ENVIRONMENTAL FEASIBILTIY OF COARSER FRACTION OF MSW LEGACY WASTE AND COST ANALYSIS OF ITS BIOMINING AND BIOCAPPING AT LANDFILL

Thesis Submitted

By

Ankush Dey

Class Roll: 002210402029

Examination Roll: M4CIV24026

Registration: 163472 of 2022-2023

MASTER OF ENGINEERING

Under the supervision of

Dr. Amit Dutta

JADAVPUR UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING

(ENVIRONMENTAL ENGINEERING DIVISION)

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DECLARATION

The Thesis titled "**Environmental Feasibility of Coarser Fraction of MSW Legacy Waste and Cost Analysis of its Biomining and Biocapping at Landfill**" is prepared and submitted for the award of the degree of Master of Engineering in Civil Engineering course of Jadavpur University for the session of 2022 – 2024. I declare that the work described in this thesis is entirely my own. No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute. Any help or source information which has been awarded in the thesis has been duly acknowledged.

Date: ---

Ankush Dey

M.C.E – 2nd Year

Class Roll: 002210402029

Examination Roll: M4CIV24026

Registration: 163472 of 2022-2023

Environmental Engineering Division

Department of Civil Engineering

Jadavpur University

JADAVPUR UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING

KOLKATA – 700032

RECOMMENDATION CERTIFICATE

This is to certify that the thesis entitled "**Environmental Feasibility of Coarser Fraction of MSW Legacy Waste and Cost Analysis of its Biomining and Bio-Capping at Landfill**" is prepared and submitted by Ankush Dey, be accepted in partial fulfillment of the requirements for the degree of Master of Civil Engineering with specialization Environmental Engineering from Jadavpur University is absolutely based upon his own work under the supervision of Professor Dr. Amit Dutta and that neither his thesis or any part of this thesis has been submitted for any degree or any other academic award anywhere before.

Signature of the supervisor & Date with Office seal

Dr. Amit Dutta

Professor,

Department of Civil Engineering

Jadavpur University

Countersigned by:

Dean

Faculty of Engineering & Technology

Jadavpur University

Countersigned by:

Head of Department

Department of Civil Engineering

Jadavpur University

JADAVPUR UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING

KOLKATA – 700032

CERTIFICATE OF APPROVAL

This is to certify that this thesis is hereby approved as an original work conducted and presented satisfactory to warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is implied that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it is submitted.

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Place: Kolkata

Date:

Ankush Dey

M.C.E – 2nd Year

Class Roll: 002210402029

Examination Roll: M4CIV24026

Registration: 163472 of 2022-2023

Environmental Engineering Division

Department of Civil Engineering

Jadavpur University

ABSTRACT

Urban India accounts for 62 million metric ton (MT) of MSW generally annually. Increased growing rate of waste generation has acquired huge land area by converting virtual mountains of old legacy waste. These old landfills are possessing real threat to the environment in terms of contaminating air, water and land. Emission of methane, carbon dioxide, ammonia, hydrogen sulphide, and volatile organic carbon (VOCs) causing from the landfill degradations, persistence of heavy metals, to vegetations, groundwater and surface water due to leaching of toxic leachate, emission of carcinogenic compounds, Hydrocarbons (HC), dioxins and furans from landfill fires are all such aspects not only deteriorating environmental standards but also inculcating human and ecological risk. In India, around 10,000 hectares of urban land is locked in these open dumpsites. Open dumping is the major problem associated with most of the Asian cities. Thus, it is needed to reclaim the existing open dumping grounds in many Asian cities and nowadays biomining remediation methods will be the most viable solution for the reclamation. Biomining is advantageous than biocapping of closed dumping site in terms of reducing the greenhouse gas emissions, reducing the footprint area of landfill, avoiding the surface water and groundwater contamination, improving reuse and recycling concepts and reducing the post-closure operation and maintenance costs which raise the requirement of biomining concepts.

Biomining involves the processes like excavation, waste stabilization, screening and separation of materials from landfills into various components including recyclable materials, combustibles, inert materials and soil-like materials (both finer & coarser fraction) with a sustainable approach to prolong the landfill life and to remediate the contamination from unlined open dumpsites. A precise study was carried out on the environmental feasibility of the coarser fraction of the legacy waste excavated from the age-old dumpsites. A correlation matrix and ANOVA helps in assessing the relationships and differences among variables in coarser fraction of soil-like materials. The study investigates the depthwise and seasonal variations of the coarser fraction of soil-like materials obtained from legacy waste at Dhapa. The coarser fraction comprising particles greater than 4.75mm was analyzed for physical and chemical properties at different depths (0 - 20)m and seasons (winter, summer and monsoon). Results show significant depthwise variations in particle-size distribution, density and moisture content. The top (0-8) m layer exhibited lower moisture content (water holding capacity – 34%) and higher coarser particles (Gravel – 21%) while the lower layers of depth between 17m and 20m showed increased density (1.47 gm/m^3) and finer particles (Sand - 78.38%). Seasonal variation revealed higher moisture content during monsoon (43.2%) and lower value in summer (38%). Physicochemical analysis indicated minimum seasonal changes for significant depthwise variations in pH, EC, and organic content. Principle component analysis identified depth and season as key factors influencing the coarser fractions characteristics'. These findings have implication for resource recovery, waste management and environmental monitoring,

highlighting the importance of considering depthwise and seasonal variation in soil-like material characterization. These statistical techniques are essential for unlocking the full potential of soil-like material from legacy waste, ensuring its safe and sustainable management.

Assessments of the total heavy metals and leachate characteristics have been done in order to trace out the variation of the concentration of the above mentioned parameters with respect to the soil depths. The concentrations (mg/kg) of the heