuttings by the direct push method can be a significant advantage for the investigation of contaminated facilities as compared to traditional rotary drilling methods.

DP soil and groundwater sampling methods can provide high-quality samples at desired locations and depths in reduced time and cost as compared to rotary drilling. Both single tube and dual tube soil sampling methods may be performed with direct push techniques (ASTM D6282). Single tube methods (e.g. MC5 tools) provide a rapid and efficient method for sampling cohesive soils at shallow depths (5 to 7m). Dual tube methods (e.g. DT325 system) utilize an outer casing to stabilize the borehole as incremental sampling is advanced. The outer casing prevents borehole collapse as sampling proceeds and increases sample integrity. The inner rod is used to recover the sample in the sample tube and insert a fresh sample tube as the boring is advanced incrementally. Dual tube methods are subject to formation heave or “blow-in” when sampling in saturated non-cohesive materials. This may aggravate sampling progress, especially in saturated sands.

Small diameter groundwater sampling devices may be installed with DP methods for initial assessments of groundwater contamination (ASTM D6001). A simple single-tube device (Screen Point16/SP16) can be effective for sampling discrete intervals (10cm to 1m) in many saturated, sandy formations. A re-useable, wire-wound stainless-steel screen (0.1mm slot) or a disposable PVC screen (0.25mm slot) may be used with this system. The screen is protected in a steel sheath behind a small expendable point as it is advanced to the target depth. Small diameter extension rods are then used to hold the screen in position as the sheath and drive rods are retracted the desired amount. A simple tubing-check valve or a small diameter bladder pump may be used to purge and sample the screened formation. Grouting may be performed as the tool string is retracted.

Several logging tools have been developed to assist the investigator conduct high-resolution site characterization (HRSC) in an expedited fashion. These tools are advanced into unconsolidated materials with DP methods. A pre-existing borehole or well is not required. The intimate contact between the probe and formation provides high-quality data at the centimeter scale. Both electrical conductivity (EC) logging and hydraulic profiling may be performed with the hydraulic profiling tool (HPT) (ASTM D8037). The EC and HPT injection pressure logs

provide an indication of lithology and permeability of the formation versus depth. Transects of EC-HPT logs are often run across sites to provide cross-sections for geohydrologic interpretation and to identify contaminant migration pathways, aquifers, and aquitards.

Additionally, cone penetration testing (CPT) may be performed to obtain information about soil lithology and density (ASTM D5778 and D6067). Tip resistance and sleeve friction, along with pore pressure for CPTμ systems, are often used for characterization of soil lithology and soil strength for site characterization and foundation design.

The Membrane Interface Probe (MIP) and Optical Imaging Profiler (OIP) are contaminant logging tools. The MIP allows the operator to identify the presence and type of volatile organic contaminants (VOCs) in the subsurface (ASTM D7352). The MIP detects VOCs in both the saturated and unsaturated zones of the formation. A small semi-permeable membrane on the side of the heated probe allows VOCs to cross the membrane but not water. Nitrogen carrier gas flows behind the membrane and transports the VOC molecules up the trunkline to gas phase detectors at the surface. The gas-phase detectors typically include a photo-ionization detector (PID), flame ionization detector (FID) and a halogen specific detector (XSD). This system provides logs of detector response versus depth as logging is conducted. Detector responses identify the type, depth, level, and location of VOC contaminants in the subsurface. The MIP system is often used for the characterization of sites impacted by chlorinated solvents such as trichloroethene (TCE) or perchloroethene (PCE) and their degradation products. The MIP is also used for the assessment of petroleum fuel releases in products with substantial levels of the volatile BTEX components (Benzene, Toluene, Ethyl Benzene, and the Xylenes).

The OIP is a new optical logging probe that uses either an ultraviolet (UV) light-emitting diode (LED) or a green wavelength laser diode to induce fluorescence of light nonaqueous phase liquids (LNAPL) in the subsurface (ASTM Practice in review). The light source illuminates the formation through a sapphire window on the side of the probe. When LNAPLs are present they fluoresce and a CMOS camera mounted behind the window in the probe captures images of the visible light fluorescence. The images of fluorescence are viewed live-time onscreen and one image every 0.05ft (~15mm) is saved at depth in the log file for later review. A graphic log of the area of fluorescence observed in the images is provided onscreen as the probe is advanced. Either visible or infrared images of soil texture may be captured at desired depths. These images are saved in the log file. The UV-OIP system is often used to assess the presence of several petroleum fuels and crude oil while the Green-OIP system is typically used for locating coal tars, creosote, and some heavy petroleum products.

Both the MIP and OIP typically include an EC array and HPT sensor to simultaneously provide data about lithology and permeability. The combined logs (MIHPT or OIHPT) are powerful tools for defining geologic control on contaminant distribution and migration. Both cross-sections of logs and 3D visualizations often are used to better understand contaminant distribution and lithologic influence on contaminant migration. Targeted sampling should be used to confirm both lithologic and contaminant log data.

The direct push sampling and logging tools are powerful and cost-effective means to conduct high-resolution site characterization in many soils and unconsolidated formations.

Case Studies on Use of XRF and PID/VOC Detector for Sub-Surface Investigation and Remediation

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ABSTRACT
Handheld XRF (X-Ray Fluorescence) Analyzers and Photo-ionization detectors (PID) are useful tools for increasing efficiency and effectiveness of site investigation and remediation during Contaminated Site Management (CSM). The recent changes in regulatory focus towards the impact of contaminated sites on the environment have triggered innovation and the use of best practices in CSM in India. ERM has been using these tools for site characterization and remediation and will be sharing experiences via case studies.

Case studies include the Indian scenario with typical contaminants and evaluation of the correlation between field screening results against laboratory analysis. Case studies show that field screening results cannot be directly used as a substitute for laboratory analysis, however, evaluation of results by correlating field screening and laboratory analysis and using other evidence such as visual and organoleptic indications will provide desired results. The advantages and disadvantages of these equipment will also be presented. Field screening will be an important tool to identify and evaluate contaminated sites currently listed by CPCB and to identify new sites.

Keywords: Chromium; zinc; volatile organic compound, XRF, PID

1. INTRODUCTION

Contaminated Site Management involves sampling and laboratory analysis of soil to delineate and to remediate the hot spots. Depending on the containments, media, logistics and turnaround time, the receipt of analysis results will range from 2-14 days. A major part of the project budget is typically used for laboratory analysis. By using field screening equipment such as handheld XRF analyzers and PID, the time and cost of the project can be reduced.

XRF works on the principle of X-Ray Fluorescence. The X-ray generated will be reflected by the sample and is detected by sensors. A Multi-Channel Analyser (MCA) measures amplitude and frequency and gives the qualitative information and concentration of that element. It's a qualitative tool to detect metal concentration in a dry soil sample. The process also works well if the soil sample has 5-20% moisture content. XRF detects more than 20 heavy metals and the operator can select the number and of metals.

In the environmental industry, PID is used to screen for the presence of VOC (volatile organic compounds) in water, soil, wastes, sludge, etc. For a majority of PIDs, VOCs include a broad range of organic compounds with carbon ranging from 1 (e.g., methylene chloride – CH2Cl2) to over 15 (e.g., diesel fuel). PID is used widely across the industry during various phases of environmental investigations (i.e. site investigation, characterization, and remediation) and for various matrices. PID can also be used to monitor the operations of a VOC removal system (such as water stripper effluents and off-gases from wastewater treatment systems). Although PIDs cannot measure VOCs directly in these media, they can indirectly measure the vapors emitted from them.

ERM will present two case studies where XRF was used and one case study where PID was used for field screening of soil.

2. Case Study 1 – Site Investigation at Delhi road, Hooghly District, West Bengal

The project was conducted under the Capacity Building for Industrial Pollution Management Project (CBIPMP) funded by the World Bank for West Bengal Pollution Control Board (WBPCB). The Site includes orphan land (public & private) along 18 kilometer stretch of Delhi Road in Hooghly District where chromium bearing sludge was dumped (over 30+ years) by some industries (no longer in operation).

The XRF analyzer was primarily used to identify the elevated concentration of chromium. Soil samples were collected from various locations and field screened using XRF to identify potential hot spots as part of the preliminary screening. Further investigation was conducted by collecting soil samples from various depths at the hot spots. Soils samples were collected from seven depth intervals and the two most impacted samples based on the results of the XRF were selected for laboratory analysis.

3. Case Study 2 – Site Investigation at Edayar, Ernakulam District, Kerala

ERM was contracted by Central Pollution Control Board (CPCB) for "Preparation of Detailed Project Report and Providing Consultancy Services for remediation of Contaminated Land and Creeks: Eloor- Edayar, Kerala. The impacted Sites are paddy fields that extend more than 100 acres. Paddy fields were reportedly impacted with wastewater containing heavy metals from a Zinc manufacturing unit.

The soil samples within the impacted area were collected as per grids and screened for metals using the XRF portable analyzer. Based on the concentrations obtained the size of the grids was reduced to delineate the major impacts. A good correlation was found to exist between metal concentrations recorded with the XRF portable analyzer and the analytical results from the laboratory. Selected samples were sent for laboratory analysis.

4. Case Study 3 – Remediation at Manufacturing Facility, Mumbai

ERM conducted site investigation and remediation of a manufacturing facility in Mumbai impacted with organic chemicals. The Site was closed and decommissioned. Large quantities of soil were removed from the Site as part of remediation and quick and effective field screening is required to reduce delays due to laboratory analysis. PID was extensively used to field screen the excavated soil before selecting limited samples for laboratory analysis.

PID was also used for detecting organic vapors which may pose health and explosion risks. PID readings in the ambient air were used as part of the health and safety plan for adjusting the personal protection equipment levels during excavation.

Status of Contaminated Sites in India

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ABSTRACT
In India, there are several contaminated dumpsites, where hazardous and other wastes were dumped historically, which resulted in contamination of soil, groundwater and surface water thereby posing health and environmental risks. Most of the contaminated sites were created when industrial hazardous wastes were disposed by occupiers in unscientific manner or in violation of the rules prescribed. Some of the sites were developed historically when there was no regulation on management of hazardous wastes. In some instances, polluters responsible for contamination have been either closed down their operations or the cost of remediation is beyond their capacity, thus the sites remains a threat to the environment. These contaminated sites need to be investigated in details and remediated on priority to levels that are acceptable considering the human health risks and environment by adopting appropriate remediation technologies. Contaminated sites often pose multi-faceted health and environmental problems to society. It can adversely impact/affect any or all parts / sections of the surrounding environment, particularly soil, surface water and groundwater and as result, people are knowingly or unknowingly get exposed to toxic substances. Contaminated sites may include production areas, landfills, dumps, waste storage and treatment sites, mine tailings sites, spill sites, chemical waste handler and storage sites. These sites may be located in residential, commercial, agricultural, recreational, industrial, rural, urban, or wilderness areas. Present article deals with different types of contaminated sites in India.

Keywords: Contaminated sites; Pollution; Site specific target levels; Remediation

1. INTRODUCTION

Environmental pollution from hazardous metals and minerals can arise from natural as well as anthropogenic sources. Natural sources are: seepage from rocks into water, volcanic activity, forest fires etc. With rapid industrialization and modern life style of consumers, anthropogenic sources of environmental pollution have increased. The pollution occurs both at the level of industrial production as well as end use of the products and run-off. These toxic elements enter the human body mostly through food and water and to a lesser extent through inhalation of polluted air.

2. BENEFITS OF REMEDIATION OF CONTAMINATED SITES

The benefits of remediating contaminated sites will be mainly associated with a reduction in levels of contamination in soil, sediments, surface water (lakes, rivers, etc.) and groundwater thereby reduced risk to human health and the environment. Remediation of contaminated sites also results in a direct economic benefit in re-discovering contaminated land in terms of real estate price stabilization (Increase supply of saleable/leasable land). Although in some cases, remediation of contaminated sites may not necessarily bring direct economic benefits; it will generate long-term environmental and social benefits.

3. TYPOLOGY OF CONTAMINATED SITES

Contaminated sites are delineated areas in which toxic and hazardous substances exist at levels and in conditions which pose existing or imminent threats to human health or the environment.

These sites often pose multifaceted health and environmental problems. They can impact all components of the environment, particularly surface waters, soils, and groundwater and can result in people being knowingly or unknowingly exposed to toxic substances. Contaminated sites may include production areas, landfills, dumps, waste storage and treatment sites, mine tailings sites, spill sites, chemical waste handler and storage sites. These sites may be located in residential, commercial, industrial, rural, urban, or wilderness areas. All these elements are combined in a typology of contaminated sites. This typology is of importance for the assessment and design process of remediation.

As per guidance document of MoEF&CC [1], typology of contaminated sites is derived based on the causing activity and pathway of spreading of contamination:

Source related:

- Type S1 : Land bound solid phase contamination
- Type S2 : Water bound sediments solid phase contamination
- Type L : Land bound liquid phase contamination

Pathway related:

- Type P1 : NAPL contaminants in soil (Non-Aqueous Phase Liquids)
- Type P2 : Groundwater contamination

Depending on a specific situation, a combination of these types may be possible. Example: a land bound storage of chromium containing hazardous waste (type S1), causing leachate of chromium to groundwater and leading to a contaminated groundwater plume (type P2), will be termed as S1-P2 type contaminated sites.

4. RISK ASSESSMENT

It is internationally agreed that it is vital to determine the chance that either humans or the environment will get in contact with the contamination. The widely accepted approach for this risk assessment is the 'Source-Pathway-Receptor' (SPR) approaches [2]. Within this approach, the source is the contamination, e.g. a leaking oil tank or a layer of pure oil in the topsoil. The pathway is the route between the source and the receptor, and the receptor is a human, animal, plant, ecosystem, property or controlled water that may be affected by the contamination. Generally accepted principle is that adverse effects of contamination are only considered to occur when contamination actually threatens humans or resources, i.e. puts them at some substantial risk. This happens only when all of the three elements (source, pathway and receptor) are present.

In various risk assessment methodologies, the contamination (source) is clearly identified, as well as what that source may affect (receptor) and through what route the source may reach the receptor (pathway). It is important to note that receptors may be located on-site as well as off-site, and also that while in a current situation there may be no pathway, this can still develop over time (sometimes long periods), by diffusion through groundwater, surface water, sediment or air.

Remediation of contaminated sites involves cleaning of contaminated media i.e. soils, groundwater, surface water and sediments by adopting various in-situ or ex-situ clean-up technologies up to a predefined remediation target levels for each identified constituent. Site specific target levels (SSTLs) for remediation are decided for each site separately adopting either the risk-based assessment approach or standard based approach.

5. PRESENT STATUS OF CONTAMINATED SITES IN INDIA

An inventory of contaminated sites in the country was initiated in the year 2003 as per the directives of Supreme Court's Monitoring Committee (SCMC) in the matter of W. P. (C) 657 of 1995. Initially in the year 2005 State Pollution Control Boards/Pollution Control Committees (SPCBs/PCCs) have reported 141 contaminated sites. The list had revised as per the study on "Inventory & mapping of probable contaminated sites" carried out by MoEF&CC under Capacity Building for Industrial Pollution Management Project (CBIPMP), during 2012-16 and published the report in 2017 in which 320 probable contaminated sites were identified. Subsequently, Central Pollution Control Board (CPCB) received additional information of 09 sites from SPCBs during 2016-17 and the list has revised to 329. During 2018-19, total 134 out of 329 contaminated sites have been selected for preliminary/detailed assessment/remediation, wherein 08 sites were found as not contaminated and for 55 sites, preliminary assessment and detailed investigation had been done. Detailed investigations along with DPRs (Detailed Project Reports) are required for remaining 71 sites. State-wise status for 55 sites in is represented in Fig. 1. There are 195 probable contaminated sites, which need a thorough assessment for its confirmation. Further, status of projects under National Clean Energy Fund (NCEF) is given at Table 1. Moreover, CPCB jointly with concerned SPCBs and responsible polluter parties have regularly monitoring and evaluating the performance of on-going assessments and remediation works at 08 sites, as given below:

i) Oil contaminated site due to leakage of underground oil pipelines of BPCL near Tondiarpet, Chennai, Tamil Nadu;
ii) Mercury contaminated soil at Kodaikanal, Tamil Nadu;
iii) Pesticides and heavy metals contaminated land and creeks at Eloor, Kochi, Kerala;
iv) Mercury contaminated sites at Ganjam, Odisha;
v) Chromium contaminated sites at Ranipet, Tamil Nadu;
vi) Chromium contaminated sites at Rania, UP;
vii) Disposal of e-waste processing black powder lying on the banks of river Ramganga, Moradabad, UP; and
viii) Remediation of Chromium contaminated groundwater at Lohia Nagar, Ghaziabad, UP.

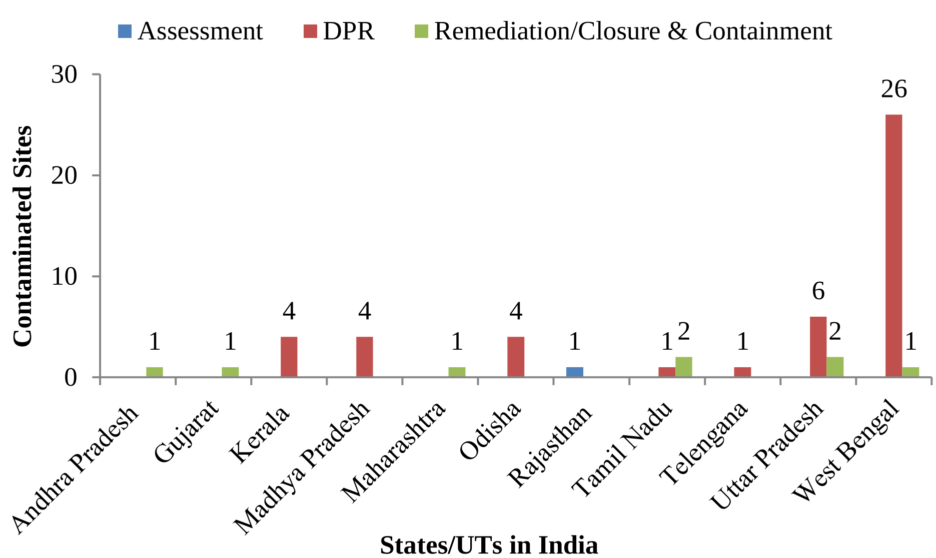

Fig. 1 State-wise distribution of 55 sites, with preliminary assessment and detailed investigation

Table 1 Status of projects under NCEF:

S. No.	State	Name of the Area	No. of Sites	Status
1	Kerala	Eloor-Edayar, Kochi	4	DPRs are completed
2	Odisha	Ganjam	3	
3	Odisha	Orichem, Talcher	1	
4	Tamil Nadu	Ranipet	1	
5	Uttar Pradesh	Rania, Kanpur Dehat	2	
6	Uttar Pradesh	IPL & Deva Road, Lucknow	4	
7	West Bengal	Nibra Village, Howrah	1	
8	Madhya Pradesh	Ratlam	4	Preparation of DPR is under progress
		Total Sites	20	

REFRENCES

Guidance document for assessment and remediation of contaminated sites in India (2015) published by MoEF&CC, Govt. of India.

https://www.wasteminz.org.nz/wp-content/uploads/Conceptual-Site-Models-Presentation.pdf (accessed on 10/10/2020).

Recent Advances in 3D Electrical Resistivity for Geotechnical and Environmental Engineering

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EXTENDED ABSTRACT

Before the '90s, electrical resistivity measurements were mostly soundings and profiling. The strong assumption linked to this type of measurement limited the use of this technique to water and mineral explorations. After this date, the implementation of 2D inversion software (res2dinv) together with the development of switching resistivity meter allowed the development of 2D Electrical Resistivity Tomography (ERT). 30 years later, 2D ERT remains the main type of measurement made over the world. One can only note that 3D acquisition is not fully developed. There are different reasons for this:

- The contractor that is generally not skilled in geophysics prefers to work with standard acquisition types
- The high number of electrodes required requires more expensive systems
- The time of acquisition on the field generally increase the price for the customer
- The data processing and interpretation may be more complex than in 2D

In this work, we present some recently published case studies using 3D electrical resistivity tomography for geotechnical and environmental engineering. We will show how it is now possible to positions the electrode more or less randomly around the targets following the site constraints. 3D software can now easily handle such unregular electrode positioning. Several case studies will show the advantages and benefits of the technique for archeological, geotechnical and environmental studies.

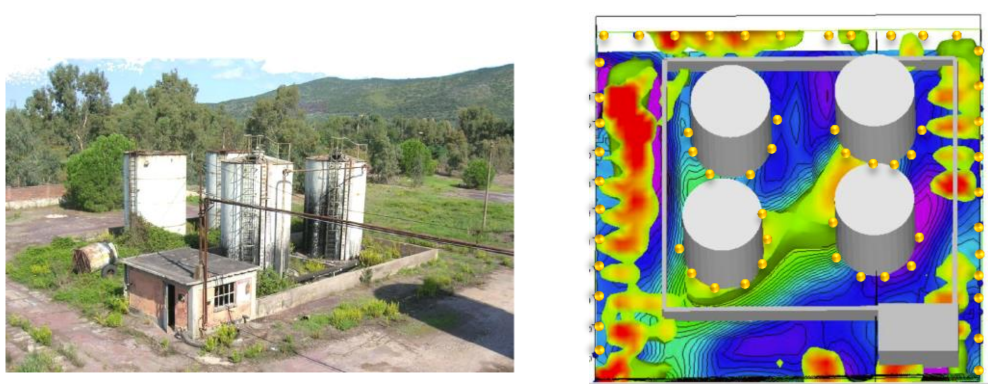

Fig. 1 Electrode positioning around potentially leaking fuel tanks

Several examples dealing with:

- Cavity detection for archeology or natural hazard evaluation
- Imaging of historical building disorders
- Tracking of building settlement remediation
- Study of geological layer continuity for tunneling

are presented. These examples all show the potential development of 3D ERT in the domain for geotechnics and the environment. They show how 3D anomalies can be imaged accurately and at a limited cost while working with strong site constraints. It is also highlighted that these specific studies require a good evaluation of the electrode configuration sensitivity which is much less regular than for standard 2D acquisitions.

In a second time, we present the potential of FullWave data acquisition for studies realized in an urbanized area with the anthropic noise that may affect the quality of the data. In this context, we rapidly show the advantage of acquiring the time series for advanced post-processing that can be realized rapidly on a computer. This type of processing allows for correcting easily spikes, non-linear self-potential drift or for removing noisy stacks, improving greatly the data quality. This advanced processing is of paramount importance for environment IP study was the IP signal is very tiny.

Finally, we show how to investigate a large volume of soil with the same technique but without using a long and heavy multicore cable to connect all the electrode to one unit. Instead of plugging 120 electrodes to one system, the FullWaver system is designed to use 40 autonomous loggers, each one, plugged to 3 electrodes. The loggers are synchronized thanks to the GPS clocks so that there is no communication between them. The first advantage of such a system is that they allow surveys that were impossible before due to sharp topography, river, building, roads, etc. The second advantage is that the depth of investigation can be increased easily without having to buy and deploy expensive, long and heavy multicore cables on the field.

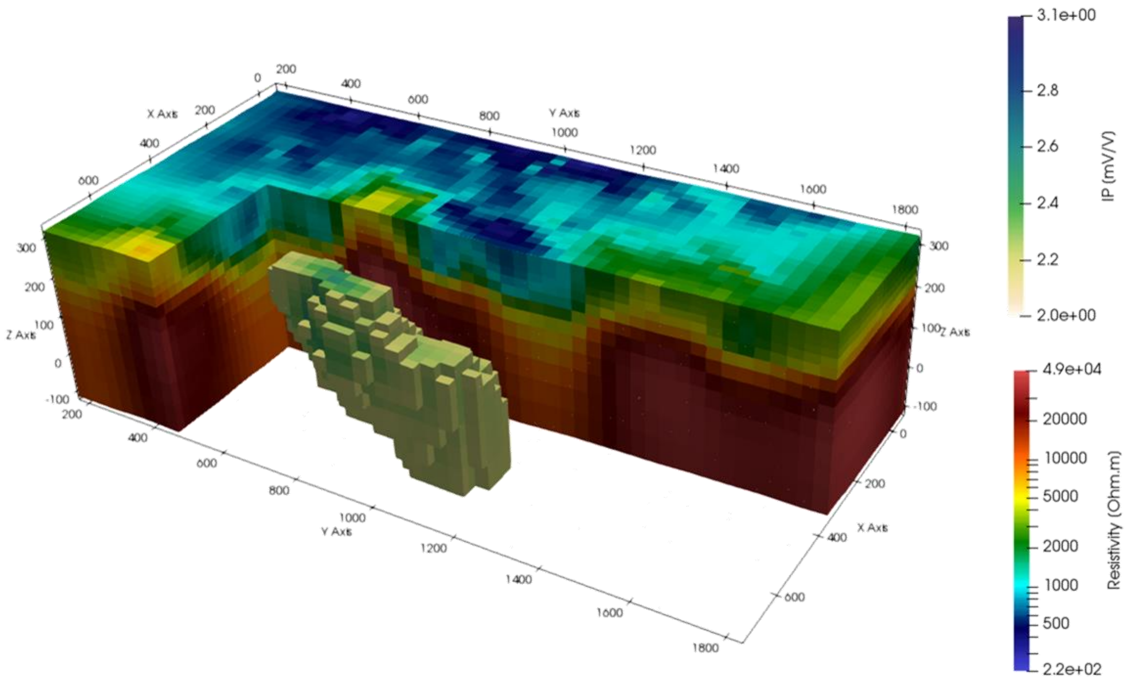

Fig. 2 Example of full 3D electrical resistivity tomography acquired thanks to distributed autonomous systems (FullWavers)

We show some examples through recently published cases study on a landslide survey, on mineral exploration and on geothermal exploration.

On-site Screening of Heavy Metals in Soils using the Thermo Scientific Niton XL3t GOLDD + Handheld XRF Analyzer

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1. INTRODUCTION

Contamination of soils by heavy elements is an important environmental problem. The most important sources of heavy metals in the environment are from human activities such as mining, smelting, iron and steel industry, chemical industry, traffic, agriculture as well as domestic activities. Chemical and metallurgical industries are the most important sources of heavy metals in soils. The presence of heavy metals in soil can affect the quality of food, groundwater, micro-organisms activity, and plant growth.

With increasing knowledge and available information about the deleterious effects of heavy metals, environmental consciousness grows globally. Public opinion all around stimulated legislators to pass laws and regulations:

- restricting the release of heavy metals in industrial or mining activities [1]
- prescribing risk assessment and/or monitoring for potentially contaminated agricultural land or residential, commercial and industrial areas.

For these reasons, the enforcement of legal limits for heavy metals often requires a site to be screened quickly to ensure adherence to regulations. XRF can be used to geochemically map a site with high-density in-situ testing to help determine the extent and boundaries of the contamination and the required remediation strategy. XRF can additionally be used to prescreen samples to be sent for independent confirmatory testing.

EPA Method 6200 [2-3] and ISO 13196 norm [4-5] have established handheld XRF as a method for soil analysis. For the last 20 years, several thousand Niton handheld XRF analyzers have been delivered to environmental professionals, universities, industries, and regulators to screen for or quantify heavy metals in soils and sediments.

With tube power, optimized geometry and graphical user interface, the Niton XL3T GOLDD+ is available for soils analysis and provides significant enhancements in both analytical performance and operation.

2. INSTRUMENTATION AND FEATURES

The Niton XL3T GOLDD+ (figure 1) is a handheld energy-dispersive XRF analyzer fitted with a proprietary miniaturized x-ray tube and a large area silicon drift detector positioned very close to the sample. The maximum power of the x-ray generator is 2W and the current is automatically ramped up to maximize the count rate recorded by the detector for each measurement. The x-ray tube can operate from 5 to 50 kV and Soils Mode can measure elements from S to U using up to 3 different beam conditions with pre-defined filters and voltages to enhance the signal-to-background ratios of fluorescence lines in the main (4-30 keV), low (3-6 keV) and high (20-40 keV) ranges of energies. The XL3T GOLDD+ Soils Mode uses a proprietary Fundamental Parameter (FP) based algorithm that accounts for the variation of sample composition by correcting for absorption and secondary excitation effects arising from the matrix to deliver accurate results.

Fig. 1 Niton XL3t GOLDD+

Users can optimize Soils Mode with different measurement times, the timing of beam conditions, data fieldsets, the format of element displays, display of pseudo-elements and matrix specific type calibration adjustments. Those parameters are stored under Soils Mode Profiles. Profiles enable users to have multiple configurations on the same instrument that can be selected to perform measurements right away using the appropriate settings. The instrument has selectable user-defined profiles: one for fast screening measurements, another one for lab-quality analysis on prepared samples or a third one using type standardization for the analysis of marine sediments.
The Niton XL3T GOLDD+ is also provided with integrated GPS to facilitate spatial visualization of data using GIS programs useful for mapping and site modeling of heavy metal pollution. External GPS can be connected to the XL3T GOLDD+ via Bluetooth. Measurement Data can be transferred to a PC using USB.

(a) (b) (c)

Fig. 2 (a) XL3t on-site Analysis of Soils (b) Mode for various applications and (c) Mapping using a GIS program

3. SAMPLE PRESENTATION

The analysis of soils can be carried out in two ways: either in-situ “point and shoot” mode or in intrusive mode [2]. In “point and shoot” mode, the handheld XRF instrument is directly aimed at the soil surface after removal of debris, small stones or vegetation. This way of operating the analyzer is suitable for screening and delivers qualitative and semi-quantitative results enabling a quick localization of pollution hot spots. For those measurements, the Soil Guard is indispensable to keep clean the window bracket of the analyzer. The instrument can be operated upside down using a tripod in combination with the easy trigger function to improve the ergonomics of “point and shoot” in-situ measurements.

In intrusive mode, a fraction of the soil is taken out of the site and subsequently homogenized using a mortar or a grinder and if necessary sieved and dried. The obtained powder is then introduced into a sample bag or a sample cup which is then presented to the analyzer using the mini test stand. Intrusive analyzes, including basic sample preparation, can be done on-site or in a laboratory. Analysis of samples cups containing homogenized powder is typically carried out for a longer time (30 seconds to several minutes) to detect elements at lower concentrations and to yield more accurate results compared to point and shoot measurements.

Fig. 3 Accessories.

4. ANALYTICAL PERFORMANCE

Over the past 20 years, considerable progress has been made in terms of sensitivity for heavy metal detection in soils.

The largest part of the uncertainty in soils analyzes does not come from the analysis method itself (laboratory-based methods or Handheld XRF) but the sampling process, that may inadequately represent the spatial distribution of contaminants [6].

When samples are homogeneous and representative, the Niton XL3T GOLDD+ Soils mode delivers very accurate results “out of the box” for the determination of heavy metals in soils. Fig 4 illustrates the good correlation between reference (dotted line) and measured values (plain lines) for Cu, Zn, As, and Pb obtained in the analysis of an extensive set of 19 commercially available standard reference materials, in which those elements were present at concentrations varying from a few ppm to several thousand ppm.

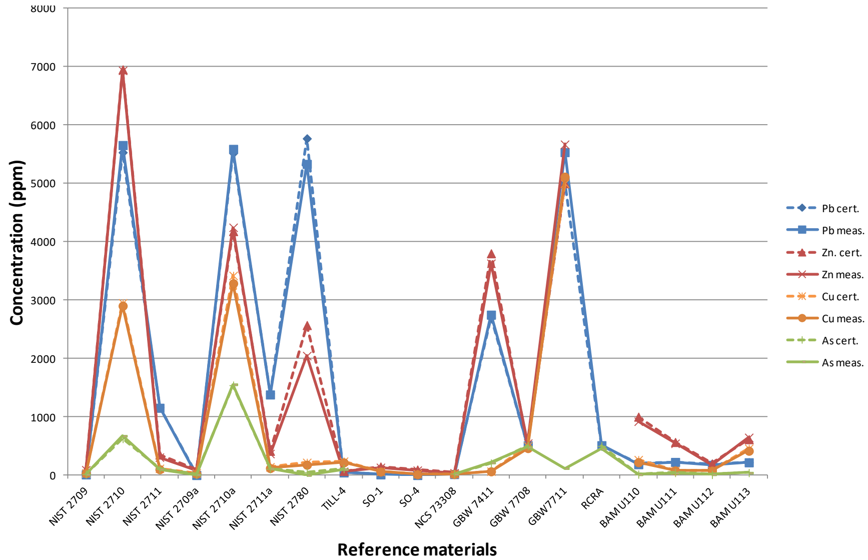

Fig. 4 Correlation of heavy metals (Cu, Zn, As, Pb) in soil standard reference materials. Fine powders introduced in sample cups fitted with 4µm PP film. 180s measurement time

5. CONCLUSIONS

Handheld XRF allows users to make a real-time assessment of soils and related samples while reducing the number and prescreening samples sent to a lab. With improved sensitivity and portability, the Niton XL3T GOLDD+ belongs to the most powerful and advanced handhelds XRF analyzers available today to:

- detect low concentrations of heavy metals, quickly in point and shoot mode.
- generate lab-quality analytical data with minimal sample preparation

Assessing on-site environmental hazards becomes fast, efficient and very cost-effective to environmental professionals, regulatory agencies, construction companies with a short return on investment due to:

- in-situ measurements and site characterization of metal pollutant hotspots per EPA Method 6200 and ISO 13196 to support real-time decision making
- Improved decision making in the field by use of HHXRF with accessories to managing uncertainty
- Reduce external lab costs by in-situ analysis, and prescreening samples for external lab analysis
- Reduce the volume of excavated soil, by continual measurement after extraction to ensure contamination is below threshold levels
- making defensible field decisions that reflect site condition thank larger sample density
- screening & clearance of construction sites: no delay for starting building works
- hazardous waste screening, capture images of waste using the on-board camera
- monitoring brownfield remediation

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Remediation of Contaminated Sites: Two Case Studies

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EXTENDED ABSTRACT

CASE STUDY 1

The earthquake in Kutch region of Gujarat on January 26, 2001 resulted in the spillage of acrylonitrile (AN) due to development of cracks at the bottom of a storage tanks.

The approach of CSIR-NEERI included:

- Assessment of release of AN (2584 KL of AN)
- Recovery of the spilled material (70 %)
- Spill simulation (to study the spread of AN)
- Assessment of contamination (1 hectare, 30 cm deep)
- Remediation of contaminated area.

A spill simulation was carried out and in-situ remediation option was short listed.

Acrylonitrile degrading bacterial culture C1 (gram negative small rods) and C2 (gram positive cocci) were isolated in the laboratory. Both the cultures were able to utilize AN up to a concentration of 2000 mg/L as the sole source of carbon and nitrogen. The concentration of AN was brought down to below detectable limit in 5 days when contaminated soil was mixed with AN degrading culture (K=1.465 mg/kg/d).

Acrylonitrile in contaminated soil in the field degraded slowly under natural conditions, however, when it was mixed with AN degrading culture along-with farmyard manure, the soil was completely remediated.

CASE STUDY 2: Assessment and Remediation of Hexavalent Chromium Contaminated Areas at Tamil Nadu Chromates and Chemicals Ltd, Ranipet.

M/s TNCCL, manufactured chromium salts and chemicals at their unit located in Ranipet Industrial Area in Tamil Nadu between 1975 to 2000. During its 25 years operation, TNCCL unscientifically dumped about 160000 MT of hexavalent chromium bearing wastes within its premises spanning an area of about 2.8 hectares. The widespread contamination of soil and groundwater in terms of Cr^{6+} has posed significant risk to human and animal life as Cr^{6+} is a carcinogenic compound. SCMC directed TNPCB to draw up a plan for immediate measures to stop environmental damage and prepare full-scale remediation/rehabilitation plan. The assessment and remediation studies were suggested by CSIR-NEERI.

Geomicrobiology for Remediation of Contaminated Environment

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EXTENDED ABSTRACT
Environmental deterioration due to release of toxic pollutants through diverse anthropogenic and natural activities pose a tremendous threat to our biosphere affecting human and other organism's health and global sustainability. Microbe based bioremediation has increasingly being considered as one of the most effective strategies to deal with most of the environmental contaminants in an environmentally sustainable way. Bioremediation (as it is commonly referred to) exploits microbial catabolic abilities to reduce, eliminate, contain, or transform various environmental contaminants to benign products. Continuous research effort has made microbially mediated bioremediation a more promising and efficient *in situ* remediation technology with high public acceptance. While it is well understood that microorganisms (mainly bacteria and archaea) with their astonishing metabolic versatility, ubiquity and adaptability aid to the remediation by oxidizing, binding, immobilizing, volatilizing or otherwise transforming contaminants, implementation of such laboratory-based knowledge is severely constrained due to several factors. Research done in past decades has clearly indicated that our failure to exploit microbial abilities adequately in bioremediation is closely linked with our ignorance about how microorganisms work in a real environment. While a cultivation-independent 'meta-omics' view is necessary to characterize any microorganisms or microbial community, a thorough understanding of local geology seems critical to appreciate and apply their catabolic repertoire towards bioremediation. This paradigm change has led to the integration of the concepts of the geomicrobiology of contaminant systems into the workings of microorganisms for pollution abatement. In recent years, we have been investigating the role of indigenous microbial communities from acid mine drainage (AMD) from Asia's largest open-cast copper mine at Malanjkhand, India and their application in developing in situ bioremediation process for the treatment of AMD contaminated soils. Acid mine drainage (AMD) is considered to be a global environmental problem faced by mining industries due to the biological oxidation of sulfidic minerals. Owing to its highly toxic nature manifested through acidic pH, elevated levels of heavy metals and sulfate, AMD is not only a threat to aquatic and terrestrial ecosystems but considered to be a major contributor in long term degradation of environmental quality. The development of an appropriate bioremediation strategy for AMD impacted environment is imperative for sustainable mining but remained critically challenged due to the paucity of knowledge on desired microbiological factors and their nutrient requirements. Microbial sulfur- and iron-metabolisms through redox transformations coupled with or without energy generation constitute the major biochemical reactions within AMD. Sulfate- and iron-reductions are the two key reactions carried out by heterotrophic sulfate- or iron-reducing bacteria (SRBs or IRBs) that could reverse the AMD generation, metal precipitation and thus decrease the soluble metal concentrations and facilitate in raising the pH of AMD or AMD impacted ecosystems. Using a biostimulation approach we first demonstrate that low-abundance members of the Firmicutes facilitate bioremediation of soil impacted by highly acidic mine waste (Gupta et al 2018). This is followed by delineating the role of more cost-effective organic carbon substrates as a biostimulant for autochthonous microbial populations relevant for bioremediation (Gupta and Sar 2019a). Microbial consortium thus enriched from the AMD system and composed of

uncultured *Clostridiales* and *Bacillales* members is characterized and tested for in situ application through microcosms. A combination of bioaugmentation (enriched consortium) and biostimulation allowed a 97% reduction in dissolved sulfate and rise in pH up to 7.5 (Gupta and Sar 2019b). The study demonstrates the importance of geomicrobiology in identifying the most desirable organisms and their successful enrichment and application in AMD bioremediation.

Keywords: Bioremediation; Geomicrobiology; Metagenomics

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Inventory of Probably Contaminated Sites in India

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EXTENDED ABSTRACT

Project Background:

The Inventory and Mapping of Probably Contaminated Sites in India were carried out as a part of the contract between the Ministry of Environment, Forests and Climate Change (MoEFCC) and the Consortium consisting of COWI as lead partner in association with Kadam Environmental Consultants, Witteveen+Bos and Tauw as sub-consultants. The project was funded by the World Bank. The key stakeholders of the project were the Ministry of Environment, Forests and Climate Change (MoEFCC), Central Pollution Control Board (CPCB), State Pollution Control Boards (SPCBs), World Bank and Blacksmith Institute.

Project Objectives were:

- To prepare comprehensive and reliable database of contaminated sites across India, which will provide information to Central & State governments when preparing and implanting the National Program for Rehabilitation of Polluted Sites (NPRPS).
- Create a methodology to be used in the future
- Create a comprehensive database tool with GIS integration specifically designed for contaminated sites management
- Collect and integrate existing data on contaminated sites in India
- Definitions of (probably) contaminated sites and levels of contamination that are considered safe or unsafe
- Database to be comprehensive and flexible for further update and be compatible with programs used by MoEF and the SPCBs
- The information on individual sites will have to be structured so that it is consistent and comparable across different types and locations of sites
- The database will provide information and tools for prioritization across sites, nationally, locally or by characteristics
- The list of contaminated sites shall be a dynamic document, and data will be adjusted on a regular basis to include additional information that becomes available.

Project Approach & Methodology:

The project was divided into 5 tasks as under:

Step	Task	Title
	Task 1 – Review and update the available information on polluted sites	
1	1.1	Collection of information from MoEF, CPCB, SPCBs, NGOs, industrial departments, industrial authorities, SEZs, municipalities, etc.
	1.2	Data processing and review, develop an Excel sheet for data introduction and upload site data in the Excel sheet and in the database
	1.3	Preliminary categorization and assessment of sites
	1.4	Generating an updated list of sites and a summary report
	Task 2 – Formulate approaches to identification and assessment of contaminated sites	
2	2.1	Review the international practices in identification, ranking, and assessments of polluted sites
	2.2	Set 'action levels' or 'levels of concern' for different contaminant groups, i.e. suggest soil and groundwater criteria for different contaminant groups
	2.3	Set up a structured process to be followed in the identification and assessment of contaminated sites
	2.4	Develop methodology to be followed for conducting a desk-based assessment of sites
	2.5	Provide a protocol for carrying out an initial assessment of identified sites
	Task 3 – Develop an inventory and database of contaminated sites	
3	3.1	Set up and introduce possible minor modifications of GeoEnviron
	3.2	Develop an Excel sheet for data introduction
	3.3	Transfer data from Excel sheet to GeoEnviron
	3.4	Demonstrate GeoEnviron
	Task 4 – Field visits, investigation and data verification/update of contaminated sites and development of GIS applications	
4	4.1	Set up criteria for site selection for field visits
	4.2	Select sites for field visit. Site specific assessment plans
	4.3	Field visit, inspections
	4.4	Organize and introduce site data in the Excel sheet and in the GeoEnviron database
	4.5	Generate an updated list of sites and a summary report
	4.6	Develop GIS applications
	Task 5 – Prioritization of sites	
5	5.1	Review and report on international approaches to objective ranking and priority setting systems for contaminated or hazardous sites
	5.2	Develop a ranking system which can be applied using the data typically available in the database
	5.3	Test the ranking system against the sample of sites from the database including review by knowledgeable specialists
	5.4	Apply the ranking system to the whole database
	5.5	Training course in GeoEnviron and in update of database for staff from MoEF, CPCB, APPCB and WBPCB

RESULTS

The above tasks were applied for 557 sites. However, the list was shortened to 320 sites and finally, 100 sites were shortlisted based on contamination of concern.

From the shortlisted 100 sites, scores and rankings were given to individual sites based on the Source- Pathway-Receptor Model. The report for the project was published by MoEF&CC.

Risk-Based Remedial Planning of Contaminated Sites

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EXTENDED ABSTRACT

A contaminated site is one where anthropogenic activity has led to the contamination that can have **an** adverse impact on humans and ecology. The process of site assessment identifies the type of contaminants and the level and extent of **the** contamination. Once the contamination is delineated, a remedial plan and remediation implementation follow. Contaminated site remediation can be quite expensive especially if the site is large. In this presentation, we discuss a risk-based approach toward remedial planning with the intent that in cases where the risk posed by the site is deemed acceptable, or made acceptable by certain interventions, then perhaps the site can be risk-managed instead of conducting full remediation.

For a contaminated site to pose a risk to humans or ecology, it must have three features: (a) a source of contamination (b) a pathway for the contaminant to migrate to a possible receptor and (c) a potential receptor. Potential receptors can be persons living on-site, children playing in playgrounds located on the site, employees in a factory operating on the contaminated land, or anyone living nearby and may get exposed through contaminated soil, water, or air. For **a** risk to manifest, all these three must be present. If, however, anyone of these three features is removed, the risk is removed and therefore the site is not as concerning as it initially was deemed to be. In this case, further mitigation may or may not be needed. For example, if the source of contamination is removed, which is a focus of active remediation, the risk posed by the site is lowered appreciably. One may also consider changes to the exposure pathway. This can be enacted through multiple ways; for example, in cases of surface contamination where dust is a concern, a clay cap can disrupt contaminant migration to the air and therefore mitigate the risk posed by the site. Alternately, if the contamination is at depth and a potable-water aquifer is impacted, a vertical cut-off wall keyed to the bedrock, that isolates the site and therefore prevents the flowing groundwater from coming in contact with the contaminated soil, may lower the risk. Furthermore, **an** intervention can happen with receptors. The most sensitive receptor for a residential site is small children or toddlers, whereas for an industrial site it is an adult. Changing land use by reclassifying a site from residential, if that is the original designation, to an industrial site will lower the risk because the sensitive receptor (i.e. a toddler) will no longer be at risk. However, one should then confirm the site does not pose additional risk to adults working on site. For example, building a paved parking lot on top of contaminated land will also lower the risk of exposure through air pollution. These are some of the ways to lower risk.

It is understood that a detailed risk assessment is time-consuming, requires a significant amount of data, and does not remove the contaminant source. However, it is still a prudent option to investigate during the planning stages because it can lead to significant savings for a client if the human and ecological risks are deemed low. It will also help identify targeted site interventions that can be used to lower the risk without having to conduct full site remediation.

However, a risk-managed site requires continuous monitoring. For example, if a cut-off wall is placed to hydraulically isolate a site, the groundwater must be periodically monitored for an indefinite time period to confirm the cut-off wall indeed functions as it was designed. Similarly,

if a clay cap was placed to prevent the contaminated dust from becoming an air pollutant, then periodic cap inspections are required to confirm breaches caused rodents, soil desiccation, or roots have not occurred. Therefore, risk management of contaminated sites requires a robust monitoring program and a contingency plan to anticipate responses to possible failures.

There are some situations where risk management may not be the solution. An example would be when the site is being sold or when the contamination has crossed the property line and has started impacting the neighboring areas. If the site is being sold, the buyers must be informed about the contamination and of remedial action that has been taken, if any. If the site is to remain contaminated, the buyers will have to formally agree to assume the liability associated with the contamination. Sometimes, environmental regulators may not allow the sale of a contaminated site, unless it has been remediated to an acceptable standard verified by the third party.

In conclusion, a risk-based approach to remedial action is a practical way to understand the risks posed by a contaminated site and make decisions with full knowledge. This added information helps decision-makers as to whether to fully remediate the site or to lower the risk and manage it by having a robust monitoring program to confirm that the risks remain low.

A Comparison of Soil Sampling Methods for Environmental and Geotechnical Studies

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EXTENDED ABSTRACT

The methods adopted for collecting samples of soil from specified depths at a given site are different when the end use is determination of geotechnical properties (eg measuring strength, compressibility, permeability) in comparison to those for determination of environmental properties (eg measuring contaminant levels). The salient differences in these methods are compared and the reasons for the differences are highlighted.

The process of geotechnical soil sampling involves (a) drilling a borehole to reach the specified depth; (b) stabilizing the hole; (c) driving or pushing a thin walled sampling tube into the base of the borehole; (d) retracting the sampling tube; (e) sealing the ends of the tube with molten wax; (f) transporting it to a laboratory in a sampling box. For environmental soil sampling the differences are (a) dry drilling methods are preferred; (b) stabilization of the borehole is done by using closed ended tubes or hollow-stem augers; (c) sampling is carried out using samplers with plastic or stainless-steel liners; (d) sealing is done with swatches and plastic end caps; (e) transportation of samples is carried out in boxes with temperature control where ever required.

Use of drilling methods such as bailers with bentonite slurry to stabilize the borehole are not adopted in environmental studies as such processes contribute to cross-contamination in a borehole. Instead, dry percussive, hydraulic push or rotary methods are preferred.

Sampling tubes used for geotechnical studies are manufactured from seamless mild steel tubes and have stringent requirements on area ratio, thereby restricting the wall thickness of samplers. This ensures that the disturbance to the structure and density of the sample is minimal. Each sampling tube is transported to the laboratory and the number of sampling tubes available at a site has to exceed the number of samples to be collected at that site. For environmental studies, area ratio is not important and the samplers are composite in nature. The sample is collected in liners which are sent to the laboratory; each sampling tube is not transported to the laboratory. The number of liners available at a site has to exceed the number of samples to be collected.

The diameter of undisturbed samples for geotechnical studies usually are in the range of 75 to 100mm or more because the diameter of samples in triaxial tests, consolidation tests or permeability tests have size requirements of 38.6 mm, 60 mm or 100 mm or more. In contrast, in environmental studies the diameter of samples can be smaller, often around 25mm in size. The length of samples for geotechnical studies is typically in the range of 300 to 600mm whereas in environmental studies these can be as long as 1500mm.

During environmental soil sampling, where VoCs are present, soil-gas syringes are used to extract pore-gas or pore-vapor as soon as the sampler reaches the ground surface from a borehole and these are transported to the laboratory for analysis. Prolonged delay in extracting the soil-gas can cause escape of the same from the sampler if the sealing is not completely airtight.

It is not possible to use conventional drilling and sampling equipment available for geotechnical site investigation purposes in environmental studies. Special equipment designed for subsurface environmental investigations should be adopted.

Choosing the Appropriate Remedial Application for your Site

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EXTENDED ABSTRACT

In the early 1900s cars were becoming more available in the US and so was the storage of fuels to support them. In the late 1970s to early 1980s, the US began the Leaking Underground Storage Tank (LUST) program due to a new awareness of impacts on soil and groundwater. In the 1980s, the US determined 450,000 USTs had leaked to the subsurface. As a result of intensive focus, in 30 years, 75% of these sites have been remediated. Diesel and gasoline petroleum products used in most retail service stations are composed of numerous volatile and semi-volatile organic compounds including benzene, toluene, ethylbenzene, xylenes (collectively BTEX), naphthalene and ethylene dibromide. Originally gasoline contained tetra-ethyl lead as an additive to provide an octane enhancer. Following concerns with the lead being released into the environment. methyl tert-butyl ether (MTBE) began to be used in gasoline as a lead replacement in the US and then throughout the world. Understanding the petroleum products and either oxygenates chemical properties and migration through the subsurface are important in determining the risk to the environment and any receptors.

The correct remedial approach should base on the type of contamination, the geology, and the risk associated with the contamination to both on or offsite receptors. This understanding comes through a conceptual site model and knowing where your complete pathways are. The better in understanding the contamination type, the migration pathways the more successful the remedial approach. The remedial cost can also be impacted by the geology of the subsurface. Clayey soils are generally cost more to remediate over sandy soils due to the remediation process and equipment. Sandy soils impacted by volatile organic compounds can be remediated using Air sparge and soil vapor extraction as on method. Clayey soils impacted with volatile compounds are remediated using dual-phase extraction. The case study of two petroleum release sites with similar risk profiles and differing geology are presented to illustrate how the remedial approach will differ in approach. One study used Air sparge soil vapor extraction to remove the petroleum contaminate at the source and in-situ resulting in clean-up of the site within 12 months. The second case study illustrates how the implementation of dual-phase extraction applied to denser soils removed the petroleum contamination over 3 years to a level no longer creating a risk to the receptors. The cost between these two approaches was significantly different due to geology determining the best approach to remediate the site.

Approach for Bioremediation of Municipal Solid Waste Dumps

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ABSTRACT

Management of Municipal Solid Waste (MSW) dumpsites has become a serious issue in all the major cities of our country. The MSW management rules (2016) have mandated for the mechanical and biological treatment of the fresh MSW. It also recommends bioremediation and biomining options for the treatment of legacy waste (old MSW). This paper presents an approach for the bioremediation of MSW in a typical dumpsite of Bangalore city. The overall objective is to improve the sustainability of the landfilling process in the city. This can be achieved by addressing the three major aspects, viz., landfill gas (LFG), leachate and the recovery of air space. The LFG generated from the site can be oxidized to carbon dioxide by designing bio-cover systems. Proper management of leachate by collection and recirculation avoids the possibility of groundwater contamination. Conversion of the existing dumpsite to a bioreactor landfill helps in decreasing the overall time required for waste stabilization and thus aids in landfill site reclamation. Even though the approach suggested in the study is site-specific, with suitable modification, the same can be applied to other sites as well.

Keywords: MSW; bioremediation; bio-covers; leachate recirculation.

1. INTRODUCTION

Bangalore generates around 4,500 tons of MSW (EMPRI 2012) per day and most of it is disposed of directly in open landfills. From the sustainability perspective, bioreactor landfills are preferred to the open dumping of waste due to the social, economic and environmental considerations (Sughosh et al., 2019). An approach for the bioremediation of MSW dumpsite is described in this paper wherein a typical open dumpsite is retrofitted to a bioreactor landfill.

2. METHODOLOGY

2.1 Typical landfill site description and waste characteristics

2.1.1 Landfill site description

A typical landfill of 4 acres in area and 20-30 m in depth with proper liner system is considered in this study. Total waste of around 1,00,000 tons is assumed to have been contained in the landfill. The age of the waste is assumed to be around two years.

2.1.2 Chemical properties of waste

The waste sample was oven-dried at 60°C until a constant weight was attained. The inerts and the plastics were removed from the sample and the residue passing through 4 mm sieve was analyzed for its chemical composition of compost. The organic content was determined from +4 mm fractions.

2.1.3 LFG emissions from landfill
LandGEM model version 3.02 has been used to estimate the total yearly emissions from the landfill. The values of methane generation rate ($year^{-1}$) and the methane generation capacity (m^3/Mg) used in the LandGEM model were 0.039 and 71.44 respectively.

2.2 Current problems encountered at the site
The majority of the landfills do not have leachate or gas collection systems. The waste contained within the landfill is saturated during the rainy season and thus increases the risk of groundwater contamination. The LFG emissions are not controlled which causes fire hazards and contributes to global warming.

2.3 Design of leachate recirculation system
In this study, the horizontal trenches are considered for the recirculation of leachate. The number and the spacing of trenches are determined based on the simulation of a typical cross-section of the landfill (50m x 20m) in Hydrus-2D. Unsaturated properties and hydraulic conductivity of fresh waste were assumed from Wu et al. 2012 and Reddy et al. 2009 respectively.

2.4 Design of bio-cover system
Laboratory experiments on anaerobically digested MBT waste as bio-cover material were carried out to determine the maximum methane oxidation potential (MOP). The MOP is then used to design the bio-cover system for the methane emission rate calculated for the site.

3. RESULTS

3.1 Waste characterization
The physical composition of the waste showed that the plastics, wood, paper, stone and undigested biomass were 27.77%, 10.43%, 7.12%, 16.96%, and 6.03% respectively. The organic content of the waste was found to be around 67%. From the chemical characteristics of waste, the C/N ratio was found to be around 5-10. For compost, this value must be around 20. The heavy metal concentration in the waste was towards the upper threshold limits (in some cases even have exceeded). The values of total organic carbon, total nitrogen, total phosphate, and total potash are below recommended levels and hence do not satisfy the quality of compost. Therefore, the compost can either be landfilled or used as a cover material.

3.2 Design of leachate recirculation system
The modeling results show that a 70% saturated moisture content in the waste can be achieved up to a distance of 10 m from the trenches with a recirculation rate of 5.5 m^3/day. Therefore, 52 horizontal trenches of 10m x 0.6m x 1m dimension distributed all along the landfill area would be enough to maintain the required moisture content in waste. The existing vertical well features present in the landfill can be used to pump out the leachate from the bottom of the landfill (Fig. 1).

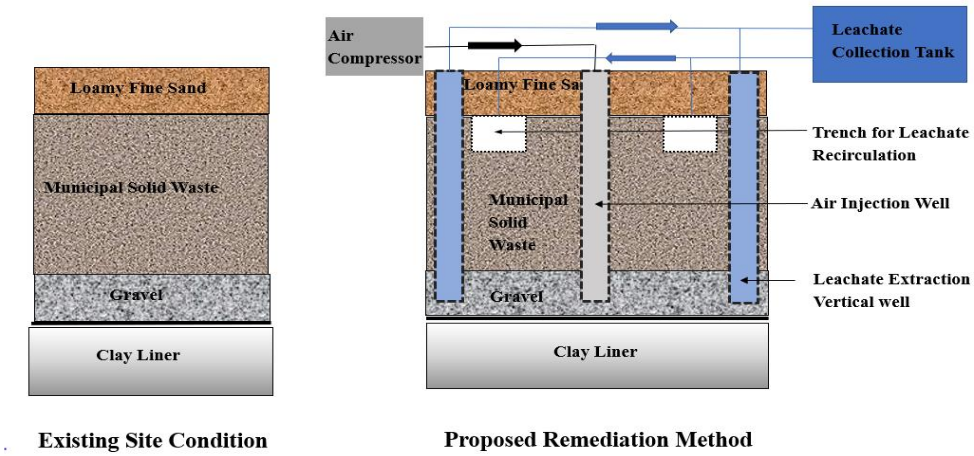

Fig. 1 Proposed modifications in a typical landfill of Bangalore city.

3.3 Design of bio-cover system.

The methane emission from the dumpsite during the year 2019 was 2.633 x 10^5 m^3/year (Fig. 2). From the column studies, the bio-cover system consisting of anaerobically digested MBT waste has a methane oxidation efficiency of 81.21% for a flux rate of 700.35 g/m^2/d. Therefore, a bio windrow system of 848 m^2 in area is required to take care of the methane emissions. The digested MBT waste of 0.8m depth with a moisture content of 30%, compacted to a bulk density of 750 kg/m^3 is sufficient to oxidize the methane emission from the dumpsite.

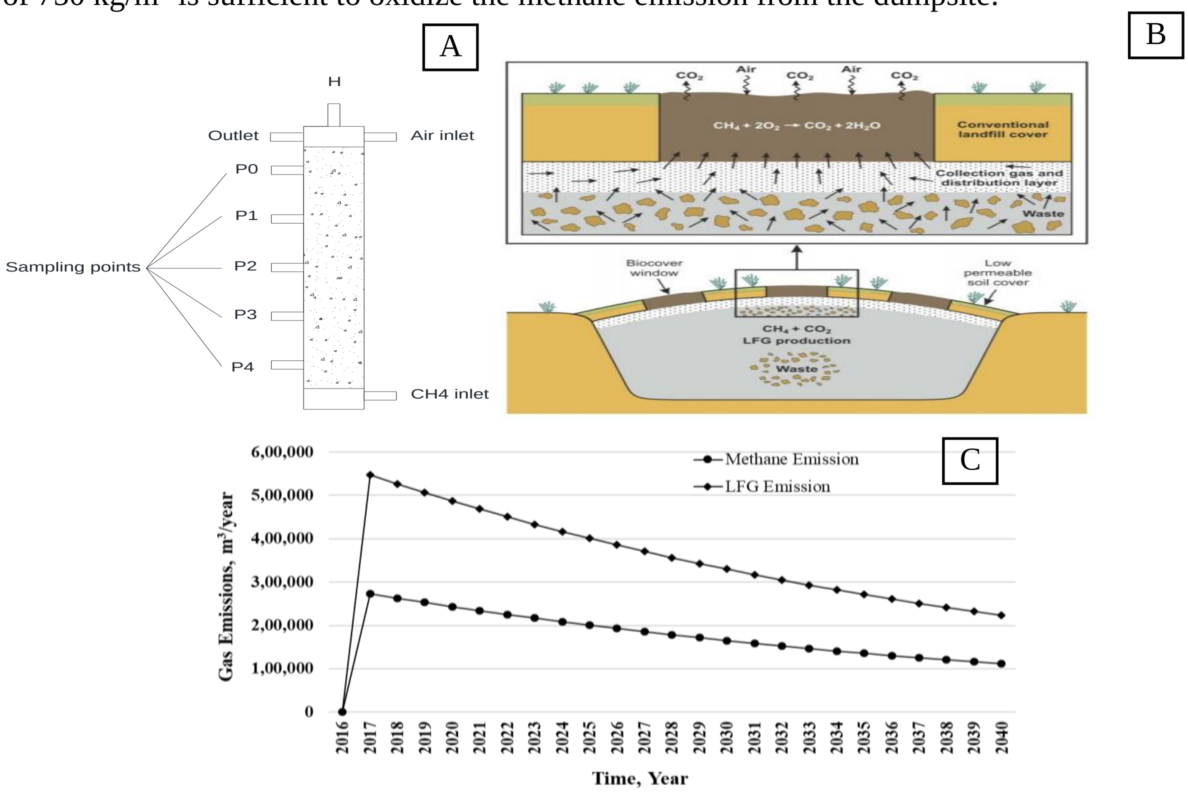

Fig. 2. (a) Schematic diagram of the experimental setup used to evaluate the MOP of the bio-cover material; (b) schematic view of a typical bio-cover (bio-windrow) system; (c) The LFG emission rate estimated from the dumpsite.

4. CONCLUSION

The study presents an approach for remediation of a typical MSW dumpsite using the bioreactor concept. The approach mainly consists of the design of a leachate recirculation system, estimation of the LFG emissions from the site and the design of the bio-windrow system to cater to the methane emissions. The approach can be applied to other MSW dumpsites with site-specific modifications.

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Prioritization of Contaminated Sites using Sparse Data
(preliminary)

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ABSTRACT
The Stage I prioritization method for contaminated site ranking in India is compared with an unbiased method to evaluate the Stage I method's ability to objective rank sites with sparse input data. Preliminary data on 320 contaminated sites in the country were used in the evaluation. The Stage I method positively correlates with the unbiased method and may yield conservatively high ranks at times. The authors illustrate the inherent uncertainty in site ranking and caution practitioners to consider ranking schemes as only one of several lines of evidence in contaminated site management decisions. Confirmation of the available, preliminary data and subsequent re-analysis is recommended to verify the authors' findings.

Keywords: contaminated site; ranking; decision analysis

1. INTRODUCTION

Contaminated site management in India is described by the Ministry of Environment, Forest & Climate Change (MoEFCC) as a multi-step process that begins with identifying and assessing probably-contaminated locations in the country; transitions to developing the conceptual site model for each confirmed contaminated location; progresses to subsequent contaminated site remediation planning and implementation; and, concludes with post-remediation environmental monitoring, assessment and remediation cost recovery, and productive site reuse (MoEFCC, 2015a). A review of the associated three-volume, contaminated site management guidance (MoEFCC, 2015a; 2015b; 2015c) indicates that it incorporates and applies the technical, economic, environmental, and social dimensions of sustainable remediation (ISO, 2017).

Step 1 of 14 steps in India's contaminated site management process is identifying probably contaminated sites via pre-existing environmental site assessments, pollution-related regulatory documentation, complaints from the public, and possibly site visits (MoEFCC, 2015a). The MoEFCC has implemented the first step resulting in the identification of 320 probably contaminated sites across the country with the following contaminants being the most frequently identified: chromium, lead, cadmium, mercury, arsenic, and copper (COWI, 2015a). As part of subsequent effort to guide further investigation of the 320 sites, a two-stage prioritization scheme was developed. The initial stage (i.e. Stage I prioritization) only requires the readily available Step 1 information whereas the Stage II prioritization method involves information gathered in subsequent contaminated site management steps (COWI, 2015c).

The Stage I prioritization method described by COWI (2015c) is the scope of this paper since its inputs are the often-sparse information initially available in contaminated site management. The purpose is to evaluate the method's ability to objectively rank contaminated sites by comparing it to an unbiased ranking method (Bruggemann & Carlsen, 2012) founded on partial order relation theory (Epp, 2011).

2. LITERATURE REVIEW[1]

2.1 Decision Analysis

Decision analysis was first described by Howard (1966) as "a logical procedure for the balancing of the factors that influence a decision". Gregory et al. (2012) are Canadian and American researchers and practitioners who have applied this logical process (a.k.a. structured decision making) to decision analyses involving public policy related to environmental management issues. Referring to Table 1, central to decision analysis is the element–attribute (EA) matrix (Roy, 1996) which describes the characteristics of each element, s_i, such as a contaminated site, in terms of specified attributes, a_j, such as the inputs to the Stage I prioritization method. These characteristic descriptions are quantified as scores, $a_j(s_i)$.

Table 1 Element–attribute matrix

Element	Attributes, A				
	a_1	a_2	a_3	$\cdots$	a_m
s_1	$a_1(s_1)$	$a_2(s_1)$	$a_3(s_1)$	$\cdots$	$a_m(s_1)$
s_2	$a_1(s_2)$	$a_2(s_2)$	$a_3(s_2)$	$\cdots$	$a_m(s_2)$
s_3	$a_1(s_3)$	$a_2(s_3)$	$a_3(s_3)$	$\cdots$	$a_m(s_3)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
s_n	$a_1(s_n)$	$a_2(s_n)$	$a_3(s_n)$	$\cdots$	$a_m(s_n)$

Roy (1996) described three decision-analysis uses of the EA matrix: ranking, sorting, and choosing. Ranking is placing a finite number of elements in priority order, which is the topic of this paper; sorting is placing elements of a finite set into predefined classes, such as high, medium, or low priority; third, choosing is the process of selecting the optimal element subset from an infinite set of elements (Roy, 1996).

Multi-criteria decision analysis (MCDA) is a collection of methods that use the EA matrix to combine multi-dimensional, values-based attributes in a coherent manner to guide decision-making among a group of engaged participants (Giove et al., 2009). There are numerous MCDA methods within the environmental science and management disciplines as documented by both Huang et al. (2011) and Adem Esmail & Geneletti (2017) who provided surveys of methods used in the 2000s and 2010s. MCDA methods can be classified into techniques focusing on infinite element sets (i.e. optimal element subset selection) and techniques suited toward finite element sets (i.e. ranking and sorting). The first group of methods is described as multi-objective decision analysis (MODA) and the second coined multi-attribute decision analysis (MADA) (Giove et al., 2009; Goulart Coelho et al., 2017). MADA methods are applicable in the context of the research described in this paper and can be further partitioned into three groups: utility–value-based, outranking, and distance-based methods. For brevity, only utility–value and outranking methods are discussed further here because of their direct relevance to this paper's purpose.

2.2 Utility–Value Methods

Multi-attribute utility–value theory (MAUVT) developed by Keeney and Raiffa (1976) is a common example of the first group of MADA methods. Among MAUVT methods, element scores

[1] Part of this literature review is a condensed paraphrase from a doctoral dissertation by Thiessen (2018).

for each attribute are usually ordinal values that are contained within a consistent range across the set of all attributes, A. Then, the set of attribute scores for each element are combined with an explicitly defined aggregation function to allow the complete ordering of all elements into a total-order set (toset) (Epp, 2011). “An aggregation function is a mathematical relation that merges several numerical input values into one numerical output value that is contextually representative of the inputs…” (Thiessen, 2018). Beliakov et al. (2007) and Grabisch (2009) have compiled information on various aggregation functions with simple additive-weighting being the most common function.

The Stage I prioritization method developed by COWI (2015c) is an example of MAUVT that focuses on environmental risk and where the simple additive-weighting aggregation function shown in Equation 1 is applied:

Equation 1 Stage 1 Priority Score

$$PS = w_I I + w_L L + w_P P + w_G G + w_{SW} SW$$

PS is the Stage I Priority Score; I, L, P, G, and SW are the Industry Profile, Land Use, Population at Risk, Groundwater System at Risk, and Surface Water System at Risk attribute scores, respectively; and, w_I, w_L, w_P, w_G, and w_{SW} are the corresponding attribute weights. These weights all equal unity and the five attributes are ordinal values in the range 0–20 (COWI, 2015c).

The analytic hierarchy process (AHP) devised by Saaty (1980) is another common example of utility–value-based MADA methods. AHP’s key difference from MAUVT is that attribute weights are implicitly defined by engaged participants through the process of pairwise attribute comparisons in terms of preference when making decisions.

2.3 Outranking Methods

In contrast to the interrelationships of all elements in a toset, a partially ordered set (poset) of elements means only some elements are interrelated (e.g. one element can be ranked against another) (Epp, 2011). In the context of the EA matrix, without an attribute aggregation function, a poset cannot be transformed into a toset. Outranking methods do not require decision-makers to declare attribute weights or state attribute preferences *a priori* to determine an aggregation function; instead, these methods evaluate the degree that an element dominates over another element across attribute scores in the EA matrix (Giove et al, 2009). Elimination and Choice Expressing Reality (ELECTRE) (Roy, 1996) and Preference Ranking Organisation and Method for Enrichment Evaluation (PROMETHEE) (Brans & Vincke, 1985) are frequently cited examples of outranking methods.

Bruggemann et al. (2014) described a more recent method that implements discrete mathematics concepts associated with the Hasse diagram, a form of a directed graph (Epp, 2011), and Hasse matrix to present a poset. They also summarise the local partial order model (LPOM) approach (Bruggemann et al., 2004; Carlsen, 2008) of deriving a toset. The first author recently applied the LPOM approach (Thiessen, 2018) to combine environmental risk, financial impact, and societal response attributes in prioritizing the remediation of abandoned oil and gas well sites in Alberta, Canada. This approach is further described in the Methods below.

3. METHODS

3.1 Stage I Priority Score Calculation

Appendix H – Results of Stage I Prioritisation in the report by COWI (2015c, pp. 668–674) lists the Stage I priority scores, PS_0, for each of the 320 contaminated sites; however, the corresponding values for I, L, P, G, and SW (i.e. the attributes, a_j) in Equation 1 are not provided in the report and are not available to the authors at this time. In lieu, an attempt to regenerate the input values (i.e. attribute scores, $a_j(s_i)$) was performed using the following information sources and instructions. Equation 1 was then used to regenerate Stage I priority scores, PS_1.

The industry processes listed in Appendix J – List of Identified Sites (COWI, 2015a, pp. 131–146) were standardized according to Appendix D – Industry Profiles and Defined Risk for Source (COWI, 2015c, pp. 656–658). I-values for each site were also obtained from this appendix. When multiple industry profiles applied at a site, the largest relevant I-values were selected.

Similarly, an L-value for each site was derived by cross-referencing the land use listed in Appendix J – List of Identified Sites (COWI, 2015a) with Table 6-2 – Scores for the Receptor Land Use in Stage I (COWI, 2015c, p. 624). Population-at-risk scores, P, were determined from the site-specific population estimates in Appendix E – Summary of Findings (Typology, Analytical Results and Population at Risk) (COWI, 2015b, pp. 554–562), which then were cross-referenced with Table 6-3 – Risks and Scores for…The population at Risk at Stage I (COWI, 2015c, p. 624). Both G and SW scores were guided by the instructions and Table 6-1 – Scores Assigned to Risk Classifications in the report by COWI (2015c, pp. 623–625) as well as Appendix E – Summary of Findings (COWI, 2015b).

These input scores were combined using Equation 1 to generate a toset of PS_1-values for the 320 contaminated sites.

3.2 Outranking Approach[2]

A brief explanation of the applied outranking approach is provided herewith details available in the dissertation by Thiessen (2018).

The attribute scores were compiled into a 320-site by five-attribute EA matrix. Then, a MADA software called Decision Analysis by Ranking Techniques (DART), developed by TALETE Srl (2008) and discussed by Manganaro et al. (2008) was used to generate a Hasse diagram and matrix. This figure and table illustrate the partial ordering of the sites calculated according to the relation set in Equation 2 (Mauri & Ballabio, 2008).

Equation 2 Relation set

$$H_{s_b \perp s_c}(s_b) = \begin{Bmatrix} a_j(s_b) \geq a_j(s_c)\ \forall\, a \in A \rightarrow 1, \text{else} \\ a_j(s_b) \leq a_j(s_c)\ \forall\, a \in A \rightarrow -1, \text{else} \\ 0 \end{Bmatrix}$$

The relation of Site b compared to Site c, $H_{s_b \perp s_c}(s_b)$, is equal to 1 if all attribute scores for Site b, $a_j(s_b)$, are greater than or equal to the corresponding attribute scores for Site c, $a_j(s_c)$. This relation means Site b is a higher priority than Site c. If this condition is not true, the second statement is tested; if true, $H_{s_b \perp s_c}(s_b) = -1$ and Site b is a lower priority than Site c. If both statements are false, then $H_{s_b \perp s_c}(s_b) = 0$ and the relative priority of Site b to Site c cannot be determined. The pairwise comparisons codified in Equation 2 are analogous to alternative pairwise comparisons in the AHP (Saaty, 1980).

The LPOM approach (Bruggemann et al., 2004; Carlsen, 2008) facilitates toset generation by using the values of 1, −1, and 0 in the Hasse matrix to approximates the unbiased, average ranks of elements (e.g. contaminated sites), $Rk_{av}(s_b)$, according to the center equation in Equation 3 below. The variable n is the number of sites (i.e. 320) and $n_{\leq s_b}$ is the number of sites with lower

[2] This section is an adapted and revised excerpt from the doctoral dissertation by Thiessen (2018).

priority than Site b (i.e. the number of 1-entries in a row of the Hasse matrix). The variable $n_{\|s_b}$ is the number of sites not comparable with Site b (i.e. 0-entry in the matrix row). To quantify epistemic uncertainty, minimum and maximum site ranks were calculated according to the left and right equations (Bruggemann et al., 2004) in Equation 3.

Equation 3 Hasse minimum, average, and maximum ranks

$$Rk_{min}(s_b) = n_{\leq s_b} + 1; \quad Rk_{av}(s_b) = \frac{\left(n_{\leq s_b} + 1\right)(n+1)}{n + 1 - n_{\|s_b}}; \quad Rk_{max}(s_b) = n_{\leq s_b} + n_{\|s_b} + 1$$

3.3 Statistical Analyses

Bivariate and residuals analyses were performed to compare the Stage I priority scores, PS_0, reported by COWI (2015c) and those calculated here, PS_1. These analyses were completed to understand the degrees of correlation and variability and thus determine if the original values for I, L, P, G, and SW should be obtained. Similarly, these analyses were conducted to understand the rank correlation and variability between the Hasse average rank method and rank determined from the PS_1-values.

Also, a site ranking plot using the three equations under Equation 3 was prepared to illustrate site rank uncertainties.

4. RESULTS AND DISCUSSION

For brevity, the bivariate and residuals plots relating PS_0 and PS_1 are not provided. Nonetheless, the scores are positively correlated yet there are bias and appreciable variability. To elaborate, the mean, median, and standard deviation of the difference (i.e. $PS_1 - PS_0$) were 6, 8, and 10, respectively ($n = 320$). This biased result indicates the Stage I priority scoring performed for this research did not accurately replicate the Equation 1 inputs originally assigned to calculate the Stage I priority scores listed in the report by COWI (2015c, pp. 668–674). The original inputs used to calculate PS_0-values should be obtained and analyzed. Even so, the preliminary results that follow here are based on internally consistent scores and have merit pending receipt and analysis of the original input scores.

As intuitively expected, Fig. 1 depicts the positive correlation between the 320 sites' ranks calculated according to the center equation in Equation 3 and the ranks based on PS_1-values. Contaminated sites with larger PS_1-values generally indicate greater priority for action. The data scatter in the figure, however, infers a precise regression relationship between the two ranking approaches cannot be developed precisely. Ideally, this relationship should converge to the diagonal line in Fig. 1. Also, the data tends to be located on the right side of the diagonal line, which indicates Equation 1 conservatively estimates a site's priority for action. The residuals analysis results presented in Fig. 2 confirm this interpretation with the mean and median residuals being biased high at 14 and 12, respectively. Furthermore, a standard deviation of 33 quantifies the large variability in the residuals. This variability indicates that a small difference in PS_1-values (e.g. perhaps 1 to 3) for a pair of contaminated sites does not necessarily mean one site is indeed a higher priority than the other. Stage I priority scores are not precise estimators, which is understandable since Stage I prioritization relies on sparse information.

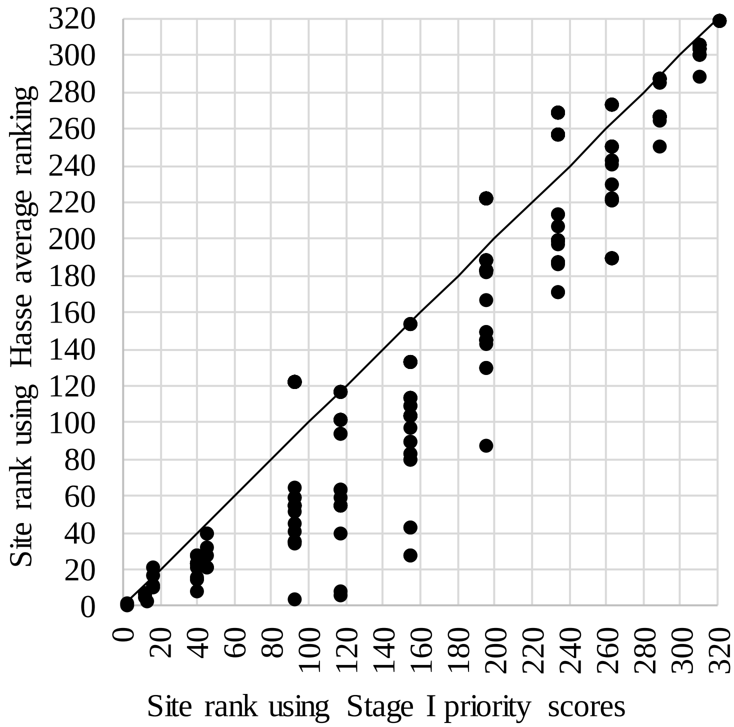

Fig. 1 Hasse average ranks v. Stage I priority score ranks

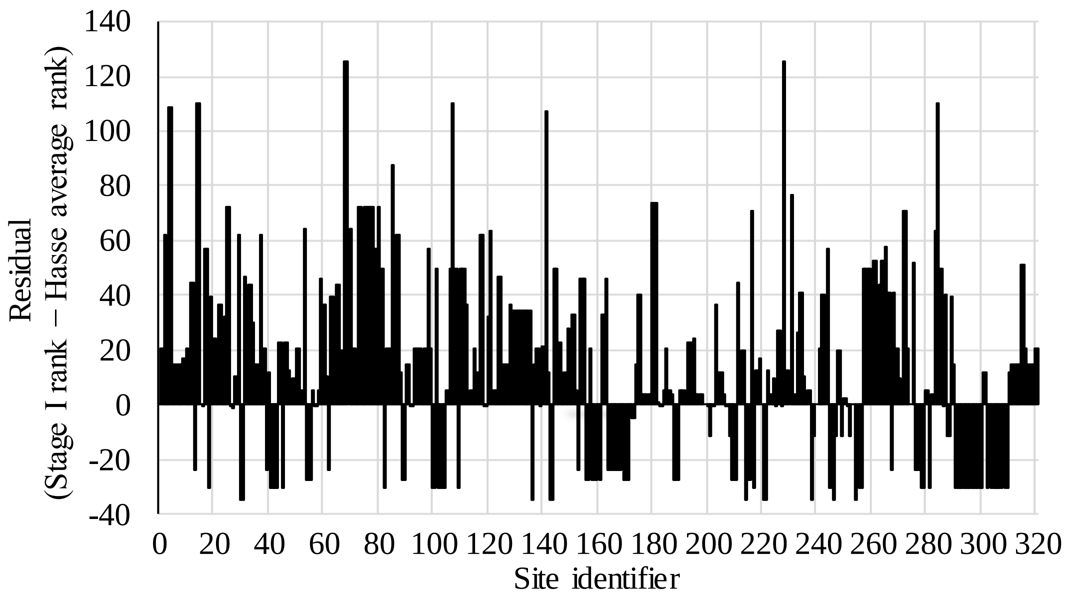

Fig. 2 Rank residuals v. site

Quantifying any prioritization method's imprecision and epistemic uncertainty provides context to decision-makers. Fig. 3 summarises the results of ranking the 320 sites according to the Hasse minimum, average, and maximum rank approaches described under Equation 3. Sites were rank-ordered using the Hasse average ranking equation; the result is the interface between the dark gray and light gray bands in the figure. The vertical thickness of these bands illustrates the inherent uncertainties when prioritization and reinforces the principle of not ascribing precision to numerical information beyond what exists.

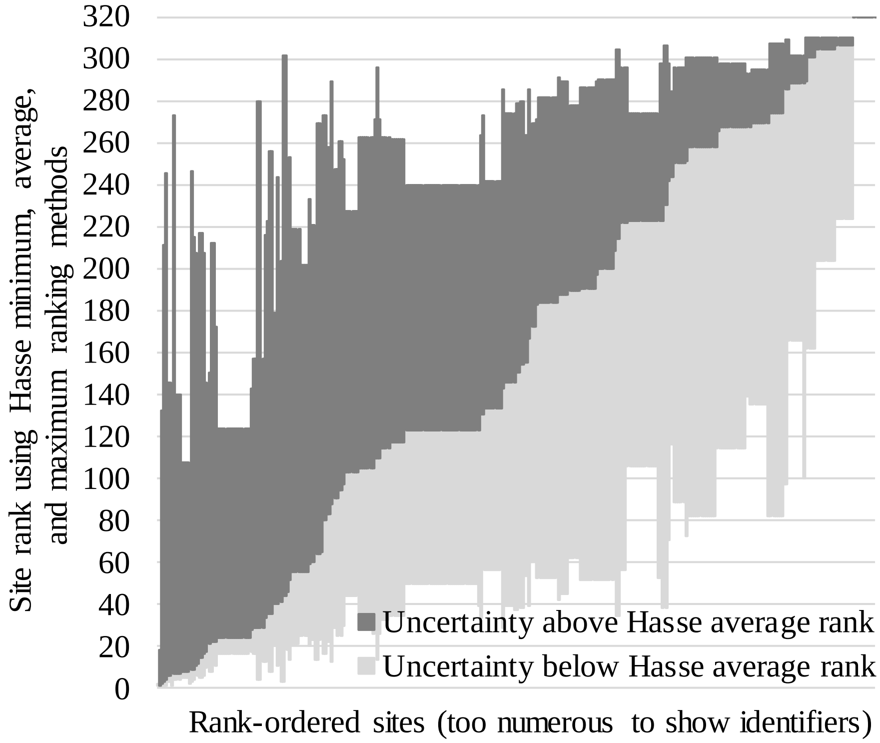

Fig. 3 Ranking uncertainty

5. CONCLUSIONS AND RECOMMENDATIONS

Returning to the purpose of this paper, the Stage I prioritization method (COWI, 2015c) yields a reasonable rank ordering of contaminated sites as evidenced by the positive correlation with the Hasse average rank method. Overall, the Stage I prioritization method also tends to conservatively estimate site priorities (i.e. biased high) compared to the Hasse average rank method. However, there are enough epistemic uncertainty in Stage I priority scores to motivate caution when estimating the relative priority of two contaminated sites. This uncertainty is not unique to the Stage I priority scores because the Hasse average rank method also exhibits uncertainties as illustrated in this paper. Therefore, prioritization schemes should be used as only one of several lines of evidence in decision making.

As noted previously, the presented preliminary finding in this paper should be confirmed by obtaining and analyzing the input scores used to calculate the Stage I priority scores presented by COWI (2015c).

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Safe Concentration Limit of Heavy Metals in Soil and Compost: Approaches in their Determination

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EXTENDED ABSTRACT

Although heavy metals are naturally present in the soils, their excessive concentrations can migrate and affect living organisms due to their toxicity to metabolism. Therefore, knowledge on maximum safe concentration limits of heavy metals for soil is important for decision making on the use of contaminated amendments in agriculture. Due to wide variations in physical and chemical properties of soils in a country like India, their sink capacity for heavy metals varies widely making the determination process for safe concentration limits much complex. Many developed countries have adopted maximum safe concentration limits in agricultural land which regulate the addition of contaminated amendments like a municipal solid waste (MSW) compost and sewage sludge compost. Such regulatory limits are absent in India.

Maximum safe concentration limits for heavy metals adopted by different countries are not uniform, but vary widely, due to different approaches adopted for their determination. Three basic approaches can be outlined for formulating limits to metal additions in soil: (1) Analysis of pathways of metal transfers; (2) limits based on effects on soil microorganisms; and (3) metal balance approach. In the first approach, United States identified 13 metal transfer pathways along with high exposure scenario for each pathway, wherein maximum annual loading for each metal has been determined based on 'highest no observed adverse effect concentration (HNOAEC)'. However, this approach of computations lacks several deficiencies like absence of sufficient technical data needed to determine pollutant transfer co-efficient, hypothetical exposure scenario for the affected organisms in each pathway, relative variations on the sensitivity among organisms in a particular pathway and lack of sufficient understanding to model accurately for all transport and ecological processes. The Netherlands have determined metal limit concentrations (C- values) above which there is a serious risk of reduction in functional properties which the soil has for man, animal and plants. These had been determined based on the integration of eco-toxicological and human toxicological metal threshold values. In UK, limits were set with the aim of protecting human and animal health and crop yields. However, researchers argued that limits for heavy metals concentrations in soil should be reduced to protect agriculturally important soil microbial processes like N_2 fixation (McGrath et al. 1994). Evidences have been recorded through long-term field experiment on large scale destruction *Rhizobium* population in treatments with high rate of metals addition through sludge, indicating current limits of UK fails to protect this important soil microorganism (Chaudri et al. 1993). Some EU countries like the Netherlands, Sweden and Denmark adopted most conservative approach (metal balance) for determination of metal limits in soil with the aim to prevent any accumulation of possibly hazardous elements in soil after considering their losses through crop removal, leaching and erosion. As a result, heavy metals concentration limits in soil adopted by these countries are lowest and most stringent. Due to different approaches adopted by different countries in Europe and USA, wide variations in maximum allowable heavy metals concentrations in soils can be observed. The set limits with respect to maximum permitted concentrations in sewage sludge or compost treated agricultural

soils varied from 100 to 1400 mg Zn kg^{-1}, 36 to 750 mg Cu kg^{-1}, 0.5 to 20 mg Cd kg^{-1}, 40 to 300 mg Pb kg^{-1}, 15 to 210 mg Ni kg^{-1} and from 30 to 1500 mg Cr kg^{-1} (Düring and Gäth, 2002).

So far, India has not adopted ‘maximum allowable/permissible heavy metal concentration limits’ in the soil for the purpose of preventing entry of these pollutants in agricultural land through contaminated amendments like sewage-sludge, MSW composts, etc. Neither, any comprehensive research study has been carried out in this direction. In a study under controlled condition, Saha et al. (2013) attempted to determine maximum safe concentration limits of heavy metals through mixed approach in soils receiving contaminated MSW compost under highly sensitive agro-ecosystem scenario (growing plant with higher metal uptake capability on a soil type having low metal fixing capacity). Maximum protective concentration limits of these metals in soil were determined by toxicity assessment caused by metal transfer from soil to plant and soil microorganisms. Although toxicity to humans through contaminated food consumption was not directly measured, the indirect approach of not allowing contamination beyond natural occurrence level was followed (Saha et al. 2010). As the lowest among the maximum concentration limits determined through above three different approaches can protect all the targeted organisms, the determined values 392 mg Zn kg^{-1}, 179 mg Cu kg^{-1}, 0.33 mg Cd kg^{-1}, 81 mg Pb kg^{-1}, 30.7 mg Ni $kg^{-1,}$ and 31 mg Cr kg^{-1} were considered as maximum safe concentration limits in soil. The adverse effect of heavy metals on microbial activity and contamination of the food chain occurred much earlier than the adverse effect on plant growth. Cadmium was found to contaminate spinach leaf at a much lower level than the levels affecting either soil microorganisms and plant growth. Even though this approach of determination of heavy metal limits may not be realistic under actual field conditions due to widely varying soil and crop types in India, these can be used for restricting metals entry through MSW compost, being highly protective. However, further comprehensive research is required across the country through network programs in this direction to relax these highly protective limits so that contaminated organic city wastes can be beneficially used in agriculture to a maximum extent while protecting soil fertility and the environment.

Keywords: Heavy metals; soil; crop; safe concentration limits.

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Bio-Strategies for Assessment and Remediation of Sites Contaminated with Recalcitrant Compounds

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ABSTRACT

Many persistent organic pollutants (POPs) are continuously being used and their residues reported in different compartments of the environment. These compounds include pesticides, insecticides, polychlorobiphenyls, polyaromatic hydrocarbons, monocyclic and nitroaromatic compounds, textile dyes and inorganic metals. As they persist in the environment for longer durations, they bioaccumulate and impart toxicity. Most of these compounds are neurotoxic, endocrine disruptors and also well-known carcinogens. The major aim of our study was to identify the potential bacteria, elucidate the degradation pathway, biochemical and genetic events and field efficacy studies for large scale bioremediation. Therefore, in this direction, biodegradation of gamma-hexachlorocyclohexane (γ-HCH, Gammexane, Lindane), DDT and endosulfan were investigated in details, which were extensively used pesticides. Additionally, a large number of bacteria were characterized which are enriched in such hazardous ecosystems. Similarly, polycyclic aromatic hydrocarbons (PAHs) biodegradation were also investigated as they are priority pollutants listed by the Environment Protection Agency (US-EPA).

Sustainable bioremediation requires inputs from microbiological, biochemical and genetics, and laboratory-scale feasibility studies. Therefore, the diverse bacteria isolated were subjected to these investigations in our laboratory. Lindane degradation genes were characterized from a *Sphingomonas* sp NM05 and the gene coding for haloalkane dehlaogenease (linB) has been cloned and expressed as it has a wide range of substrate activity on various chlorinated compounds. Additionally, the effect of biosurfactants such as rhamnolipid and sophorolipid was found to increase the solubilization of HCH isomers by 3–9 folds. HCH-spiked soil slurry incubated with surfactant also showed around 30–50% enhanced degradation of HCH. In this report, the progress made on biodegradation of two different classes of compounds such as pesticides and PAHs will be discussed as an option for a sustainable ecosystem preventing hazard to human and environmental health.

Keywords: Persistent Pollutants; Microbial Diversity; Bioremediation

1. INTRODUCTION

Huge amounts of persistent organic pollutants, including organochlorine pesticides (OCPs) and polychlorinated biphenyls, were used extensively in the developing countries for industry, agriculture and health care for vector control programs. The last five decades, which are known as 'legacy of pesticides', has led to the contamination of water, sediments, air, land and food products. Distribution of endosulfan hexachlorocyclohexane (HCH) and DDT (1,1,1-trichloro-2,2-bis (4-chlorophenyl) ethane were also recorded along the Indian coasts and in the water samples of Delhi showing higher levels when compared to European economic commission (EEC) norms. Dumping sites of several Asian countries had extremely higher levels of DDT, HCHs, and PCB (polychlorinated biphenyl). Many tropical countries having higher levels of these residues may act as a global sink and lead to more contamination by volatilization into the atmosphere. These residue levels were hundreds to thousands of times higher than those in general soils implying possible risk to the human health of the local communities.

Similarly, owing to a large number of oil drilling activities undertaken by Oil and Natural Gas Corporation (ONGC) is well spread many parts of the country, contributing around 75 percent to Indian domestic production. Crude oil is the raw material used by downstream companies like IOC, BPCL, and HPCL (a subsidiary of ONGC) to produce petroleum products like Petrol, Diesel, Kerosene, Naphtha, and Cooking Gas-LPG. On the debit side, huge quantities of sludge containing toxic compounds are being continuously generated. Among these organic compounds such as polycyclic aromatic hydrocarbons (PAHs) find a way to the environment and are considered as ubiquitous pollutants having mutagenic and carcinogenic potential. These are highly persistent in the environment and are extremely toxic to human and thus the United States- Environmental Protection Agency (US-EPA) listed 16 PAHs as priority pollutants. The environmental fate of PAHs is associated with both abiotic and biotic factors including bio-accumulation, volatilization, chemical oxidation, photo-oxidation, and biotransformation. PAHs are persistent due to their hydrophobicity and ability to absorb into the soil particulates resulting in decreased bioavailability and biodegradation or bioremediation.

2. Biodegradation of persistent pollutants: Pesticides and polyaromatic hydrocarbons

Gamma-hexachlorocyclohexane (γ-HCH, Gammexane, Lindane) a chlorinated pesticide has been widely used for crop protection and prevention of vector-borne diseases for over decades. During its production, four major isomers are formed in the proportion of α-HCH (70%), β-HCH (8%), γ-HCH (13%), and δ-HCH (9%), but only gamma isomer has the insecticidal property. These isomers are highly hydrophobic, persistent, and ubiquitously distributed in the environment and by their lipophilic properties, they accumulate in the food chain and lead to toxicity. Current practices to detoxify organochlorine pesticides rely on chemical treatment, incineration, and landfills. A *Sphingomonas* sp. NM05 was isolated and characterized for its ability to biodegrade all the four isomers of HCH. The strain NM05 utilized around 90% of α-,γ- and d-HCH, and around 60% of the beta-HCH when exposed to individual isomers 0.34 mol (100µg/ml). Degradation intermediates were less chlorinated and complete mineralization of HCH isomers was achieved by employing the bacterium. Similarly, a *Chromobacterium* (chloroalkanes), and *Pseudomonas* (Endosulfan) were also studied in detail for their degradation efficiency. These cocktails of organism are available for remediation of chlorinated toxicants in field conditions.

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous pollutants having mutagenic and carcinogenic potential. These are highly persistent in the environment and are extremely toxic to human and thus the United States-Environmental Protection Agency (US-EPA) listed 16 PAHs as priority pollutants. In India, more than 10 major industries are involved in oil drilling activities and a large number of crude oil-contaminated coastal sites and many inlands at refineries are waiting to be remediated. At IITR, a bacterial consortium was developed to degrade phenanthrene, pyrene, fluoranthene, benzo(a)pyrene and phthalate both when they are present individually or as in crude oil sludge. Two different crude oils namely Assam Crude Oil and Bombay High Crude Oil have been studied for the removal of PAHs in these under laboratory conditions. Metabolites of degradation pathway, genes, and enzymes involved in pyrene and phthalate degradation were also identified.

Biosurfactants comprise a group of diverse amphipathic molecules with distinct chemical structures produced by several microorganisms. Bioremediation processes are severely affected by low aqueous solubility of the persistent pollutants; therefore, their bioavailability may be enhanced by the addition of surfactants. These compounds are organic molecules that can be chemically and biologically produced. Biosurfactants are a promising help in soils washing for the desorption of soil-bound chemicals and also to increase solubility.

Therefore, we have screened 6 different bacteria having the ability to produce biosurfactants. Application of the biosurfactant produced by a *Lysinibacterium species* has resulted in enhanced solubilization of HCH, Endosulfan, and PAHs. Also increased bioremediation of contaminated soils is shown. In general, this overview indicates the great potential of biosurfactants on the remediation of contaminated sites.

3. FIELD BIOREMEDIATION

Field demonstrations for the feasibility of bioremediation have also been undertaken by us. There are several sites contaminated with organic pollutants are available in India, such as Union Carbide India Ltd., (UCIL), Bhopal, Udyogmandal Region, Eloor, Kerala, Yawalkar Pesticide Ltd., Nagpur. Besides these, the Central Pollution Control Board (CPCB) has identified 136 severely contaminated hazardous sites. Among these, the priority sites are polluted with Mercury in Ganjam, Odisha, Chromium in Orichem, Talcher, Odisha, Chromium in Rania, Kanpur Dehat, UP, Pesticide in Deva Road, Lucknow, UP, Chromium in Ranipet, Tamil Nadu, Acid Ratlam, Madhya Pradesh, Chromium Nibra Village, Howrah,

Treatment and restoration of each site need a separate strategy which may include the geochemistry, load and type of pollutant, organic content, and moisture, etc., Usually, site decontamination is expensive and time-consuming. From acquiring the site, the field remediation process needs sufficient rigor and achieves useful results.

Recently, two sites contaminated with 1. Chlorinated Pesticide-HCH Muck and 2. Crude oil sludge was chosen for their bioremediation. At Ummari village, near Lucknow, 5-acre land having the dump is being treated with an HCH-degradative bacterium. Similarly, a consortium of bacteria is being employed for PAHs degradation in crude oil sludge. For the process facilitation, biosurfactants isolated characterized by several bacteria will be used in the field. The progress made and strategies being followed will be shared during the presentation.

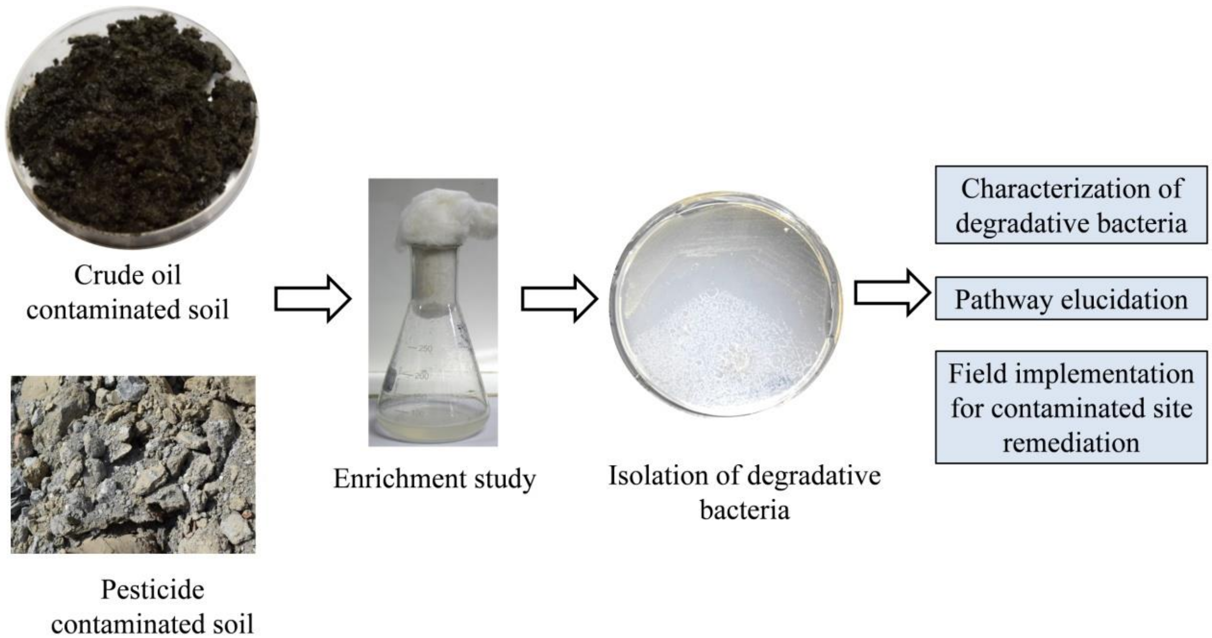

Fig. 1 Schematic diagram representing isolation of degradative bacteria and key steps involved towards field studies.

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Integrated Geophysical Investigations at a Tailings Pond

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ABSTRACT
In a mining area, filling of slime was commenced in one of the deepest pits. Initially, it was noticed that some of the water was seeping from the bed of mine pit. After almost a year a major sinkhole/crater got created in the western part corner of the pit and a vast amount of slime (about 60000 to 70000 m^3) went underground. The oozing or coming out from the surface was not noticed anywhere in the surrounding area. This phenomenon, therefore, mandated an investigation to understand as to where the huge amount of water and slime had gone or where it had accumulated inside the subsurface.

The geophysical investigations comprising of hydrogeological study, Induced Polarization and Earth Resistivity Tomography (ERT) were conducted which successfully achieved the objectives and provided an in-depth understanding of the phenomenon. Present paper details the findings of integrated geophysical investigations at a tailing pond.

Keywords: Geophysics at tailing pond; tailing pond investigations

1. INTRODUCTION

Waste generated in the mining process is a necessary evil. Typically waste generated in mining is due to unusable ore, sludge generated post-mineral processing and subsequent processes. Traditionally, this large volume of waste is stored in tailing dams.

In a mining area, filling of slime was commenced in one of the deepest pits. Initially, it was noticed that some of the water was seeping from the bed of mine pit. After almost a year a major sinkhole/crater got created in the western part corner of the pit and a vast amount of slime (about 60000 to 70000 m^3) went underground. The oozing or coming out from the surface was not noticed anywhere in the surrounding area. This phenomenon, therefore, mandated an investigation to understand as to where the huge amount of water and slime had gone or where it had accumulated inside the subsurface.

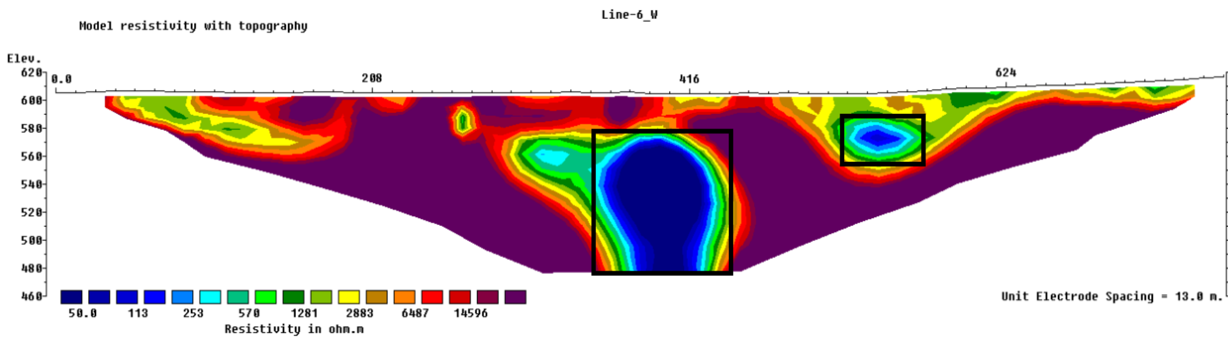
The scope of work involved conducting geophysical investigations for determination of subsurface conditions in the area surrounding the slime pond where a crater had been formed and a substantial amount of material had entered the subsurface. The scope also included hydrogeological investigations to gain an insight into prevailing hydrogeological conditions, which would be needed for the interpretation of geophysical data.

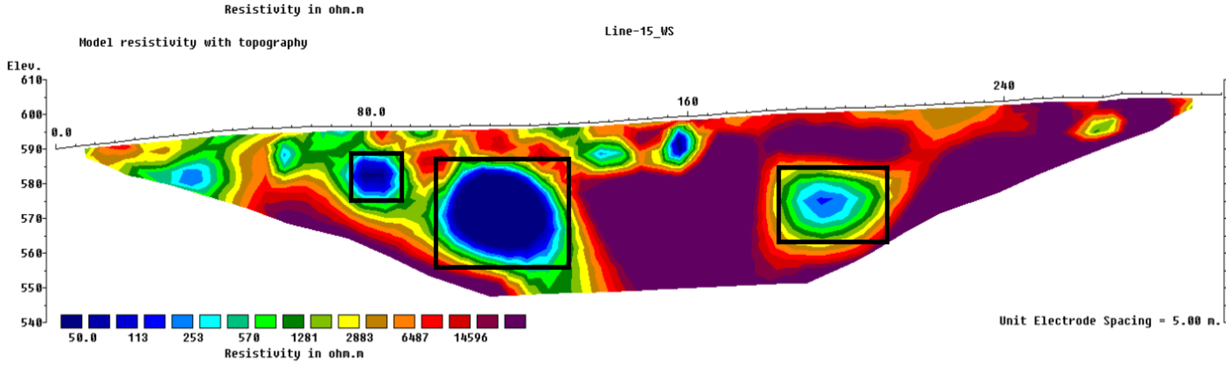
2. METHODS DEPLOYED

Electrical Resistivity Imaging and Induced Polarization surveys were conducted surrounding the in-pit slime dam area of the mine. In general, the electrical resistivity of rock is high, whereas that of soils is lower and for saturated zones, it is lowest.

3. RESULTS

Based on investigation results. various weak and saturated zones were interpreted in and around the slime dam, which was then marked in various sections. A good correlation between geophysical anomaly and geological features was observed. The significant observation of results indicates the occurrence of saturated zones at over many ERT profiles located in the northwestern part of the area. An inference can be drawn that these zones may have provided the seepage path to slime and water from the in-pit slime dam or seeped slime and water may have accumulated in these zones. Typical zones observed are presented in figures hereunder:





4. 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. Application of geophysical techniques for monitoring water storage dams in an accepted practice and the same can be applied as a health monitoring tool and safe management of tailing dams and tailing ponds. The onset of problems like structural deterioration of embankment, seepage and foundation failure can be very effectively detected by judicious and timely investigation of these structures by geophysical techniques.

Entailing Transformation in Sanitation Facilities using DRDO Bio toilet, an Eco-friendly and Appropriate Sanitation Solution

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EXTENDED ABSTRACT

Attaining quality of life through a sustainable level of resource use and providing a good life to meet basic needs for over 7 billion people residing in states of defined boundaries is a unique challenge humanity is facing today. There are few environmental components that drive the development of the human race, and among them, water (and sanitation) is one of the most significant ones. The availability of quality natural water resources has always contributed to the settlement and expansion of any society. Both Millennium Development Goals (MDGs: 2000-2015) followed by Sustainable Development Goals (SDGs: 2015-2030) having the most direct international agenda ever, associated with environmental sustainability and related safe disposal and use of wastewater and excreta to maximize environmental benefits and betterment of public health and sanitation problem. Several international institutions have stressed upon the serious situation of sanitation which is clearly linked up with the health of the environment in spreading contamination. More than 80 percent of the wastewater generated from anthropogenic activities (like the dumping of human wastes and excreta etc.) is directly released into the environment, polluting both surface and groundwater sources (including ponds, tube wells, boreholes, springs, dug wells, etc.). The consequences of waterborne diseases are far-reaching and related morbidity directly affects the country's GDP. Diarrheal diseases alone contribute to 13% of deaths in under-five children. More than two billion people globally are living in areas having enormous water shortages. The condition of water availability in India is grim. According to the recent report released by the Niti-Aayog (https://niti.gov.in/sites/default/files/2019-08/CWMI-2.0-latest.pdf), 21 major cities of this country (including Delhi, Chennai, Bengaluru, Hyderabad) are going to have zero groundwater levels by 2020. As the population increases, demand for the water enhanced automatically. However, minimizing wastewater loss and potential reuse require sustainable technology especially for low-income countries.

Problems with sanitation issues have multiple facets to deal with. Fecal sludge management using pit latrines or septic tank systems involves five basic steps: capture, storage, transport, treatment, and reuse. Although commonly used, several reports suggest the problem with these service-intensive technologies with respect to sludge contamination, cleaning, transportation, and treatment. In India, being groundwater level is very high, especially in the rainy season and occasional flood proneness, general pit-based disposal (including soak pit after septic tank) process is not scientific. Apart from the plains, the complexity of sanitation services is much larger in hilly terrains due to the complexity of topography, approachability and low temperature. Appropriate and affordable, indigenous technology development and implementation are, therefore, the need of the hour.

Flush toilet system is a commonly used toilet throughout the world, especially in India. It requires water to flush the squat pan for cleaning the area to make it hygienic and to dispose of the fecal matter into the accretion site (or vessel) through the pipe. A water shield (e.g. P-trap) in-between helps to keep the toilet area more cleanly by keeping away foul smell and other objects like flies etc. Although this water shield is very important, however, a considerable amount of

water (6-8 L) is required for proper flushing. Therefore, as per the existing extent, the development of user-friendly technology that can reduce both the water loss (through flushing) and sludge generation (frequent septage cleaning) is the need of the hour.

DRDO-Bio toilet technology developed by this laboratory involves anaerobic biodegradation of human fecal matter in a specially designed anaerobic tank (bio tank). A highly efficient bacterial consortium digests human feces into biogas, carbon dioxide, and effluent water. Effluent water from the tank is secondarily treated using a natural Reed bed that cleans the leftover smell, BOD, COD, suspended solids, fecal coliforms and other pathogens and color of effluent water which then may be reused for flushing, gardening, etc. Detailed lab-based studies on the functionality of the system revealed it as a potential technology that can be implemented in different climates and conditions. Advantages of this technology involves: decentralized system (as per requirement of user: customizable for individual to community), simplicity with design and construction, economically adaptable, minimum maintenance, wide application, minimizes water consumption and/or loss by reusing of water, load reduction on STPs (if water is drained), potential for harnessing biogas as an alternative energy source. Thus, the technology may be an appropriate, affordable sanitation solution for different climates and conditions by reducing widespread contamination to our water resources.

Keywords: Sanitation; Metagenome; Reed bed

Investigations at a Fuel Oil-Contaminated Land for Source Identification

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ABSTRACT
Leakage of petroleum fuel from underground storage tanks and consequent contamination of soil and groundwater is a common pollution issue reported from places throughout the world. The contamination of open drinking water wells with diesel fuel was investigated at a place in Kerala with the aim of fixing the responsibility of pollution. Investigations adopting scientific principles could identify the actual polluter from two suspected polluters.

Keywords: Fuel oil contamination; groundwater flow; environmental forensics

1. INTRODUCTION

Leaking underground fuel storage tanks has caused contamination of soil and groundwater all around the world (Kuppusamy et.al., 2020, Rice et.al., 1995, Dowd, 1984). Environmental forensic tools are adopted for establishing responsibility in such cases (Lynch., 2019, Khan et. al.,2019, Zee 2019, Morrison, 2000, Sementelli & Simons, 1997). In this case study, investigations were carried out at a place where the open wells used as the source of drinking water were contaminated with diesel oil from a retail outlet. There were two possible sources for the discharge- two retail outlets serving the area. Systematic investigations were carried out to identify the real polluter.

2. THE CASE

In the first week of March 2019, a group of residents living approximately North and North-West of a retail petroleum outlet in Kerala approached the dealer of the outlet with the complaint that their wells are contaminated by the fuel leaked from the retail outlet. The dealer refused to accept their claim. The residents approached public health officials with the complaint. At the behest of the public health officials, a leak testing of the diesel storage tanks and diesel pipelines at the outlet was carried out. As the tests did not reveal any possibility of leakage from the facility, they continued with the sale of fuels.

Meanwhile, the residents approached the District Collector for redress. The District collector asked the dealer to dewater the seven contaminated wells under the supervision of the Kerala State Pollution Control Board (KSPCB) officials. Large quantities of fuels, in some cases as high as 1300 liters, were collected from the contaminated wells. The residents demanded to excavate the tank storage pits to identify possible leakage. The two diesel tanks were exhumed in the first week of April. Leak testing of these tanks was carried out in the presence of public and KSPCB officials. The tanks withstood the pressure that it was expected to withstand. Though the pipelines carrying diesel showed some pressure drop, it was not sufficient to explain the quantity of fuel collected from the contaminated wells. As the testing of diesel tanks did not lead to any conclusion regarding the source of fuel in the wells, the other remaining tanks (Two of petrol and the third of high-speed diesel which was not in use) were also exhumed. These tanks also did not show any signs of leakage, but one of the pits that housed a petrol storage tank had fuel remains

in the soil. Faced with the lack of evidence to provide a convincing explanation for the observation of the fuel in the neighboring wells, the company approached NIT Calicut.
A few meters away from the outlet that was primarily suspected to be a source of discharge, there was one more retail outlet. So, the investigations were with two major objectives

(i) To identify which one among the two outlets is the actual polluter
(ii) If the primary suspect is the actual polluter, how the pollution happened when all their tanks and pipelines passed the leak test.

3. THE INVESTIGATION

3.1 Information collected from field

A reconnaissance of the area was carried out. It was ensured that there were no possible sources other than the two outlets that could have contributed diesel in the groundwater. The following information was collected from the field

(i) Location details of retail outlets
(ii) Location and depth details of all the contaminated wells
(iii) Narratives from the well owners on the chronology of events
(iv) Narrative from retail outlet operator
(v) Narrative history of the site from local people, including information on possible terrain modifications that had happened in the past many years

3.2 Analysis of the collected information

The contour map of the investigated area is shown in Figure 1. A terrain model of the area was also prepared, which is shown in Figure 2. In the Figures, S1 is the outlet that is the primary suspect and S2 is the other outlet serving the area. The following important points may be noted from the topography of the area:

(i) The general slope of the terrain is from S1 (the primary suspect) towards the wells. Normally, the groundwater flow also follows the terrain slope unless there are specific interferences that are capable of changing the direction of flow (e.g., a community well with very high discharge) or the terrain slope got modified significantly due to human interferences. In this case, the groundwater flow in all possibility is in the direction of terrain slope, i.e., from S1 transports towards the wells
(ii) Following the same logic as above, the direction of groundwater flow at the S_2 outlet is towards South-East. Hence, even if there is a leak in any of the tanks of that outlet, the wells on the south-east side of it only will be getting affected.

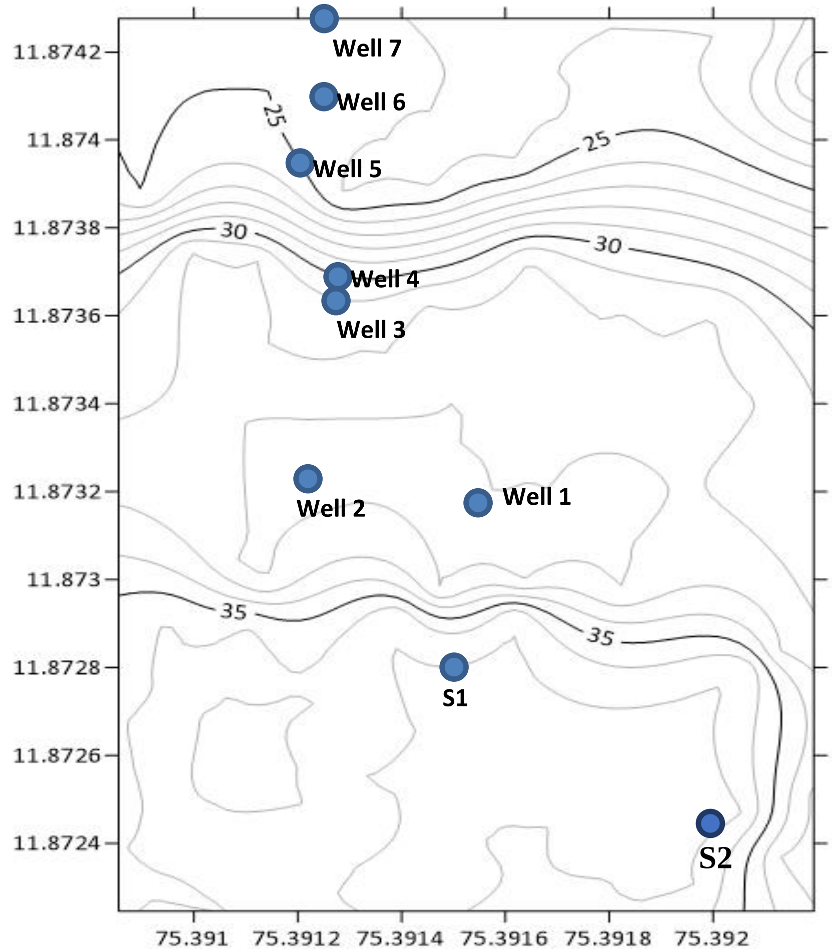

Fig. 1 Contour of the investigated area

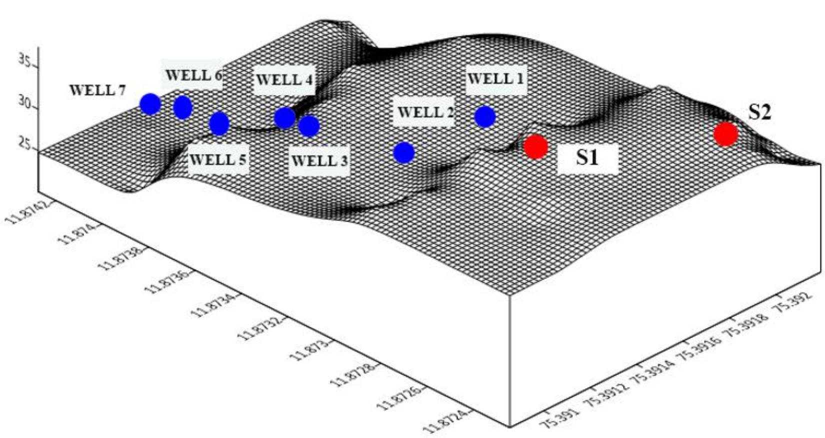

Fig. 2 Terrain model showing the location of contaminated wells and possible sources

Laterite formations were found to be underlying the area connecting the outlet and the wells. This observation has the following implications:

(i) Connected pores, capable of conducting water at high speed can get formed in laterite formations. These connected pores act like submerged pipes and carry a large quantity of groundwater or any other liquid that enters the formation.
(ii) In the instant case, based on the narratives by the well owners, it is clear that a large quantity of fuel has flowed through the groundwater system within a short period of time. This is possible as the flow is through the laterite formations

The outcome of the leak testing of the tanks and pipelines at the outlet may be summarized as follows:

(i) No tanks showed signs of leakage.
(ii) The small holes noticed in the excavated pipelines were also not sufficient to explain the large quantity of fuel noticed in the wells. Moreover, the pits from where the pipes were excavated did not show any signs of fuel leakage from pipelines.
(iii) Had the source of the fuel in the wells been leakage of underground storage tanks or pipelines, the contamination would have started at a lower rate and then intensified over time. Normally, leaks due to corrosion start in small quantities and as time progresses, increase in volume. In the instant case, within a month of noticing it for the first time in the wells, the volume of fuel reached as high as 1300 liters in one of the wells, and comparable quantities in other wells. Considering the fact that dewatering was undertaken after one month of noticing contamination for the first time, it may also be argued that the whole flow occurred in a still smaller span of time. Thus, the source of fuel in the well appears to be a one-time discharge of fuel into the groundwater rather than long term discharge characteristic of leakage due to corrosion

4. CONCLUSIONS

The conclusions were based on the field observations and uncontested information collected from various stakeholders during the visit. The conclusions made from the analysis of information collected from the field are given below.

(i) The fuel observed in the wells is sourced from S1, the primary suspect
(ii) The fuel was discharged into the soil over a short span of time; even the possibility of a one- time discharge in large quantity cannot be ruled out
(iii) The discharge appears to be due to personal error, rather than any mechanical or instrument failure
(iv) Possibility of corrosion-induced leakage from the outlet as the reason of contamination can be ruled out

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Sewage contamination of groundwater - Fixing responsibility

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ABSTRACT
When the pollution event is characterized by pollutants which can have multiple sources, responsibility allocation becomes challenging. In a place like Kerala, India, where a majority of the households depend on open wells dug into unconfined aquifers for domestic water requirements, and onsite wastewater treatment and disposal systems like septic tanks and soak pits for sewage treatment, the vulnerability of the population to waterborne diseases is significant. In the current study, an environmental forensic investigation was carried out at a place where contamination of open wells due to the septic tank effluent from an apartment complex was alleged. The apartment happened to be a place where patients undergoing treatment for a specific disease were staying. The presence of the drug traces and metabolites or other such unique chemicals in water samples was adopted as the pollution signature for investigation. Analyses were carried out using GC-MS and HPLC. The pollution signature adopted was found to be very effective in identifying the source of pollution.

Keywords: Dug well; Septic tanks; Pollution signature

1. INTRODUCTION

Septic tank is a widely accepted on-site sewage treatment method in the southern Indian state of Kerala. The simplicity and cost-effectiveness of the method as well as the absence of centralized sewage collection and treatment facility are the reasons behind its popularity. The treated effluent from the septic tanks is discharged into soil absorption systems like the soak-pits and dispersion trenches. Range of coliforms in the septic tank varies with design and characteristics of wastewater reaching into it. Studies by Centre for Science and Environment and Ministry of Urban Development reported fecal coliforms of the order105 cfu/100ml in septic tanks (Luthra et al., 2017) The efficiency of a septic tank for the removal of microorganisms is in the range 35%-56% only (SWEEP Enviro, 2015). Thus, fecal coliform levels of the order 104-105 cfu/100ml can be expected in the septic tank effluent. Because of this, many regulations specify a minimum distance between the soil absorption system that receives the septic tank effluent and the dug-wells that are used as a source of freshwater. The Kerala Building Rule, 2015 specify only 7.5 m between the soak-pit and the well. Clearly, this distance is not sufficient to ensure the removal of fecal microorganisms to a level that is protective of human health. Studies show that Kerala is having the highest number of household latrines in India (Harikumar and Madhava, 2013). The reliance of the State on groundwater sources for meeting its water requirement is as high as 80% (Ministry of Water Resources River Development and Ganga Rejuvenation Central Ground Water Board, 2015). According to a report by the Groundwater Department of Kerala, published in 2013, the open groundwater well density in Kerala is one of the highest in India with 200 wells per sq. km in the coastal region, 150 wells per sq. km in the midland and 70 wells per sq. km in the high land (Joy et al., 2013).

2. THE CASE

The present study is based on the investigations carried out at a site where the groundwater wells are allegedly contaminated by the septic tank effluent from an apartment building. The obvious choice of signature pollutant to investigate the issue is fecal coliforms. But, adopting fecal coliforms as the signature pollutant, in this case, will not lead to useful conclusions. This is because, all the well owners have septic tank-soak pit system within their premises capable of contributing the same signature pollutants, that is, *E. coli*. Moreover, in almost all cases, the well owners' soak-pits are closer to their well than the apartment's. Thus, identifying another suitable pollution signature becomes critical to the success of the investigation. This study reports the procedure adopted for investigating the case, thus highlighting the importance of selecting suitable site-specific pollution signature(s) for successful environmental forensic investigations.

3. THE INVESTIGATION

Investigations revealed that, in this specific case, the apartment complex is inhabited mostly by patients who are undergoing treatment in the nearby hospitals, to whom it is rented out. This opened up another possibility in selecting pollution signature. It is a well-documented fact that on the consumption of any pharmaceutical compounds, incomplete assimilation of drugs occurs in the body and 10-90% of the drugs are excreted in their parental or metabolized form after their administration (Kemper, 2008), (Kümmerer, 2009), (Ronco et al., 2019). Thus, presence of pharmaceuticals or its metabolites in the septage of the apartment complex, and the presence of the same in the wells of adjacent plot owners would be a confirmation of the septage from apartment complex reaching the wells.

3.1 Sampling and Analysis

Samples were collected from the sewage treatment plant (STP) receiving the wastewater from the apartment complex. Apart from STP, samples from 11 drinking water wells that the owners suspect as being contaminated by the effluent of the apartment complex were also collected. Also, one background sample is collected from some distance that does not fall within the influence of the Apartment discharge.

The apartment STP samples were analysed in GC-MS for identifying the compounds present. GC-MS analysis showed the presence of more than 50 compounds which was a mixture of various pharmaceuticals, personal care products, food processing products and many other organic compounds. Identification of signature compounds was done by trial and error method. Initially, the highest peak area chromatograms of pharmaceutical compounds were identified and selected. HPLC methods were optimized to detect these compounds if present in the well water. Secondly, the next higher peak area chromatograms were chosen. After that, irrespective of the peak area, compounds identified as having medicinal properties in the analysis were chosen and their methods for detection in LC were optimized to test their presence in well water samples.

The GC-MS analysis conducted on the samples collected from the sewage treatment facility of the apartment meant for the accommodation of the patients showed the presence of many drug residues in the samples. The same residues were detected in the wells when analyzed using HPLC, which concluded that the discharge from the apartment is contaminating the wells of nearby residents.

4. CONCLUSIONS

One of the most critical steps in environmental forensic investigation is identifying the pollution signature that is characteristic of the case under investigation. There could be very common signatures that give very reliable results; like fecal coliforms indicating discharge from facilities treating sewage. But, unless the signature is unique, the polluter will very easily escape from his liabilities taking the help of an efficient advocate. Thus, it is essential to have a unique signature, which is often site-specific. This study showed that compounds that are ingredients of medicines routinely used by patients can be a possible signature to investigate sewage pollution.

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Case Studies of *in-situ* Remediation of LNAPL and Heavy Metal (As) Polluted Shallow Groundwater Sites

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ABSTRACT
Contamination of soil and water due to the presence of light non-aqueous phase liquids (LNAPLs) and heavy metals is a ubiquitous problem. *In-situ* treatment of these contaminated resources is receiving increasing interests and where applicable, can serve as a cost-effective management alternative. Amongst the various methods applied for the removal of these contaminants, the most environmentally benign options are through *in-situ* bioremediation and the use of permeable reactive barriers (PRBs). Two different cases of engineered bioremediation and *in-situ* use of permeable reactive barriers made of pumice supported nano zero-valent iron (nZVI) composites are investigated in the laboratory using a series of experiments for in-situ treatment of LNAPL and heavy metal contaminated groundwater, respectively. The findings of these practical experiments are then used in the field for *in-situ* treatment of toluene and arsenic polluted shallow groundwater resources in India.

Keywords: In-situ Remediation; Permeable Reactive Barriers; Engineered Bioremediation; Arsenic; LNAPL

1. INTRODUCTION
Soil-water systems are continuing to be affected by petrochemical hydrocarbons, generally referred to as non-aqueous phase liquids (NAPLs), and heavy metals especially Arsenic (As). The presence of these pollutants in soil and groundwater systems is of serious concern for the production of safe drinking water. Though light-NAPL compounds are immiscible with water, their solubility is several orders of magnitude higher than the permissible level for drinking water (Gupta et al. 2019). Arsenic, commonly found either as arsenate [As(V)] and or arsenite [As(III)], is also a widely present toxic heavy metal element mostly found shallow in groundwater resources. The exposed human population belt of Asia, mainly residing in foothills of the Himalayas lying in Pakistan, India, Bangladesh, Myanmar and Taiwan (Ravenscroft et al. 2009), is called as South-east Asian Arsenic Belt (SSAAB). Several efforts have been made to develop remediation techniques for managing these pollutants impacted sites since the 1980s (Essaid et al. 2015).

In the case of NAPLs, such technologies may focus on recovering mobile light NAPL, treating the residual fraction in soil, managing dissolved-phase and/or vapor-phase plumes (Yadav and Hassanizadeh, 2011). These physicochemical techniques are usually expensive and might result in incomplete mass removal or toxicity of these pollutants along with their serious impacts on the indigenous biota of soil capable of natural bioremediation (Yadav et al. 2014). The natural bioremediation is safer and less disruptive than most of these other conventional technologies; however, it takes a considerably long time to restore the polluted site under the prevailing environmental conditions. Therefore, engineered bioremediation techniques like biostimulation and bioaugmentation are gaining popularity due to their faster remediation rates (Basu et al. 2015).

The performance of various engineered bioremediation techniques is investigated here using a series of batches and column setups integrated into treatment wetland with and without plants.

While in the case of arsenic, the zero-valent form of iron has been used extensively for its removal from polluted water since the 1990's. (Powell et al. 1998). Fine to ultrafine powders of nZVI is mostly used in filtering units which reduce hydraulic conductivity of the porous adsorbent significantly. The reaction products of ZVI are expanded by corroded iron, H_2 gas and different mineral precipitates which clogs the system by reducing its hydraulic conductivity. The non-expanding base material of pumice used by Bilardi et al. (2016) to preserve the hydraulic conductivity of nZVI seems promising to overcome this problem. Therefore, pumice supported nZVI composites are used here as PRBs material for in-situ removal of arsenic from polluted groundwater using a column experiment followed by its application in the field.

2. MATERIALS AND METHODS

A series of LNAPL bioremediation experiments have been performed using a) column setups integrated into an unplanted and planted wetland, and b) microcosm setups. Likewise, PnZVI (pumice-nano zerovalent iron) has been developed and used in column setups for Arsenic removal.

2.1 Case Study-I: Treatment of LNAPL

A large-scale vertical column setup (120 cm high with an inner diameter of 15 cm) made of Plexi-glass and wetland setup (60 cm-L×30 cm-W× 60 cm-H) was fabricated for conducting the proposed experiments. There were 23 sampling ports at a depth of 5 cm along with the column depth. The column was packed homogeneously with saturated clean sand as aquifer material with a particle size of 0.5--1.0 mm. *Canna Generalis* was planted in one wetland under controlled conditions. Polluted groundwater was collected in a carboy from shallow hand pumps near a petroleum refinery in India. The source of toluene was prepared with an oversaturated stock solution in Millipore water and then dissolved toluene (250 ppm) from carboy and groundwater from wetland was applied as a continuous source to the attached column by a peristaltic pump. A constant groundwater velocity of 0.625 cm/h was maintained in the vertical direction throughout the experiment. The schematic diagram of these experimental sets is shown in Fig. 1.

Four different cases of bioremediation treatments have been studied for the degradation of toluene under controlled conditions. The first case was to study the natural degradation of toluene considering different initial concentrations. The second case was to study biostimulation by the addition of wastewater to contaminated groundwater. In the third and fourth cases, two simulated wetlands were used to study plant-assisted biodegradation strategies of biostimulation and bioaugmentation.

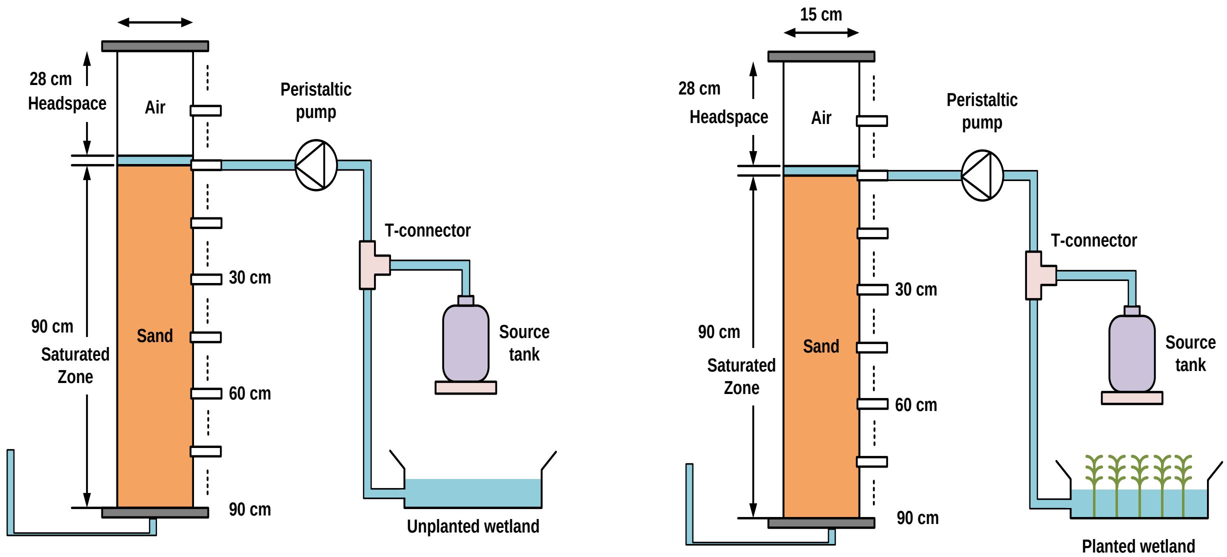

Fig. 1 Schematic diagram of the column set-up integrated with (a) unplanted wetlands (b) wetland planted with *Canna Generalis* to investigate bioremediation of toluene in the subsurface.

2.2 Case Study-II: In-situ removal of arsenic

A vertical column setup made of plexiglass having 20 cm height and 4.5 cm inner diameter, used for conducting continuous flow experiments with PnZVI. Two Nylon mesh pieces were placed on both ends of the column to prevent any loss of adsorbent during the experiment. A 16 cm layer of the adsorbent PnZVI was packed uniformly between a 2 cm layer of silica sand (1-2 mm) filled at the bottom and top of the column by gently tapping on the column. After filling the column setup, the porous material was saturated with nitrogen purged distilled water in excess to remove any air bubbles from the column. After that, As(III) solution (5mg/l) was applied from the bottom against gravity to avoid any preferential flow path at a constant rate of 30 ml/hr by a peristaltic pump. This experiment was conducted for 30 days, and the samples were collected from the outlet port for further analysis.

3. RESULTS AND DISCUSSIONS

A high equilibrium concentration of toluene at top ports rather than at lower ports in columns indicates effective toluene biodegradation with soil depth. Similarly, the observed equilibrium concentration of toluene was higher in the case of unplanted wetland asserting the accelerated biodegradation rate in the column setup integrated into the planted wetland. The difference of the relative concentration of toluene between input and output fluxes at 100 h was found as 13.34 % and 30.86% for planted and unplanted wetland setups, respectively. The estimated biodegradation rates show that the toluene degradation was 2.5 times faster in the planted wetland setup as compared to that of an unplanted wetland setup. Also, observed bacterial count along with measured dissolved oxygen proved that toluene degraded aerobically at a faster rate in the planted soil column setup in comparison to the unplanted column setup. Simulations show that as time reached 80-100 h there is no significant change in the toluene concentration profile and, thereby, confirming established equilibrium condition of solute transport. In the case of microcosm experiments, the rate of degradation of toluene is found as follows: natural degradation $\simeq$ biostimulation < plant-assisted biostimulation << combination of bioaugmentation and biostimulation. The results showed that the rate of toluene degradation increases dramatically in cases of plant-assisted bioaugmentation and biostimulation. The outcome of these case studies emphasizing the positive role of the rhizospheric zone in the process of LNAPLs biodegradation where a combination of bioaugmentation and biostimulation is the most effective strategy.

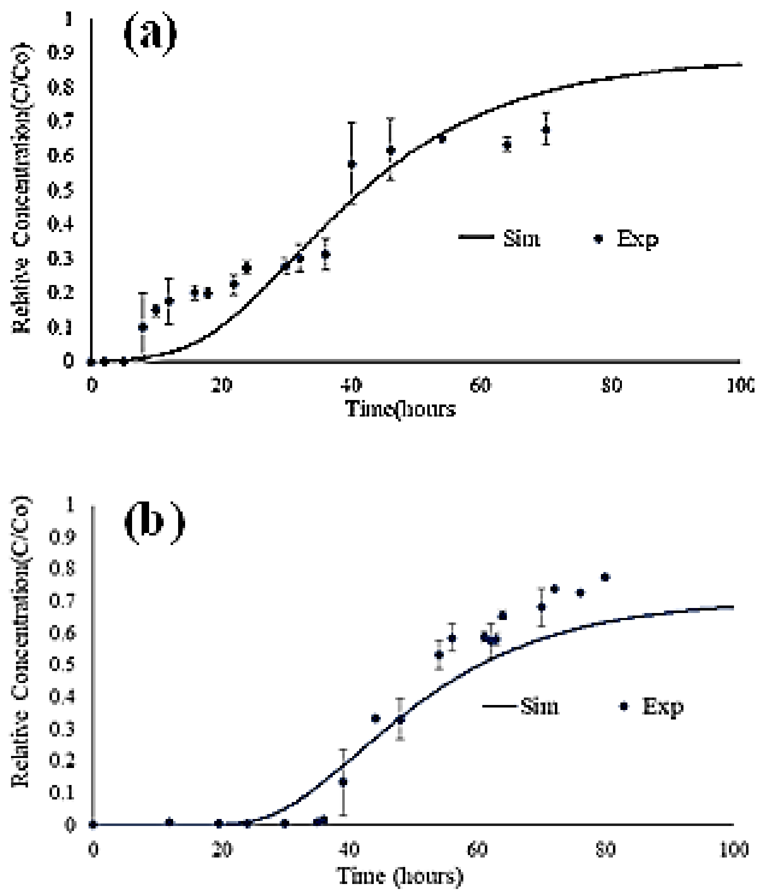

Fig. 2 Experimental and simulated BTCs for sampling ports at 85 cm depth from sand in the column setup attached with a) unplanted wetland, b) planted wetland.

Column experiments were conducted to assess the feasibility of developed composite as the reactive material in the permeable reactive barriers for in-situ Arsenic remediation. The average concentration of Arsenic in the effluent was observed as 5.97 µg/l at the end of the experiment which is lower than the WHO standard (10 µg/l) in drinking water. A rise in the BTCs was observed around 29 pore volumes, after that the concentration increases sharply. A mass balance calculation was performed and it was found that 99% As(III), i.e. 108.9 mg, was removed out of 109.05 mg of the supplied As(III). Saturated hydraulic conductivity of the packed column was determined by the constant head permeability method at different intervals throughout the experiment to evaluate the changes. There was a slight reduction in the hydraulic conductivity during the operation of the column, however, it was still found to be similar to the average hydraulic conductivity of typical arsenic-contaminated aquifers. Thus, the hydraulic conductivity of the reactive material is adequate for its application as a permeable reactive barrier in the in-situ remediation of arsenic.

4. CONCLUSIONS

A series of laboratory experiments and numerical runs have been performed to investigate the performance of treatment wetlands and different bioremediation strategies under varying subsurface conditions. A high removal rate for toluene was observed in a column setup integrated with planted wetland than the unplanted case due to the active participation of root zone microbes. Likewise, the rate of toluene degradation increases dramatically in cases of plant-assisted bio-augmentation and bio-stimulation in microcosms. The developed adsorbent demonstrated a 99% removal of Arsenic in the column set up in 30 days of the experiment. The findings of this study show that the developed composites using nZVI and the pumice as base materials can directly be utilized in the continuous flow systems as compared to the nZVI powders. Results of the lab-scale column experiment can be used to estimate the minimum thickness and longevity of a PRB for a real field application. The present study provides crucial information on the in-situ treatment of LNAPL and arsenic polluted groundwater resources under varying site prevailing conditions.

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Balancing between Goal Specification, Modelling and Site Characterization Efforts

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EXTENDED ABSTRACT
A general aim of contaminated site assessment is to find site specific suitable solutions for the handling of contamination with acceptable costs. The options for site specific solutions cover a broad range. Examples are the excavation of the contaminated subsurface material, the containment of the contaminated area, and the use of natural attenuation as an option for the site management. None of these options require a site characterization and modeling of flow and transport in the full complexity of an aquifer along the chain source – path – receptor. Already the relevance of different parts of the chain and therefore the need of their assessment depends on the goal of the site investigation (see Table 1). Consequently, it can be stated that the information required for the planning and evaluation of the suitability of the different options could be significantly different in terms of location and detail. The level of detail required in the information also depends on the modelling approach used for the design and impact assessment of remediation measures. A complete description of the contaminated site suitable for the evaluation of all options is not feasible due to limited accessibility and budget available for the site characterization. Furthermore, financial and regulatory constrains can restrict the variety of options.

Table 1 Goal oriented evaluation for contaminated site assessment

Selected goals for a contaminated site assessment	Most relevant part(s) of the site	Characterization targets	Model Needs
Assessment of the risk that contamination reaches certain location	Path & receptor	Subsurface features with high permeability and their connectivities	Estimator for travel-time probability
Evaluation of the usefulness of different options for a site remediation	Source & path	Low conductivity zones close to the source	Source geometry+(reactive) transport model +
Evaluation of natural attenuation as an option for site management	Path	Biogeochemical characterization	Reactive transport model

A site-specific preselection of options for a later remediation or handling of the site could be very suitable for the definition of clear goals for the site investigation and the modelling.

Thereby, an iterative process will be often necessary for balancing between suitable goal definitions, realization of an appropriate modelling concept and acceptable site characterization efforts.

For this iterative process a general work flow for a goal-oriented site assessment as shown in Figure 1 is proposed. The general work flow comprises of three main steps: (i) formulating the right questions, focusing on what is needed rather than looking for a detailed description of subsurface structures and processes in the hope that this will provide answers to any possible questions. The goal needs to be specified including specifications like acceptable uncertainty. (ii) Successively, a model should be tailored to these specific questions considering available field data and additional site characterization needs for model parameterization. (iii) Finally, the model should be evaluated with regard to the goal specifications. In case that the acceptability criteria of the goal are not meet, new models should be considered in line with additional field work necessary.

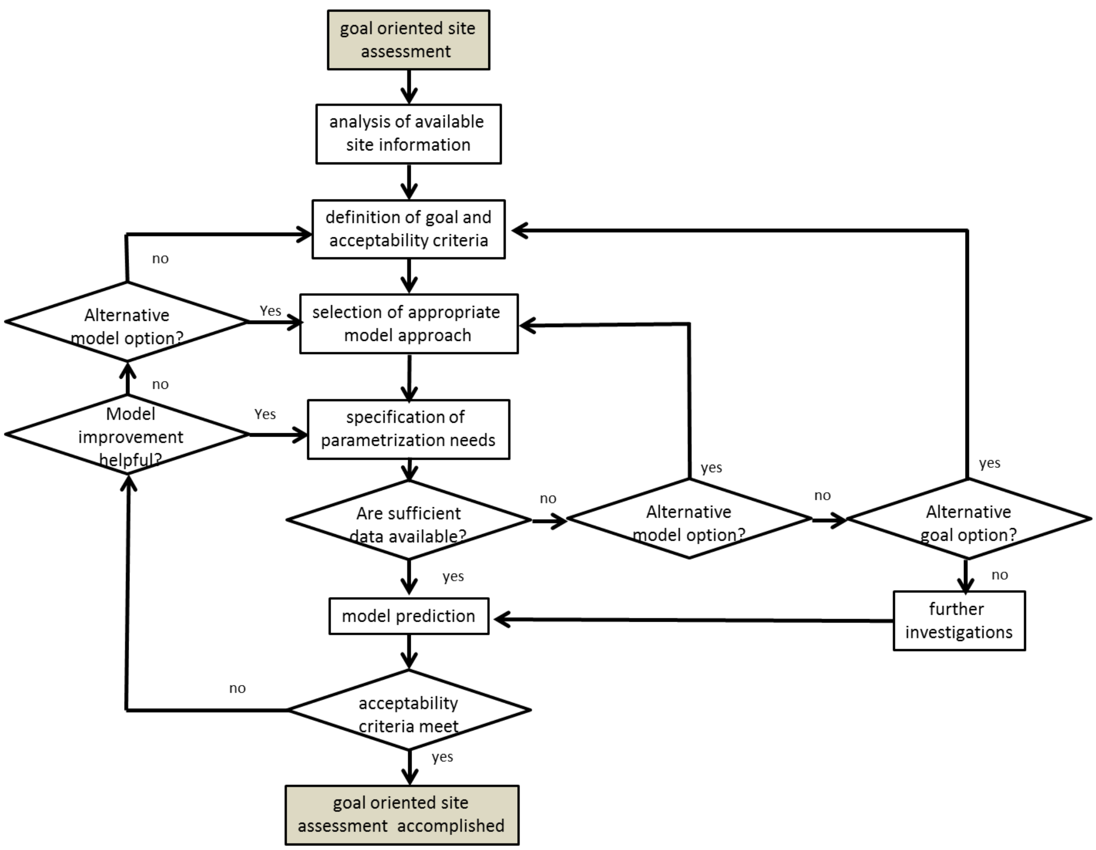

Fig. 1 General work flow for a goal-oriented site assessment.

Use of Sustainability Principles and Field Screening Tools to Optimize Contaminated Media Disposal Volume for Soil Remediation Project in India

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1. INTRODUCTION

Jacobs has been contracted to perform environmental monitoring, remediation and provide protection measures during source area removal works for a site in India. The works consisted of the design and implementation of the excavation, removal, pre-treatment, and segregation of shallow impacted soils that have been identified as containing hazardous and non-hazardous wastes, and the transportation and disposal of these materials to appropriately licensed waste management facilities. The objective of the waste segregation activities was to reduce the amount of materials transported off-site (reduce truck emissions, health and safety concerns, etc.) and reuse materials on-site to further reduce the need to transport materials on-site.

2. METHODS

The remediation works were designed to remove the landfill contents for recycling, reuse or disposal off-site to appropriately licensed facilities. Delineation works defined an average contaminant depth of 2.0 meters below ground level (m bgl) with a maximum depth of 2.5 m bgl. Depths range between 1.6 to 2.5 m bgl.

Learnings from Stage 1: Field Pilot Study works conducted in May-June 2017 were used to refine and optimize Stage 2: Full-Scale Remediation works. The general criteria for removal of contaminated materials and backfilling of clean fill were included in a Remediation Work Plan. Preparatory activities were conducted in advance of excavation, segregation, treatment and disposal activities as summarised below.

2.1 Establish the Works - Baseline Conditions Survey

Baseline conditions were established prior to remediation works including a topographical survey, ground penetrating radar (GPR) survey of the landfill contents, photograph log and detailed list of assets and utilities within the vicinity of the remediation works and site access areas.

2.2 Protection of Workers Health and Safety (H&S)

Temporary storage area facilities, environmental impact mitigation measures, allocation of required Personal Protective Equipment (PPE) i.e. hardhats, eye protection, ear protection, etc. were installed. Welfare facilities such as drinking water fountains, toilets, decontamination areas, change rooms, emergency eyewash, emergency showers, fire extinguishers and pantry areas for meal consumption were provided to the site workers.

Our team focused on social welfare responsibility measures including tracking potential health impacts (entrance/exit physicals and H&S training provided for extended team members including subcontractors). Jacobs ensured that a legacy of H&S awareness was left with the local laborers and extended team.

2.3 Establishment of Stockpiling and Staging Areas

The excavation and treatment of the contaminated soil mass were executed sequentially materials deposited in temporary depots constructed on a concrete base with a liner to prevent the mixing of materials. Excavated material was visually and mechanically screened with verification using field screening instruments [X-ray fluorescent (XRF) and photoionization detector (PID) units] for waste characterization and H&S monitoring purposes and remediation confirmatory samples to verify remediation objectives prior to backfilling.

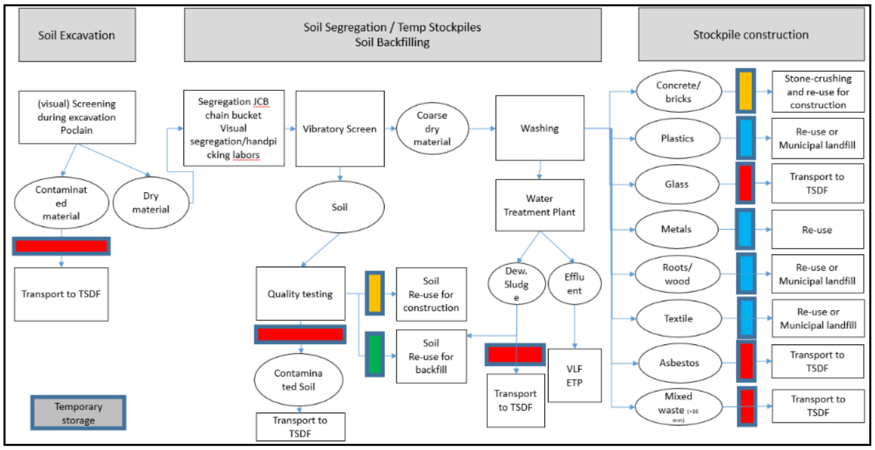

Fig. 1 Materials Flowchart

3. RESULTS AND DISCUSSION

The waste segregation techniques described resulted in the separation of wastes from the landfill contents summarised below. The project is approximately 50% complete (total waste volume 17,500 m^3) with the works continuing post-monsoon at the end of September.

Table 1 Excavated Material Mass Balance

Category	Quantity separated
Total Waste Excavated	8,600 m^3
Segregated clean for backfill	3,800 m^3
Concrete debris for further processing	1,200 m^3
Offsite disposal	1,250 m^3
Stockpiled for further processing	2,892 m^3
Recyclables (plastics, metals, etc.)	27 m^3
Asbestos Containing Materials (ACM)	342 kg

Large construction debris (concrete materials, etc.) are not included above, where these materials were broken down for concrete crushing and reuse for on-site construction activities.

4. CONCLUSIONS

The outcome of the source area waste segregation techniques (reduce, recycle and reuse) achieved the stated objective to reduce the amount of materials disposed at the off-site disposal facility, recycled materials (plastics, etc.) and reused materials where possible. The volume of materials disposed off-site was reduced by approximately 50% which achieves a key performance indicator (KPI) and the reduction of the number of trucks on the road achieves a sustainability KPI.

Subsurface Investigation on Perchloro Ethylene Drycleaning Site, Michigan, USA

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ABSTRACT

The Site-specific objective of the subsurface investigation at the Site was to assess the impact and define the horizontal and vertical extent of volatile organic compounds (VOCs) associated with PCE in soil and groundwater at the Site and the adjacent residential property(ies).

Based on the Site soil borings, the soil at the Site is sand to silts up to a maximum boring depth of 45 feet below ground level. Groundwater was encountered within 36 feet below ground level and flowing in the North-Northeast direction. Volatile organic compounds (specifically cis-1,2-Dichloroethene (DCE), Tetrachloroethylene (PCE), Trichloroethylene (TCE) and Vinyl chloride (VC)) were the fingerprints of contamination at the Site. PCE, TCE and VC were detected above the most restrictive cleanup criteria in groundwater samples. Based on the results of the subsurface investigation, the Site soil and groundwater samples showed levels of VOCs (including PCE, TCE, and VC) above the most restrictive (residential and commercial) Michigan Department of Environmental Quality (MDEQ) Cleanup Criteria.

1. INTRODUCTION

The owner of the Drycleaning Facility hired Innovative and Quality Solutions, Inc. (hereinafter referred to as "IQS") to conduct a Remedial Investigation and Feasibility Studies (RI/FS) at the Site. The purpose of the RI/FS was to assess any potential recognized environmental conditions at the Site soil and groundwater. In-pursuant to the RI/FS, as per the established ASTM 1527 standards, environmental site assessment (ESA) has to be conducted to acquire historical activities and identify potential recognized environmental conditions at the Site.

The ESA would give a proper road map to conduct RI (subsurface investigation) and subsequently feasibility studies for identifying or selecting economical and time-bound remedial measures.

2. HISTORICAL INVESTIGATION

Following the review of several resources and documents, the Drycleaning Facility with a Laundromat was reportedly established in 1958. From 1958 until 2006, a commercial Dry Cleaning and Laundromat was in operations, performing washing, extraction, and drying.

3. SITE LOCATION AND DESCRIPTION

The Site is located at the northeast corner of South Washington Street and Dunlap Street. The surrounding adjacent properties include single-family residential houses to the north, east, and southeast; a daycare center to the south and a residential apartment complex to the west. The Site can be accessed from South Washington Street on the west side and Dunlap Street on the south side. A Site Location Map and Site Orientation Map are presented in Figure 1: "Site Location Map" and Figure 2: "Site Orientation Map" respectively.

4. SCOPE OF WORK

To accomplish the overall objective of the project, IQS completed the following tasks:
Task 1: Prepare Work Plan, Site-Specific Health and Safety Plan and Quality Assurance and Quality Control Plan.
Task 2: Vertical Profiling.
Task 3: Installation of up to four permanent monitoring wells on-site.
Task 4: Prepare a RI and FS report.

The following tasks (1 thru 3) of the above scope of work were conducted in order to meet the Site-specific objectives:

- Subsurface investigation including installation of seven (7) soil borings, four (4) vertical profile borings, two (2) 1", 5-foot screen temporary monitoring wells and four (4) 2", 15-foot screen permanent monitoring wells.
- Collected several soils and groundwater samples as described in the section below.
- Conducted surveying of the monitoring wells.

4.1 Preliminary Subsurface Investigation

The Preliminary Subsurface Investigation activity was conducted utilizing direct push technology (Geoprobe®) and hollow stem auger (HSA) by Terra Probe Environmental. The investigation included the installation of soil borings (SB1 thru SB7 and vertical profiles (VP1 thru VP4) and installation of two temporary monitoring wells and four permanent monitoring wells. The investigation was conducted under the direct supervision of IQS personnel. The soil borings including vertical profile borings were installed on October 18, 2005, January 25 and February 24, 2006. The permanent monitoring wells were installed on March 8, 2006. These activities were conducted to define the horizontal and vertical extent of contamination associated with the Site.

Soil Borings

Seven (7) soil borings were drilled, and six (6) soil samples were collected one each from soil borings SB1, SB2, SB3, SB5, SB6 & SB7. The samples were collected to assess and to define the extent of the VOCs contamination in the soil and groundwater at the Site as shown in Figure-3: "Soil Boring and Monitoring Well Location Map". These soil boring locations and samples were strategically selected based on the historical Site information including the IQS' phase I Environmental Site Assessment and previous subsurface investigation conducted by Villa.

Based on the IQS's and Villa's investigation results, IQS conducted four vertical profile borings and collected 2 soil samples from VP1 and one each from VP2 and VP4 at various depths to define the vertical and horizontal extent of the contamination at the Site. The vertical profiles were installed up to a maximum depth of 40 feet below ground level (bgl) using Geoprobe®) (double casing). Groundwater was observed at approximately 37.4 feet bgl at VP1 and 32 feet bgl at VP2. IQS installed two 1" temporary monitoring wells (TMW1 and TMW2) at VP1 and VP2, respectively.

One depth-specific grab soil sample was collected from six (6) selected soil boring locations and two vertical profile borings (VP2 and VP4), and two depth specific grab soil samples were collected from VP1 as shown in the attached Boring Logs. The soil samples were analyzed for volatile organic compounds. The chemical analysis of the soil samples was based on the historical usage of the Site. The samples were collected based on the field observation and PID readings. The soil boring locations and list of analytes are attached as Figure-3 and Table-1, respectively.

All soil samples were field screened utilizing a PID. The soils encountered were classified and logged in accordance with the Unified Soil Classification System.

For the volatile organic compound (VOC) analysis, IQS collected ten (10) grams of grab soil sample which were placed in a 25 ml vial containing 10 ml of methanol as a preservative in accordance with USEPA Method 5035. The balance of the sample was placed in a 4-ounce glass jar, sealed, and placed in an ice-filled cooler for the analysis of moisture content. Soil samples were submitted to the Fibertec Laboratory for analysis. The applicable MDEQ target method detection limits were used for all analytical tests. The tabulated test results and laboratory analytical data with a chain-of-custody are attached as Table 2: "Soil Sample Analytical Results" and "Laboratory Analytical Data and Chain-of-Custody", respectively.

Permanent Monitoring Wells

IQS mobilized to the Site on March 08, 2006, to install four permanent monitoring wells as shown in Figure 3. Terra Probe Environmental was retained to install these wells. The four monitoring wells were installed at a maximum depth of 45 feet bgl. The locations of these wells are strategically selected to define the extent of groundwater contamination from the historical release of PCE. Monitoring wells were installed using a 4.25-inch hollow stem auger and were constructed of 2-inch diameter polyvinyl chloride (PVC) by 15-foot well screen with 2-inch diameter PVC risers. Wells are set to intersect the water table and to facilitate seasonal groundwater level fluctuations. Each borehole was filled with a silica sand filter pack to a depth of approximately 2-foot above the well screen and rest with bentonite seal to the top of the borehole. Wells were completed with flush mount manhole covers encased in concrete. Locking well caps were placed on each well opening.

Groundwater was observed ranging from approximately 34 to 36 below the top-of-casing (TOC).

All the monitoring wells were surveyed utilizing an established onsite benchmark as shown in Figure 6.

5. INVESTIGATION RESULTS

The following subsections present the results of the RI for the Site. These subsections include geological and analytical results.

5.1 Geology/Hydrogeology

The Site geological information and data were generated during the soil boring and sampling activities.

Groundwater was encountered at different depths ranging from approximately 34 feet to 36 feet below TOC as shown in Figure 6:" Groundwater Flow Map". The regional general groundwater flow was estimated to be north-northeast within the Site investigation area. Based on the Site soil borings SB1 thru SB7 and vertical profile borings, the soil at the Site is sand to silts with some intermediate gravel layers appears to be continuous up to a maximum boring depth of 45 feet below ground level. No competent confining layer was observed within the investigation depths. Borings were terminated at approximately 48 feet bgl. Groundwater was observed at approximately 37 feet bgl at MW2 and approximately 34 feet bgl at MW1.

According to the USGS topographic map, the Site is located at an approximate average elevation of 858 feet above the National Geodetic Vertical Datum.

5.2 Analytical Results

5.2.1 Soil. A summary of tabulated analytical results of target compounds in the Site soil samples is provided in Table 2.

The soil analytical results were compared with the current Part 201, MDEQ Generic Cleanup Criteria Table, Operation Memorandum #1, Attachment A – "Soil: Residential and Commercial I." This criterion is based on the zoning/land use and as defined in the Part 201-Land Use Category.

Volatile Organic Compounds

Volatile organic compounds (specifically cis-1,2-Dichloroethene (DCE), Tetrachloroethylene (PCE), Trichloroethylene (TCE) and Vinyl chloride (VC)) were the fingerprints of contamination at the Site. DCE was detected above the TMDL but below the most restrictive cleanup criteria (Drinking Water Protection or Groundwater and Surface Water Interface Protection) in soil samples SB1(15-16'), SB5(15-16'), SB7(23-24'), GP1(15-16'), GP4(15-16'), GP11(15-16' & 19-20'), GP12 (13-14'), GP13(15-16') and GP14(0-1' & 15-16'). PCE was detected above the most restrictive cleanup criteria in all of the soil samples collected to date. TCE was detected above the most restrictive cleanup criteria in soil samples SB1(15-16'), SB7(23-24'), GP1(15-16'), GP4(15-16'), GP11(15-16' & 19-20'), GP12 (13-14'), GP13(15-16') and GP14(0-1' & 15-16'). VC was not detected above TMDL in any of the soil samples, except GP14(0-1') and VP2Dup (23-24'), which had detections above the most restrictive cleanup criteria.

The laboratory analytical results are presented in "Laboratory Analytical Data and Chain-of-Custody". The soil analytical results are presented in Table-2 and Figure 4: "Soil Analytical Results Map".

5.2.2 Groundwater. During the vertical profiling activity, IQS installed two temporary monitoring wells (TMW1 and TMW2 at VP1 and VP4, respectively). These monitoring wells were installed to gather SWL data and screen the groundwater quality, which would aid in selecting the locations for installing permanent monitoring wells. Groundwater was observed at approximately 37' bgl at TMW1 and approximately 34' bgl at TMW2. Following the installation of TMW1 & TMW2, IQS collected a groundwater sample from TMW1 and tried to collect groundwater sample from TMW2, but unable not collect groundwater sample from TMW2, because of the slow groundwater recharge and unable to purge sufficient volume of groundwater to fill in two 40-ml VOA sample vials. Based on the temporary monitoring wells data including groundwater elevations at TMW1 & TM2, and analytical results from TMW1, four permanent monitoring wells (MW1 thru MW4) were installed ranging from depths 43-48 feet bgl.

The groundwater samples were collected from the temporary and permanent monitoring wells using a bladder pump. Two-polyethylene tubes were inserted into each well and attached to a bladder pump with silicone tubing. New tubes were used for each well. The wells were initially purged until the effluent was clear of turbidity and more than three casing volumes of groundwater were purged prior to collecting the sample. Once a clear sample stream was obtained, the groundwater samples were collected. The purge water was containerized in 55-gallon steel drums and transported off-site for future disposal. Two hydrochloric acid preserved 40 ml VOA vials were collected for VOCs analysis. The groundwater samples were placed in a cooler on ice and transferred under proper chain-of-custody procedures to the Private Lab.

Volatile Organic Compounds
Volatile organic compounds (specifically cis-1,2-Dichloroethene (DCE), Tetrachloroethylene (PCE), Trichloroethylene (TCE) and Vinyl chloride (VC)) were the fingerprints of the contamination at the Site. DCE and TCE were not detected above the TMDL in any of the groundwater samples. PCE was detected above the most restrictive cleanup criteria in TMW1 and MW2. Also, PCE was detected in MW3 above TMDL but below the most restrictive cleanup criteria. VC was detected above the most restrictive cleanup criteria in TMW1 and MW1.

The laboratory analytical results are presented in "Laboratory Analytical Data and Chain-of-Custody". The soil analytical results are presented in Table 3 and Figure 5: "Groundwater Analytical Results Map". The groundwater flow is presented in Figure 6: "Groundwater Flow Map."

6. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the evaluation of the available information and results generated during the RI activities at the Site.

6.1 Conclusions

Based on the results of the subsurface investigation to-date, the Site soil and groundwater samples showed levels of VOCs (including PCE, TCE, and VC) above the MDEQ-RRD Cleanup Criteria.

Soil boring samples within the proximity of the drycleaning machine area and within the shallow depths ranging from 2' to 24' showed elevated levels of PCE concentration above soil saturation concentration screening levels.

The general groundwater flow was estimated to be to the north-northeast.

6.2 Recommendations

Based on the remedial investigation results, in IQS's opinion, the vertical extent of contamination in soil has been defined. The horizontal extent in soil has not been defined and appears to be extending in all four directions beyond the Site boundaries; however, the elevated levels of PCE are predominantly observed in the central northern half of the Site and within the proximity of drycleaning machine area. Based on the current soil analytical results, an additional investigation may be required to define the extent of the contamination.

The groundwater appears to be flowing to the north-northeast beneath the investigation area. Based on the current groundwater analytical results and estimated groundwater flow direction, an additional investigation may be required to define the extent of the contamination.

The Circular Geoenvironment - Maximizing Geoenvironmental Services to Minimize Environmental Harm

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Keywords: circular economy; geoenvironmental services; resource recovery.

1. INTRODUCTION

The environment provides services that can be harnessed or engineered to achieve the needs of society in a manner that can reduce or eliminate the need for intensive interventions, for example, bio/phytoremediation and passive mine-water treatment. The geoenvironment contains the resources, the energy and the genetic capability necessary to provide a much wider range of services than is currently the case. It is the aim here to draw on recent research to demonstrate the potential for geoenvironmental services to contribute to society in ways which extend and go beyond the traditional view of the geoenvironment as a source of raw material and a sink for waste, but little in between, including in resource supply and infrastructure provision.

2. THE GEOENVIRONMENT'S ROLE IN THE CIRCULAR ECONOMY

Traditional linear economies extract materials, usually from the geoenvironment, and process them for consumption. Ultimately, these are returned to the (geo)environment, as waste or pollution. The transition to circular economies aims to amend product design to facilitate reuse, repair or recycling and eliminate waste, minimizing resource extraction in the process. It is questionable to what extent this is practically achievable as there will always be wastes that are challenging to reuse or manage, particularly large-volume wastes from processes such as in extractive industries.

Recovery of resources from geological waste storage has long been practiced to a degree, but the concept has been extended to more recent, engineered waste deposits as well as those where the resource quality is low making recovery financially and technically challenging (Sapsford *et al.*, 2017). It is a challenge to make a case for recovery purely on financial grounds with currently available techniques. Individual sites can contain a significant value, but extraction would likely be unviable using traditional, intensive mining or contaminated land remedial methods, particularly on the basis of achieving a financial return, and so they remain untouched.

Geoenvironmental processes *in situ* offer an opportunity to tackle such problem wastes if their long-term nature is considered as a benefit (Sapsford *et al.*, 2017). Like other, natural, cycles (e.g. water, nitrogen), the 'resource cycle' can be driven in part by processes in the ground that alter, transport or concentrate the resource in a manner that maximizes its subsequent utility. Slow, 'passive' recovery allows harvesting of energy from natural processes and flows (e.g. groundwater) to bring about the desired change with minimal input and costs offset by resource recovery. Mobilization is achievable in the very long term by leaching and natural degradation but can be accelerated through biological activity. For example, bioleaching (from microorganisms and plants) can enhance the mobility of metal resources. Once mobilized, groundwater flow channeling through properly engineered wastes or flow control can deliver the resource to zones where a range of biogeochemical processes can be employed to concentrate the resource for recovery.

3. GEOENVIRONMENTAL SERVICES FOR GROUND ENGINEERING

Much ground engineering is additive – materials and energy are used to shape, direct and restrain soil, rock, and groundwater to achieve the desired outcome. To what extent can geoenvironmental services contribute to the aims of this industry in a way that works with rather than contests natural processes? The field of bio-geoengineering is looking to use these services to develop tools that are starting to find the application. Biomineralisation (e.g. microbially induced carbonate precipitation, MICP) offers an alternative to cementitious materials such as grouts or even concrete for ground improvement (DeJong *et al.*, 2013) and contaminant encapsulation (Mugwar & Harbottle, 2017). Vegetation contributes to soil stability through the physical presence of roots, through moisture uptake and through plant-soil interactions via biopolymers (Chen & Harbottle, 2019). These processes, managed by biological systems, are responsive to changes and adapt to their environment. Can we harness this to develop smart engineering which is not only congruent with but can enhance its environment through the ecosystem as well as geoenvironmental services?

As an example, ground structures deteriorate with time as damage accumulates. Because of their scale and/or inaccessibility they can be challenging and costly to maintain. The concept of self-healing materials is the first step towards autonomous structures that can sense, respond to and mitigate against damage to or change in the material or its environment, reducing deterioration and reducing the need for significant maintenance or replacement. The concept is advanced with construction materials such as concrete (De Belie *et al.*, 2018) but similar concepts are applicable to geo-materials. We have demonstrated that soil bacteria have the potential to offer self-healing MICP whereby spores embedded in the carbonate matrix are activated by damage to the matrix and exposure to nutrients (Botusharova *et al.*, 2020) with subsequent recovery of compressive strength. This response to damage allows self-healing MICP systems to prevent and overcome damage to earth structures from chemical and physical processes in the ground.

4. CONCLUSION

Geoenvironmental services provide an opportunity to harness the energy and materials provided by the natural environment to achieve the requirements of environmental and infrastructure management and mitigate the environmental impacts of the current state of the art.

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Heavy Metals in Soils from Landfills – an International Review

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EXTENDED ABSTRACT
Landfills are contaminated sites requiring aftercare for at least 80 to 450 years (Laner 2011). However, urbanization and increasing environmental standards often resulted in the reclamation of old landfills. Landfill mining (LFM) is an approach to managing landfills and allows to recover resources as well as space. The resource potential is even though low due to large quantities of soil-like materials (SLM), which are of low economic value and expensive to transport (Krook et al. 2012). Consequently, the contamination of SLM is crucial for its recovery and the economic feasibility of LFM projects.

The objective of this study was to investigate the content of heavy metals (arsenic, cadmium, chromium, copper, lead, nickel, zinc) in SLM on an international basis. Comparing chemical analyses of SLM from Asia, Europe, and the US, this research focused on:

- Which contamination similarities exist internationally for SLM
- Which ranges of heavy metal concentrations might be expected

Statistical calculations were carried out using data of chemical analyses from 36 landfills in Asia, Europe, and the USA (see Table 1). The medians and box-plots were compiled for each continent.

Table 1 Countries of investigated landfills and references

Continent	Country	References
Asia	China	Xiaoli et al. (2007), Zhou et al. (2015), Rong et al. (2017)
	India	Esakku et al. (2003), Kurian et al. (2003), Somani et al. (2018)
	Sharjah	Goeschl and Rudland (2007)
	Thailand	Prechthai et al. (2008)
Europe	Austria	Wolfsberger et al. (2015)
	Belgium	Quaghebeur et al. (2013)
	Estonia	Burlakovs et al. (2016, 2018)
	Finland	Särkkä et al. (2016)
	Germany	Nine own studies, Finck (1999)
	Italy	Masi et al. (2014)
	Sweden	Hogland et al. (2004), Jani et al. (2016), Burlakovs et al. (2018)
North America	USA	Von Stein and Savage (1993), Visalli and Reis (1997), Atik and Grimes (1998a, b), Smith et al. (1998), Hull et al. (2005), Jain et al. (2005), FDEP (2009)

Cadmium concentrations turned out to be similar in Asia and Europe, nickel concentrations in Europe and USA, and lead concentrations in Asia and the USA, respectively. Zinc and arsenic concentrations generally tended to disperse, whereas those of nickel and chromium seemed to be more homogeneous.

With regard to North America, arsenic, chromium and copper concentrations proved to be low, while for zinc the highest concentrations were recorded (see Table 2). In terms of Asia, arsenic, chromium, and copper concentrations were higher compared to Europe and the US. In contrast, for zinc were recorded the lowest concentrations. Landfills in Europe revealed the highest lead concentrations, while the concentrations of chromium, copper, nickel, and zinc ranged between the values reported from Asia and the US.

Heavy metal concentrations reported by Kaartinen et al. (2013) and Lopez et al. (2018) proved to be ten times higher than those of this study. Using XRF measurements tools might result in this noticeable difference.

Table 2 Heavy metal medians and 90th percentiles of landfills in different continents

	Asia		Europe		USA	
Element (mg/kg)	Median	P90	Median	P90	Median	P90
As	5.6	31.0	9.1	20.5	3.7	7.8
Cd	0.9	4.2	0.9	3.5	1.7	6.0
Cr	120	191	33	130	26	39
Cu	217	540	68	300	31	96
Ni	48	64	27	69	21	43
Pb	83	330	117	430	61	356
Zn	262	1070	410	1200	598	1400

By and large, the international comparison showed some similarities of heavy metal concentrations in SLM, regardless of the continent. In addition, this study provides an overview of the heavy metal concentration ranges. However, values should be interpreted with caution, since different sampling methods (e.g. numbers, depth, grid, composite, etc.), sample treatment (using screens with different opening sizes) and standard of chemical analyses varied. The publication of medians, percentiles and maximum values of SLM would be useful in the future.

Keywords: landfill mining; heavy metals; soil contamination

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Assessment of the Impact at Contaminated Sites

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EXTENDED ABSTRACT
Assessment of Impact on soil and groundwater at contaminated sites is an important first step in mitigating the impact of contamination. Careful planning and development of a strategy are necessary to collect representative and pertinent site-specific data that enable sound decision making in remedial efforts.

Assessment involves invasive and exploratory penetration of soil using drilling machines (hand or machine operated) to collect samples that can be analyzed in a laboratory to evaluate the type and concentration of contaminants. The most important aspect of assessment involves the collection of representative soil and groundwater samples to understand the source and movement of contamination within the subsurface. To advance a boring and collect a representative sample, a drill rig is necessary. Depending on the location (the type of geology), different types of drill rigs are used such as Hand auger, CPT rig, Geoprobe drill rig, hollow stem auger rig, sonic rig, air rotary casing & hammer rig or mud rotary drill rig. No matter what drill is used the primary purpose is to collect depth specific representative soil samples to understand the source of contamination. In India the most commonly available drill rigs are:

- Mud rotary drill rig - advantage – cheap, locally available; disadvantage – carries contamination vertically down, cannot evaluate geology, messy operation.
- Air rotary drill rig. – advantage necessary to drill in rocky formation; disadvantage – carries contamination vertically down, cannot collect samples, cannot screen appropriately.

Over the last five years, it is our observation that most drilling for environmental site characterization in India are performed using hand augers (manual drilling) or machine-assisted drilling such as mud rotary and/or air rotary methods. These drilling methodologies are not capable of collecting depth specific samples or prevent cross-contamination. These rigs were designed and manufactured for the installation of bore wells at non-contaminated sites.

At contaminated sites, most of the contamination is typically shallow (upper 50 feet) and close to the source area, therefore, it important to ensure that the drilling methodology used for assessment of the extent of contamination should not spread the contamination. For environmental projects, subsurface soil and groundwater samples are commonly collected before installing a monitoring well network. This needs to done to evaluate the vertical and lateral extent of impact before installing wells and used to evaluate if monitoring wells are indeed necessary and plan out the number of wells needed to monitor a contaminant plume before commencing well drilling since lithology and location of contamination is not understood.

- Hollow Stem Auger – why is this rig important? – Prevents contamination from moving vertically down, can collect depth specific samples, log geology, set screens at appropriate depths; disadvantages – expensive, depth of drilling is limited to 200 feet.
- CPT – uses a probe to assess geology. Advantages – small rig size, easy to move around, the diameter of penetrating borehole is small, can collect depth specific soil and groundwater samples; disadvantages – expensive, carries contamination down, cannot set

wells and multiple holes required for sampling, no sample for logging the geology and validating the probe data.

- Geoprobe – used for rapid assessment of soil and shallow groundwater. Dual tube methodology prevents cross-contamination. Advantages – collect depth specific soil and groundwater samples, can set wells; disadvantages – expensive, replacement sampling tubes are difficult to procure and limited to 150 feet in depth.
- Air rotary casing hammer rig - drilling techniques typically used in rocky terrain and offers deep well construction. advantages – the casing and hammer modification prevent cross-contamination; disadvantages – no soil samples no cores.
- Sonic drilling is typically used for assessing and installing wells to deeper water-bearing zones; advantages –can collect depth specific soil and groundwater samples, can be advanced in rocky formation, can collect rock cores; disadvantages – very expensive.

Case Study: Assessment and installation of Monitoring wells at Tondiarpet, Chennai.

Stratus Environmental imported a hollow stem augur rig to India and used this rig to advance exploratory soil borings and converted these boring to monitoring wells. In all, Stratus installed 32 monitoring wells, 13 soil vapor extraction wells and 10 air sparge wells at the Tondiarpet site. The depth specific soil samples collected during the drilling were used to develop a soil cross-sectional profile, an understanding of the lateral extent of impact to soil and groundwater and develop a remedial methodology. Currently, more than 50% of the contamination has been remediated.

Advantages of Environmental Subsurface Profiling over Soil Sampling

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EXTENDED ABSTRACT

Soil sampling provides samples of actual porous medium and, ideally, of the pore fluids. Soil cores are the baselines against which other methods are evaluated. Traditional subsurface investigations obtain soil samples which might be cross contaminated while sampling or by the equipment handling. These soil samples are not suitable for environmental applications such as characterization and remedial design of contaminated sites. Heterogeneity in the subsurface occurs at small scale and traditional methods cannot capture this characteristic. Thus, routine soil sampling cannot be used to obtain contaminant mass distributions, concentration gradients and diffusive fluxes and cannot generate a Conceptual Site Model (CSM)

High Resolution Site Characterization (HRSC) is subsurface investigation appropriate to the scale of heterogeneities in the subsurface which control contaminant distribution, transport and fate, and should also provide degree of detail needed to understand:

- Exposure Pathways
- Processes affecting fate of contaminants
- Contaminant mass distribution and flux by phase and media (mobile and immobile)
- How remedial measures will affect the problem

It is to be noted that the above definition of HRSC is a functional definition. It depends on the objectives of the investigator as well as the nature of the site.

Some tools for obtaining vertical profiles in contaminated sites:

- Soil Coring: Direct push, Sonic, Auger and Rotary
- Direct push ground water sampling devices: Geoprobe SP16/SP21, Waterloo APS, BAT Sampler, Cone Sipper
- Hydrostratigraphic Measurements: EC, Cone penetrometer, Hydraulic Profiling tool
- Qualitative contaminant data: MIP, LIF, PID, FID, Immunoassay, Colorimetirc
- Quantitative contaminant data: Mobile Laboratory, Fixed Laboratory

HRSC results provide the detailed information necessary to design and implement targeted in-situ and ex-situ remedial measures.

Contamination caused by Open Dumpsites in Delhi: Results of Sub-Surface Investigations

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ABSTRACT

There are several un-engineered open dumpsites of Delhi which have been operational for many years when MSW rules were not in force. Most of the dumpsites are very close to habitants and this creates a risk of health hazards to nearby residents and citizens of Delhi. As the dumpsite is managed in an unscientific manner, it creates frequent problems of foul odor, bird menace, contaminated groundwater, and surface water, fire, smoke and discharges, and ponding of leachate in and around the dumpsite. The objective of this paper is to review the degree to which contamination is being caused by the open dumpsite. Samples of leachate, surface water, and groundwater and soil-like material derived from legacy waste were collected from the open dumpsite and from nearby areas and tested within a laboratory. During investigations, the samples of groundwater were collected from drilled boreholes, leachate and surface water was sampled from nearby drains and water pond for one of the major dumpsites

Keywords: Leachate; Groundwater Contamination; Surface Water Contamination; Pollution, Waste Characterization

1. INTRODUCTION

One dumpsite is considered in this paper. The dumpsite is spread over 50 acres and has a maximum height of 60 meters. It accommodates Municipal Solid Waste (MSW) including waste/Silt/ Construction and Demolition waste from different areas of Delhi. This dumpsite continues to receive 1000 to 2500 MT of fresh MSW daily. The entire site is covered with waste, and waste extends well beyond the site boundary in some places. The schematic view is shown in Fig.1.

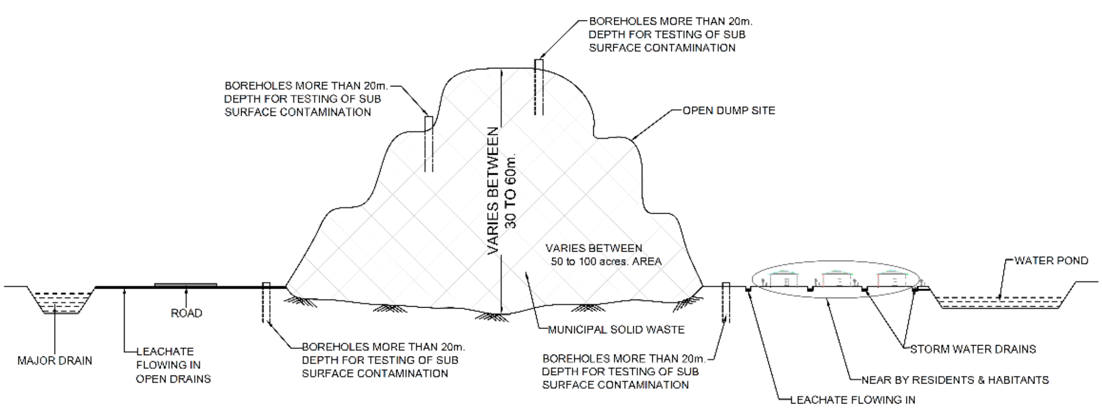

Fig. 1 Schematic view of Open Dumpsite

Fig. 2 Photographs showing the spread and height of open dumpsites of Delhi

1.1 Contamination by Leachate

The average rainfall per year in Delhi is 790 mm. The waste has an uneven surface thus limiting runoff, although with steep slopes and rainfall occur mainly during the monsoon period, thus limiting the evaporation that occurs. During the dry months, the evaporation is reduced by the development at the surface of a "soil water deficit", i.e. the surface of the waste is dry, and water is not available for evaporation. The exception to this is where fresh, moist waste has recently been deposited. In consideration of the above, a reasonable conservative upper estimate would be that of the 790 mm/year incident on the dumpsite 500 mm/year is absorbed by the waste and becomes leachate. For estimation of leachate quantity, the open dumpsite spread within 50-100 acres is considered and this would result in a current leachate generation from rainfall in the dumpsite of 105,000 m^3/year. If it is assumed that waste input is typically 2000 tons per day for 365 days per year and that 25% of this mass is moisture which is above the field capacity of the waste following compression due to overlying waste, this would result in an additional 182,500 m^3/year of leachate. The total current leachate generation rate would, therefore, be conservatively estimated (upper bound estimate) as 287,500 m^3/year, an average of 788 m^3/day or approximately 9 liters/second. In part this leachate will break out on the slopes of the dumpsite and flow along the surface leachate channels off-site, mainly being discharged into the adjacent major drain and to the open surface water drains in the vicinity of the dumpsite. The remaining leachate will pass vertically downward into the groundwater which underlies the site.

A total of 12 boreholes were augured into the waste (Waste Boreholes (WBH)) more than 20 meters depth in the waste, from which samples of waste and leachate were obtained to assess the characteristics of the waste and leachate. The characteristic of leachate from the WBH boreholes is shown in Table 1 in the column "Average Waste Boreholes Leachate Quality". The samples of surface leachate taken from the various open-drain west, northeast and south side of the dumpsite and are presented in Table 1 in column "Average Surface Drain Leachate Quality". The identified data is then compared with typical characteristic data for Acetogenic Landfill Leachate and Methanogenic Landfill Leachate, in addition to being compared with Type C Surface Water Standards (IS-2296-1982).

Table 1 Results of quality of Leachate in Waste Boreholes (WBH) and Surface water drains

Tested Parameters	Typical Acetogenic Landfill Leachate	Typical Methanogenic Landfill Leachate	ISI-IS: 2296-1982 Type C Surface Water Standards	Unit	Average Waste Boreholes Leachate Quality	Average Surface Drains Leachate Quality
pH	5-6.5	6.5-8.0	6.5-8.0		7.77	7.85
Color	100-2,000	100-2,000	300	pt.co.	22859.60	7476.18
BOD	20,000-40,000	50-1,000	3	mg/l	1047.56	704.33
COD	25,000-60,000	1,000-5,000		mg/l	9152.39	3603.53
BOD/COD	>0.5	<0.5			0.12	0.12
TDS			1500	mg/l	21894.94	19262.42
Iron	several hundred	<50	50	mg/l	238.94	31.74
Chlorides	1,500-3,000	1,500-3,000	600	mg/l	6608.94	6720.46
Sulphate			400	mg/l	872.61	1469.24
So4/Cl					0.13	0.29
Nitrate			50	mg/l	348.24	142.03
Ammoniacal Nitrogen	500 - 2,500	500 - 2,500	0.39(UK DWS)	mg/l	1828.44	979.14
Zinc	10-100	<1	15	mg/l	13.36	0.39
Alkalinity	5,000-15,000	3,000-10,000		mg/l	8592.39	5131.25
Total chromium			0.05	mg/l	5.63	1.47

As shown the BOD concentrations for the leachate in the WBH in waste boreholes had an average of 1047 mg/l and the COD an average of 9152 mg/l. The ammoniacal nitrogen had an average of 1828 mg/l. The pH is high, an average of 7.77.

The BOD concentrations for the surface drains had an average of 704 mg/l and the COD an average of 3603 mg/l. The ammoniacal nitrogen had an average of 974 mg/l. The pH was identified as being high, with an average of 7.85.

The results for the WBH boreholes and the surface drains identified a highly variable leachate quality with characteristics between acetogenic and methanogenic phases. This is likely to result from the open dumpsite not being operated as a controlled sanitary landfill in cells and new waste is thus placed above waste which is very much older. Accordingly, it is likely that leachate from young waste above may mix with leachate from old waste below and this is very much what is seen in the results. The mixing of acetogenic and methanogenic type leachates results in a variable but typically strong leachate quality which has a very significant potential to impact groundwater and surface water resources.

1.2 Groundwater Contamination

A hydrogeological survey was carried out at the dumpsite. The dumpsite and large water pond are hydraulically connected but considering the elevation of the groundwater at the dumpsite and water pond, the results revealed that groundwater flow from beneath the dumpsite is away from rather than towards the water pond.

1.2.1 Boreholes

Groundwater samples were obtained from the boreholes located around the perimeter of the waste mass within the site. The water quality results for these boreholes are presented in Table 2. The groundwater quality results table also identifies the average leachate quality identified in the waste boreholes, as presented previously and the ISI-IS: 2296-1982 Surface Water Standard for surface water which would be conventionally treated before being consumed, both for comparative purposes.

Table 2 Results of quality of Leachate in Waste Boreholes (WBH) and Groundwater in Boreholes (BH)

Tested Parameters	ISI-IS: 2296-1982 Type C Surface Water Standards	Unit	Average WBH Borehole Leachate Quality	Average BH Groundwater Quality at the dumpsite
pH	6.5-8.0	-	7.77	7.52
Color	300	pt.co.	22859.60	472.35
BOD	3	mg/l	1047.56	93.11
COD		mg/l	9152.39	783.72
BOD/COD			0.12	0.27
TDS	1500	mg/l	21894.94	6841.83
Iron	50	mg/l	238.94	0.36
Chlorides	600	mg/l	6608.94	1774.03
Sulphate	400	mg/l	872.61	442.89
SO_4/Cl			0.13	0.39
Nitrate	50	mg/l	348.24	41.78
Ammoniacal Nitrogen	0.39 (UK DWS)	mg/l	1828.44	236.33
Zinc	15	mg/l	13.36	0.04
Alkalinity		mg/l	8592.39	2599.69
Total chromium	0.05	mg/l	5.63	0.05

In the peripheral groundwater boreholes, the average BOD was 93.1 mg/l, COD 784 mg/l, TDS 6841 mg/l, Chloride 1,774 mg/l and ammoniacal nitrogen 236 mg/l. These concentrations are typical of a moderate to weak dumpsite leachate and not typical groundwater. The locations of boreholes are also adjacent to the dumpsite which has identified strong leachate within it, which will be flowing downward and outward. It is therefore not surprising that the groundwater within the boreholes around the dumpsite perimeter is very contaminated with dumpsite leachate.

1.2.2. Handpumps

Samples were also taken from three off-site groundwater supply hand pumps. Two handpumps were located close to the site boundary and one approximately 1.5 km northeast of the site. The hand pump groundwater quality results presented in Table 3 also identifies the average leachate quality identified in the waste boreholes, and the ISI-IS: 2296-1982 Surface Water Standard Class A for water having disinfection only and Class C for water which would be conventionally treated before being consumed, all for comparative purposes.

Table 3 Results of quality of Leachate and Groundwater in nearby Handpumps

Tested Parameters	ISI-IS: 2296-1982 Type-A Surface Water Standards	ISI-IS: 2296-1982 Type C Surface Water Standards	Average WBH Borehole Leachate Quality	Unit	Hand-pump-1	Hand-pump-2	Hand-pump-3
pH	6.5-8.5	6.5-8.0	7.77	-	7.255	7.645	7.72
Color	10	300	22859.60	pt.co.	0.1635	4.305	1.0559
BOD	2	3	1047.56	mg/l		3.31	4
COD			9152.39	mg/l	12	30.5	41.5
TDS	500	1500	21894.94	mg/l	1983	2020	4348
Iron	0.3	50	238.94	mg/l	BDL	BDL	BDL
Chlorides	250	600	6608.94	mg/l	410	400	1499
Sulphate	400	400	872.61	mg/l	146.5	234.5	303.5
Nitrate	20	50	348.24	mg/l	0.95225	0.65075	0.865
Ammoniacal nitrogen	0.39 (UK DWS)		1828.44	mg/l	BDL	BDL	BDL
Zinc	15	15	13.36	mg/l	1.7121	0.1019	0.01775
Alkalinity			8592.39	mg/l	606	438.5	481.5
Total chromium	0.05	0.05	5.63	mg/l	BDL	BDL	BDL

*BDL- Below Detection Level

In the hand pumps the highest BOD was 4 mg/l, COD 41.5 mg/l, TDS 4348 mg/l, and Chloride 1,499 mg/l, Ammoniacal Nitrogen was not detected. These concentrations fall outside of the standard for water that can be consumed with conventional water treatment, but do not show the dumpsite leachate like quality identified for the groundwater boreholes around the dumpsite perimeter. It is not known if the hand pumps are in use, whether the water is used for human consumption or what if any treatment may be carried out before consumption. It is of interest to note that the quality at one Hand Pump which is at significance distance from the dumpsite is of significantly worse quality than at the water at the other two hand pump locations which are adjacent to the site. However, this handpump is immediately adjacent to the surface water pond.

1.3 Surface water Contamination

1.3.1 Major Drain adjacent to open dumpsite

Surface water testing was carried out on the major drain adjacent to the site at three locations, upstream, adjacent to the site and downstream of the site. The drain flows from north to south passing adjacent to the western boundary of the site. The drain had a visible flow at the time of the investigation and the survey identified a shallow gradient of the surface level from north to south confirming flow. This drain meets another drain flowing from the west close to the southern tip of the open dumpsite. The drain adjacent to the site has an obvious dark color which ends where the two drains meet without any visible plume extending downstream. This could indicate that the downstream flow volume is totally dominated by the stormwater drain, that organic matter is significantly and immediately oxidized where the drains meet or that the waters do not mix and there is a hidden deeper plume of denser darker water. At the time of the survey, the water level of the drain adjacent to the site where its confluence with the western drain is slightly lower than the level at the nearby surface water pond. Hence, it is indicated that the drain and surface water pond are not directly connected. The ISI-IS: 2296-1982 Surface Water Standard Class A for water having disinfection only and Class C for water which would be conventionally treated before being consumed, the site average groundwater quality results and the site average waste boreholes leachate quality and drinking water standards (IS 10500) are also presented for comparative purposes in Table 4.

Table 4 Results of Surface Water Quality of Drain adjacent to Open Dumpsite

		Average WBH Borehole Leachate Quality	Average BH Groundwater Quality at the dumpsite	ISI-IS: 2296-1982 Type C Surface Water Standards	Major Drain adjacent to open dumpsite			Parameters of Drinking Water (IS 10500)	
Tested Parameters	Unit				Upstr-eam Side	Adja-cent to Site	Down-stream Side	Desira-ble limit	Permi-ssible limit in the absence of alternate source
pH	-	7.77	7.52	6.5-8.0	7.3	7.245	7.14	6.5-8.5	6.5-8.5
BOD	mg/l	1047.56	93.11	3	13.0	22.5	22.5	-	-
COD	mg/l	9152.39	783.72	-	167.3	237	79.5	-	-
TDS	mg/l	21894.94	6841.83	1500	3317.3	3847.5	1720	500	2000
Iron	mg/l	238.94	0.36	50	0.4	0.199	0.09285	0.3	1.0
Chlorides	mg/l	6608.94	1774.03	600	794.3	1016	462	250	1000
Ammoniacal Nitrogen	mg/l	1828.44	236.33	-	28.7	49	11.75	-	-
Total chromium	mg/l	5.63	0.05	0.05	0.0	BDL	BDL	0.05	0.05

*BDL- Below Detection Level

The upstream side of the adjacent drain was identified as heavily contaminated with BOD of 13.0 mg/l, COD 167.3 mg/l, Ammoniacal Nitrogen 28.7 mg/l and Total Dissolved Solids (TDS) 3,317 mg/l. E Coli was present in the upstream water but absent elsewhere which could suggest an animal fescues source to the upstream contamination. The drain adjacent to the site shows significantly increased contamination, with BOD 22.5 mg/l, COD 237 mg/l, Ammoniacal Nitrogen 49 mg/l, and TDS 3,848 mg/l. It is likely that this sudden deterioration is due to the discharges of surface water leachate from the site and thus the site appears to be having a significant impact upon surface water. At the downstream location, also downstream of the confluence with the stormwater drain, the quality has improved to a degree with BOD 22.5 mg/l, COD 79.5 mg/l, Ammoniacal Nitrogen 11.75 mg/l, and TDS 1,720 mg/l, however, this quality still greatly exceeds the Type C surface water standard. This slightly improved quality will be due to the dilution effect of the stormwater drain or that the water from the two drains is not mixing and only a surface plume derived from the stormwater drain was sampled.

1.3.2 Water Pond and Two small Surface-water pools

Samples were also taken from the nearest large surface water pond at three locations and from the two small pools to the north and west of the site. The results of the surface water quality testing of water pond and two small surface water pools are presented in Table 5 below. The ISI-IS: 2296-1982 Surface Water Standard Class A for water having disinfection only and Class C for water which would be conventionally treated before being consumed, the site average groundwater quality results and the site average waste boreholes leachate quality, drinking water standards (IS 10500) are also presented for comparative purposes in Table 5.

Table 5 Results of Surface Water Quality of Water Pond and Two small Surface-water Pools

		Average WBH Borehole Leachate Quality	Average BH Groundwater Quality at the dumpsite	ISI-IS: 2296-1982 Type C Surface Water Standards	Surface Water Pools		Water Pond (avg. of 3 samples)	Parameters of Drinking Water (IS 10500)	
Tested Parameters	Unit				North of dumpsite	Northwest of dumpsite		Desirable limit	Permissible limit in the absence of alternate source
PH	-	7.77	7.52	6.5-8.0	7.88	7.69	7.49	6.5-8.5	6.5-8.5
BOD	mg/l	1047.56	93.11	3	212.00	160.67	39	-	-
COD	mg/l	9152.39	783.72	-	1479.64	1417.12	333	-	-
TDS	mg/l	21894.94	6841.83	1500	5725.33	7666.67	4481	500	2000
Iron	mg/l	238.94	0.36	50	1.41	1.86	0.081	0.3	1.0
Chlorides	mg/l	6608.94	1774.03	600	2007.71	2224.31	1349	250	1000
Ammoniacal Nitrogen	mg/l	1828.44	236.33	-	310.92	122.91	BDL	-	-
Total chromium	mg/l	5.63	0.05	0.05	0.14	0.17	BDL	0.05	0.05

*BDL- Below Detection Level

The average results for the parameters identified in surface water pond samples were BOD 39 mg/l, COD 333 mg/l, and TDS 4,482 mg/l. These concentrations are even higher than were seen in the surface water drains. Ammoniacal Nitrogen was however recorded as "Below Detection Limit", for all three samples. The absence of Ammoniacal Nitrogen could result from retardation and decay whilst passing through soil and/or rock between the source and the water pond, assimilation into biomass in the water pond or Nitrification, biological oxidation by aerobic bacteria in the water pond. The small surface water pools to the north and west of the site outside of the site boundary identified highly contaminated water comparable to the groundwater and leachate quality seen at the site as determined from the borehole samples.

1.4 Contamination in soil-like-material that can be recovered from legacy waste through landfill mining

In accordance with Section 15 and Clause J of Schedule I of MSW rules 2016, the feasibilities of Bio-Mining/ Bioremediation/Landfill Mining of the legacy waste were assessed at the open dumpsite with several tests. It is found that the soil-like material below 4mm size from Bio-Mining/Landfill Mining of legacy waste had high contaminants and was not found suitable for use for the off-site application. The contaminants in the Soil-like material (minus 4 mm) were assessed based on the following parameters.

1.4.1 Total heavy metals in the solid matrix of Soil like material

Table 6 presents the comparison of heavy metals analyzed in the Soil-like material with compost standards (MSW rules, 2016) and local soil (Delhi silt).

Table 6 Total heavy metal in the solid matrix of Soil-like material

Metals (mg/kg)	Soil-like material	Local soil	Compost standards
Zn	660-1003	28-63	1000
Pb	92-191	3.8	100
Cd	5.8-7.9	0.9-1.8	5
Ni	35-70	11-22	50
Ba	116-124	23-65	-
Cr	182-422	19-40	50
Hg	2.0-4.5	0.32-0.45	0.15
Cu	329-788	7-18	300

With respect to the local soil, the Zinc, Lead, Cadmium, Nickle, Barium, Chromium, Mercury and Copper were found to be high in the Soil-like Material and with respect to the compost standards Lead, Chromium, Mercury and Copper were found to be high in the Soil-like Material reclaimed from the open dumpsite.

Table 7 Results of Intensity of Color, Organic Content, and Total Soluble Solids

Tested Parameters	Soil-like material	Local soil
Intensity of color (Platinum-Cobalt Unit)	225-460	25-30
Organic content (%)	12-19	1-1.2
Total soluble solids (%)	1.8-2.2	0.1-0.2

Table 8 shows the comparison of physicochemical characteristics of water extract prepared from soil-like material with water extract of local soil and drinking water standards.

Table 8 Physicochemical characteristics of water extract

S.No.	Parameters	Dumpsite	Local soil (Delhi silt)	Drinking water standards
1	pH	8.2-8.5	7.2	7-8.5
2	EC (μS/cm)	2687-3284	269-374	-
3	TDS (mg/L)	1800-2200	180-250	500
4	Hardness (mg/L)	600-1100	144	500
5	Alkalinity (mg/L)	120-240	60	200
6	COD (mg/L)	140-260	30	Nil
7	Ammoniacal nitrogen (mg/L)	11 to 28	2-2.5	0.5
8	Nitrate (mg/L)	165	BDL	45
9	Fluoride (mg/L)	0.012-0.226	0.616	1
10	Bromide (mg/L)	BDL	BDL	-
11	Sulfate (mg/L)	375-500	33	200
12	Chloride (mg/L)	255-450	70-100	250
13	Magnesium (mg/L)	43-63	7	-
14	Calcium (mg/L)	150-360	45	75

*BDL- Below Detection Level

With respect to the water extract prepared from local soil, pH, EC, TDS, Hardness, Alkalinity, COD, Ammoniacal nitrogen, nitrates, sulfates, chlorides, calcium and magnesium in the water extract of Soil-like Material were found to be excessively high. With respect to the drinking water standards, TDS, Hardness, COD, Ammoniacal nitrogen, nitrates, sulfates, chlorides, calcium and magnesium in the water extract of Soil-like Material were found to be excessively high.

2. CONCLUSION

This paper presents an overview of sub-surface contamination caused by one of the major open dumpsites of Delhi. The study was conducted and results of a sample of contaminated substances such as groundwater, surface water, and soil revealed that the concentration of municipal solid waste in the dumpsite had progressively polluted these elements over time.

The major drain adjacent to the dumpsite receives leachate through surface water flow from the open dumpsite. The sewerage flowing in the surrounding surface water drain from nearby colonies also goes to the surface water pond, which is also polluted. The groundwater in the area is contaminated by all these three sources i.e. major drain adjacent to open dumpsite, water pond nearby to dumpsite and open dumpsite itself. Hence, for groundwater decontamination, it is essential that all these three sources are cleaned up before any decontamination scheme /operations are started. The major contamination occurs due to leachate flowing on surface drains and percolating down in the soil, so it is important that:

- The generation of leachate must be reduced. The generated leachate should be collected and managed with proper treatment and safe disposal/reuse.
- Dumpsite should not receive further fresh MSW

For reducing pollutions, following remedial measures should be initiated:

- Providing stable slopes by re-grading.
- Landfill mining to the extent possible to extract materials required for use of landfill closure and for reducing the quantities of waste.
- Cover with C & D / Landfill mined inert materials to reduce fire and smoke which will reduce dust & odor emissions.
- Provide leachate collection and management system to reduce leachate generation and treatment of leachate.
- Provide landfill gas collection and management systems (destruction /power generation) to reduce the emission of greenhouse gas in the atmosphere.
- Provide a multilayer liner system as specified in MSW rules to reduce leachate generation by almost 90 % and facilitate the efficient recovery of gas and leachate.
- To monitor for contamination of groundwater regularly. For monitoring purposes minimum 5 (Five) Nos. monitoring wells can be drilled. If impacts of contamination in the groundwater abstractions are identified in the future after all the above-mentioned precautions (point 1 to 6), the scheme for groundwater decontamination by means of cut-off wall or groundwater pumping can be implemented in second phase after capping of the dumpsite and cleaning of other two sources i.e. major drain adjacent to open dumpsite and water pond nearby to dumpsite.

Soil like materials obtained from Landfill mining have high contaminants and were not suitable for off-site application as the material is neither “good soil” nor “compost/soil enhancer” nor “inert”. However, many experts recommended using this material for filling barren land/borrow pit or create embankment. Before using such materials for filling, pilot-scale trials and tests required for its consequences as these are may cause contamination of the surrounding ground and groundwater. It is most likely that such materials can be recovered only in the quantities which are required for covering the dumpsite and to control the fire as part of site closure.

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Remedial Measures Following Failure of Leachate Collection Layer of Hazardous Waste TSDF

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EXTENDED ABSTRACT

During a routine inspection of the hazardous waste treatment storage disposal facility (TSDF) at Laksar, Uttarakhand, in 2018, multiple air pockets underneath the liner were observed protruding from the primary leachate collection system, exposing the liner.

I was requested to investigate the cause, possible contamination and remedial measures by a committee of the CPCB and SPCB member secretaries. Despite a commitment for funds for the investigation, the investigation has not been funded thus far and the study was done on a shoestring budget. A review of the site, the hydrogeological conditions and the weather conditions preceding the appearance of air pockets indicated two possibilities:

1. Liner uplift by water pressure
2. Liner uplift by wind

Further investigation revealed, among other issues, concerns about the following:

1. The integrity of primary and secondary leachate collection system
2. The capacity of leachate collection and management system to collect and treat the leachate during the monsoon period
3. Anchoring of liner

Initial investigation focused on the liner uplift by wind due to the improper anchoring of the liner. Later on, going through site conditions, the chronology of extreme weather events preceding the appearance of the air pockets and available literature, I deduced that liner uplift by water pressure was the primary cause. The landfill is located near a non-perennial source of surface water stream which has a meandering flow of about 0.25 m depth during the monsoon.

After halting the further usage of the landfill cell and having the standing 1.5 m head of leachate pumped out and treated, I investigated the primary leachate collection layer. The layer was uplifted at multiple locations and was not fit for its purpose. The leachate collection pipes, their alignment, and the slope were disturbed. Thus, the operator was directed to remove the layers of the primary leachate collection layer above the entire liner for the inspection of the liner, which was found to be satisfactory. The operator was then made to relay the primary leachate collection layer while taking care to rectify the errors that were detected in the initial construction of the leachate collection layer. These included a protection layer above the liner, a porous layer of sufficient depth and a geotextile layer all over the primary leachate collection layer. The typical practice in India is to wrap the leachate collection pipes with the geotextile. The literature review revealed that such a practice leads to relatively quick clogging around the geotextile, leading to a non-functional leachate collection system. The reason for such clogging around the geotextile when it is wrapped around the leachate collection pipes is that the high concentrations of heavy metals and ligands around the geotextile lead to precipitation on and around the geotextile, preventing the leachate from being collected by the leachate collection pipes. Available data suggested that a better alternative is to lay the geotextile over the final layer of the primary leachate collection system, to prevent clogging due to fine particles.

Parallel investigations included rudimentary analysis to identify the flow of groundwater during the monsoon and non-monsoon periods, and groundwater sampling upstream and downstream of the TSDF to investigate the contamination of the groundwater. While no conclusive proof was available from the analysis of heavy metals, considering the effects of the redox chemistry of the subsurface on the heavy metals, a second round of sampling focused on TDS and chloride, whose concentration was very high in the leachate. Chloride is typically stable under most redox potentials and is not adsorbed onto the soil, nor does it usually precipitate. But, ligand formation was a possibility. The analysis indicated a possibility, but not conclusive proof, of contamination of groundwater in the vicinity of the TSDF by the leachate. Considering the shallow groundwater table and possible shallow contamination, if any, and the known locations of the possible source of contamination, permeable reactive barriers were considered and will be placed if further investigations, if any, reveals contamination of the groundwater.

Water balance to account for the leachate during the active period of the landfill operation and the leachate management capacity of the landfill were analyzed, to try to account for any significant leak from the landfill and primarily to consider whether the current leachate management system is designed to handle the leachate generated during the active phase. Relevant remedial measures were suggested and are being implemented. Upon my advice, piezometers were installed to monitor the groundwater level below the surface. During the inspection, the landfill at Laksar had considerable standing leachate. The leachate collection and treatment system should be designed in such a way to reasonably handle the leachate generated during such phases. But, the current leachate collection and incinerator based treatment system is inadequate to handle the leachate generated during the monsoon season during the active phase. Thus, the operator was requested to augment the leachate collection and storage or treatment system; the operator has now initiated steps to build a stand-by solar evaporation pond. Aspects investigated included the leachate collected through the primary and secondary leachate collection systems. The lack of measurable head in the secondary leachate collections system (leak detection system) indicated that the primary liner was probably operating effectively. The one caveat was that there would be no leachate collected in the secondary collection system if the leachate collection system was poorly installed or has clogged. Inspection of the secondary collection sump indicated that leachate had seeped through to the secondary leachate collection system. Samples taken and analyzed from this sump indicated the fluid to be leachate. As per the markings on the periphery of the collection tank, the head was higher in the past. Lack of a verifiable leachate flow measurement system hindered the ability to measure the leachate collected by the secondary leachate collection system and to gauge the integrity of the primary leachate collection system. While it is not uncommon for leachate to be collected in the leachate detection system, the lack of worthwhile data from the system, precluded any further analysis.

The investigation is a work in progress. The operator has been cooperative during the investigation and has complied with all the directions given to him. The above document is for furthering academic knowledge in the academic community only and should not be used for possible litigation.

Keywords: Hazardous waste landfill; TSDF; leachate collection layer

Heavy Metal Contamination in Soil of Jaipur City

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ABSTRACT
The study presents the initial findings regarding heavy metal contamination of the soils of Jaipur city. Five heavy metals i.e. Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb) and Zinc (Zn) were assessed in the soil samples. The mean concentrations of the heavy metals (mg/kg) in Jaipur were as follows: 79.79, 41.03, 25.75, 15.15 and 10.2 for Cd, Cr, Cu, Pb, and Zn respectively. Cadmium was found to be exceeding the soil limits and the mean concentrations encountered in other studies for urban soils. Pollution indices indicated the main contribution of lead and zinc. Although the values of hazard indices for any of the metals did not exceed 1 (for adults), cadmium produced the maximum values of hazard index. The cancer risk from the carcinogens i.e. Cd, Cr, and Pb was within the acceptable range.

Keywords: heavy metals; risk assessment; urban contamination; India; Jaipur

1. INTRODUCTION

Due to the continuous urbanization and industrialization in many countries of the world, heavy metals are continuously emitted into the terrestrial environment and pose a great threat on human health (Luo *et al.*, 2012; Karim *et al.*, 2013) The sources of heavy metals in the environment are mainly derived from anthropogenic activities. For urban soils, the anthropogenic sources of heavy metals include emission from industrial activities (power plants, coal combustion, metallurgical industry, auto repair shop, chemical plant, etc.), emissions from vehicles (particulates from vehicle exhaust, tire wear particles, weathered street surface particles), domestic emission, weathering of building and pavement surfaces (Ahmed and Ishiga, 2006; Manta *et al.*, 2002; Sharma, Agrawal and Marshall, 2007; Hu *et al.*, 2011; Luo *et al.*, 2012, 2015; Karim *et al.*, 2013; Sarker *et al.*, 2015; Kumar *et al.*, 2019).

When excess amounts of heavy metals enter the pedosphere, soil quality decreases due to the reduction of soil productivity. In addition, exposure to heavy metals may pose a health risk to human beings. For example, acute and chronic exposure to Arsenic would result in skin disorders including skin cancer. Furthermore, most of the heavy metals are released in huge quantities from industrial and agriculture activities and accumulate in soil (Jiang and Li, 2020). The industrial and agricultural activities are continuously rising due to the rapid social and economic development and consequently, soil pollution is becoming an increasingly severe environmental problem, especially in industrial and agricultural regions. As urban soils act as a sink for heavy metals, these are important indicators of urban environmental quality. Soils polluted with metals can affect human health, soil microbial community, water resources (surface and ground), food quality, flora, and fauna. Therefore, the study of soil contamination is an important way of determining the origin, distribution, and level of heavy metals.

The present study attempts to investigate the distribution of heavy metals in the soils of Jaipur city and to estimate the non-cancer and cancer risk due to the heavy metals present in soils of the city.

2. MATERIALS AND METHODS

2.1 Jaipur City Profile

Jaipur city is the capital and largest city of the Indian state of Rajasthan. Its municipal boundary of the city extends from 26º46' N latitude to 27º01'N latitude and 75º39'E longitude to 75º57'E longitude. The population of Jaipur city is about 31 Lakhs as per census 2011.

Jaipur city is a popular tourist destination in India. The city has a number of industrial clusters. The industries in Jaipur consist of mineral-based, cement manufacturing, textiles, cotton-based, paper-based, electrical appliances industry and food-based Industries (MSMEDI, 2016).

2.2 Sampling and Analysis

Five heavy metals (i.e. Cd, Cr, Cu, Pb, and Zn) were selected for the study. A total of 27 samples were collected from nine locations in Jaipur (Fig.1). Sampling sites selected represented a variety of land uses e.g. commercial and residential, public parks and stadiums and industrial areas. All the samples were collected with a stainless-steel spatula and kept in PVC packages, at room temperature. For laboratory analysis of heavy metals, the samples were first digested and then analyzed with Atomic Absorption-spectrophotometer (Bhattacharya *et al.*, 2010). The process of digestion included adding HNO_3, H_2SO_4, and $HClO_4$ to the soil sample and subsequent heating. Finally, the sample was filtered through Whatman No. 42 filter papers. The filtered samples after digestion were taken to Atomic Absorption-spectrophotometer for determining heavy metals.

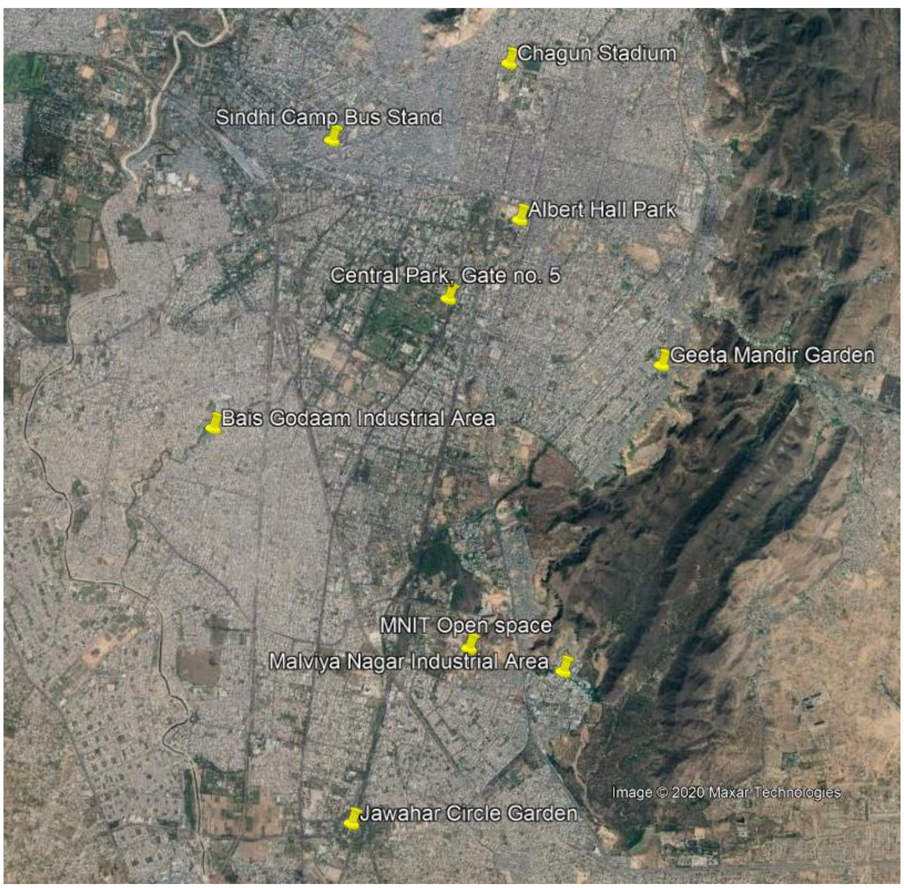

Fig. 1 Sampling locations in Jaipur city (Source: Google Earth)

2.3 Risk Estimation

After determining concentrations of heavy metals, the risk for non-cancer and cancer was estimated. The assessment of non-cancer risk is done for three different pathways of exposure i.e. oral intake, intake of re-suspended particulates emitted from the soil through the mouth and nose and intake through exposure to skin.

The following equations are used for determining hazard quotients (non-cancer effects) (Chabukdhara and Nema, 2013).

$$Intake_{ingestion} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (1)$$

$$Intake_{inhalation} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (2)$$

$$Intake_{dermal} = \frac{C \times SA \times SAF \times ABS_{Dermal} \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (3)$$

$$Health\ Quotient(HQ) = \frac{Intake}{R_f D} \quad (4)$$

$$Hazard\ Index(HI) = \sum HQ_{ex} P \quad (5)$$

Where Intakeingestion and Intakeinhalation and Intakedermal represent the estimations of intake via each route of exposure respectively; C – concentration corresponding to upper limit of 95% confidence interval; IngR – ingestion rate expressed in mg/day; EF – exposure frequency (days/year); ED – exposure duration; BW – body weight; AT – averaging time; InhR – inhalation rate (cu.m./day); PEF – particle emission factor (cu.m/kg); SA – skin surface is available for daily contact (cm2); SAF – skin adherence factor; ABSdermal – dermal absorption factor; The values of the input parameters were used as provided in (Chabukdhara and Nema, 2013).

Cancer Risk is estimated as the incremental probability of an individual developing cancer over the lifetime as a result of exposure to a potential carcinogen. It is estimated by multiplying inhalation intake with the cancer potency factor of the respective carcinogen.

$$Cancer\ Risk = Intake_{inhalation} \times Cancer\ Potency\ Factor(CPF_s) \quad (6)$$

3. RESULTS AND DISCUSSIONS

3.1 Heavy Metal Concentrations

The concentrations for the heavy metals in Jaipur city are in the following order: Zn>Pb>Cr>Cu>Cd. The mean values of the heavy metal concentrations (mg/kg) in Jaipur were as follows: Cd (10.2), Cr (25.75), Cu (15.14), Pb (41.03) and Zn (79.79).

When compared to mean concentrations in road-side soil (Kumar et al., 2019) from India, Cd is the only metal that surpasses the mean concentrations (Table 1). When the concentration of Cadmium in Jaipur city is compared with other studies (e.g. mean concentrations of urban soil in China and Swedish limits for soil), its concentration is higher. The concentrations of other heavy metals were lower.

Within the city, the highest concentrations for Cd and Pb are found in the soils of location L-1. This site also carries the second-highest concentrations of two other metals i.e. Zinc and

Chromium. The site is an open space in MNIT Jaipur and treated wastewater from the sewage treatment plant in the institute is frequently drained in this space after fulfilling the landscaping needs of the campus. The highest concentration of Chromium was found out to be in Malviya Nagar industrial area. For Copper and Zinc, the highest concentration was near Sindhi Camp bus stand, a location bustling with commercial activities and having the central bus depot of Rajasthan State Road Transport Corporation.

Table 1 Descriptive statistics for heavy metals concentrations in Jaipur city and comparison with mean concentrations and soil limits

Location	Cd	Cr	Cu	Pb	Zn
Min (Present study)	5.75	13.1	6.7	21.45	40.3
Max (Present study)	13.9	42.85	52.9	63.85	154.35
Mean (Present study)	10.20	25.75	15.14	41.03	79.79
Std Dev (Present study)	2.349	6.157	9.740	9.224	21
Road side soil (Kumar *et al.*, 2019)	0.66	55.35	42.25	54.66	88.86
Soil from urban areas in China (Li et al 2014)	0.88	76.80	99.20	61.30	133.0
Swedish limits for soil (Kumar *et al.*, 2019)	0.4	120	100	80	350
Canada soil guidelines (Kumar *et al.*, 2019)	-	64	63	140	200

The contamination at a location can be defined by pollution indices, which is a function of the target values of heavy metals in soil (Cheng et al., 2014). The pollution indices for all the locations were calculated and have been shown in Fig. 2. For Cadmium, the pollution index was higher than 1 at L-1 only. For Chromium, the pollution indices for all the sites were below 1. There were two locations only for which the pollution indices of copper exceeded the value of 1. For lead and zinc, pollution indices of all the sites exceeded the value of 1.

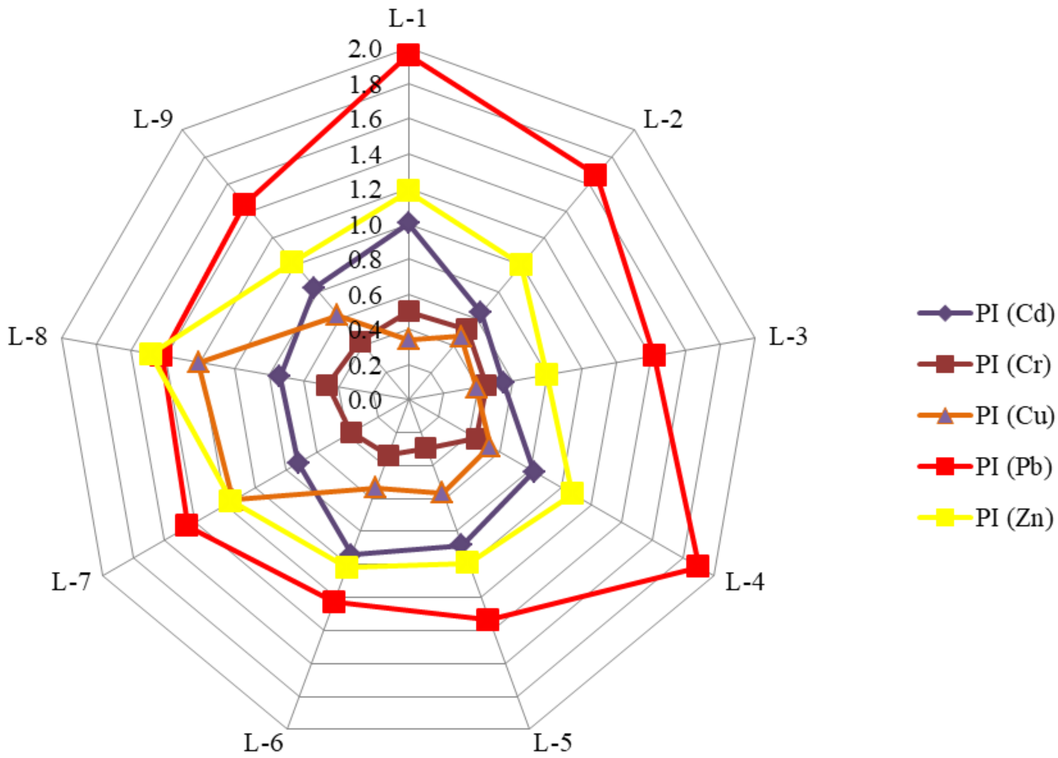

Fig. 2 Pollution indices for heavy metals at different locations in Jaipur

3.2 Risk assessment for non-cancer and cancer

Risk estimates for non-cancer and cancer effects have been made and shown in Table 2. The calculations for risk were done for the adult population only.

Table 2 Estimates of hazard index (non-cancer) and cancer for adults

Heavy Metal	HQ-Ingestion	HQ-Dermal	HQ-Inhalation	HI (non-cancer)	Cancer Risk
Cd	1.72E-02	6.88E-03	2.54E-06	2.41E-02	5.90E-10
Cr	1.45E-02	2.89E-03	2.13E-06	1.74E-02	9.91E-08
Cu	6.24E-04	8.30E-06	9.18E-08	6.32E-04	-
Pb	1.98E-02	5.26E-04	2.91E-06	2.03E-02	2.37E-09
Zn	4.48E-04	8.94E-06	6.59E-08	4.57E-04	-

For non-cancer effects, the values of hazard quotient vary from 0.0004 to 0.02 for the ingestion route; 8.3E-06 to 6.88E-03 for dermal route and 6.59E-08 to 2.91E-06 for inhalation route. It can be inferred from the hazard quotient that ingestion is the main exposure route in urban soils. For ingestion and inhalation, lead produced the maximum hazard quotients, whereas, for dermal contact, cadmium was associated with the maximum hazard quotient. To calculate the hazard index, hazard quotients from all three routes were added. The values of hazard index vary from 0.0005 to 0.02, with the highest value corresponding to cadmium. From these initial results, cadmium seems to be of prime concern for the safety of human health in Jaipur city.

For the cancer risk, the calculations were done for the carcinogens i.e. cadmium, chromium, and lead. The cancer risk was found to be in the range of 5.9E-10 to 9.91E-08. Although the cancer risk found to be in the acceptable range, it is noteworthy to mention here that the maximum risk for cancer was associated with Chromium metal.

4. CONCLUSIONS

The present study demonstrates the initial findings of heavy metal contamination in Jaipur city. Following are the conclusions from the study:

- The concentrations for the heavy metals in Jaipur city are in the following order: Zn>Pb>Cr>Cu>Cd. The mean values of the heavy metal concentrations (mg/kg) in Jaipur were as follows: Cd (10.2), Cr (25.75), Cu (15.14), Pb (41.03) and Zn (79.79).
- Interestingly, cadmium concentration was the lowest among all the heavy metals tested. However, when compared with mean values from other studies and soil limits, cadmium was found out to be in exceeding concentrations.
- For lead and zinc, pollution indices were higher than 1 for all the nine locations. For cadmium and copper, the pollution indices exceeded the value of 1 for one and two locations respectively. For chromium, none of the locations exceeded the value of 1 for the pollution index.
- The hazard quotients were calculated for three routes i.e. Ingestion, dermal and inhalation. Ingestion was found to be the main route of exposure for urban soils. Cadmium gave the maximum value of the hazard index and seems to be the main concern in Jaipur city.
- Cancer risks were estimated for cadmium, chromium, and lead. Although cancer risks for all three metals were found to be in the acceptable range, the maximum value was obtained for chromium, as opposed to cadmium.
- The study shows the contribution of different metals in damaging the urban environment and highlights the importance of comprehensive environmental planning.

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Ground and Surface Water Contamination due to Boragaon Dumpsite in Guwahati City

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Keywords: Physicochemical; leachate; dumpsite; contamination

1. INTRODUCTION

In Guwahati city, presently the municipal solid waste disposal system is mere open dumping of wastes generated, at one location, Boragaon, which is around 12 kilometers from the central city. The Boragaon landfill site, which is being operated as a non-engineered dumpsite for the last 11 years is causing a potential threat to the surrounding environment and expected to cause serious surface and groundwater contamination in its vicinity. To evaluate the environmental impact from this dumpsite, sampling and physicochemical analyses of leachates collected in both winter and monsoon seasons from dumpsite are carried out. To analyze the impact of leachates, samples of groundwater and surface water are collected within a radial distance of 0.30 km from the downstream side of the dumpsite, which, after analysis, clearly indicates the likely contamination of ground and surface water due to landfill leachate.

2. MOTIVATION AND OBJECTIVE

Our study area, Guwahati, is the second-largest city of eastern India after Kolkata with a total population more than one million, located between latitude 91°34"E & 91°51"E; longitude 26°04'27"N & 26°13'51"N. The average annual rainfall within the range of 1500mm and 2200 mm. The groundwater table varies from an average depth of 5-15 m from the top surface (Bakshi et al.,2006) and at the nearby location of Boragaon dumpsite it is 3-5 m from the top surface. The objective of this study to check the effects leachates generated from the open dumpsite on ground and surface water at the nearby areas and also to check the discharge potential of the leachates in stormwater drains based on Indian standard.

3. METHODOLOGY

To study the extent of the groundwater contamination in nearby areas of Boragaon dumpsite, 3 wells were selected within 0.3 km radial distance to collect groundwater samples (Hossain et al., 2010) and surface water samples are collected from the stormwater drains where untreated leachate is discharged. In-situ parameters for the leachate such as temperature, electrical conductivity (EC), pH, salinity and dissolved oxygen (DO) were tested at the site itself. All the samples were analyzed for selected relevant physicochemical parameters and heavy metals. For groundwater samples, total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), ammonia (NH_4^{+}), chloride (Cl^{-}), fluoride (F^{-}), sulphate (SO_4^{2-}) and nitrate (NO_3^{-}) are examined in laboratory. The concentration of TA, TH, Ca^{2+}, Mg^{2+}, and Cl^{-} were estimated by the titration process whereas Fluoride was estimated by SPANDS. SO_4^{2-}, NO^{3-}, NO_2^{-} and NH_4^{+} were determined using UV/VIS spectrophotometer. The concentrations of cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), nickel (Ni), lead (Pb) and zinc (Zn) were determined using a SpectrAA

4. IMPORTANT OUTCOMES

Total dissolved solids (TDS), electrical conductivity (EC), and Na^+ exceeded the BIS limits, for drinking water in the groundwater samples with pH and Fe exceeding BIS limits in 60% of the samples and Cl and As in 30% of the samples. The higher concentration of iron (2.36 mg L^{-1}), chloride (2600 mg L^{-1}) and As (0.65 mg L^{-1}) in groundwater is found to be alarming.

Contaminants in leachate which were exceeding the maximum permissible limits were identified as chloride, BOD, COD, total dissolved solids, fluoride, and lead. The presence of these contaminants in excess is responsible for the pollution of surface water sources. The COD content in all the samples was exceeding the maximum permissible limit. Surface water samples showed a high percentage of COD, Ammonium, Cadmium, Chromium and Lead which were exceeding the maximum permissible limit.

5. CONCLUSIONS

MSW dumpsites are causing a hazard to the environment and health of surrounding living beings by contaminating surface and groundwater. Necessary steps should be taken by the authority to prevent further contamination of groundwater from leachates in Boragaon dumpsite.

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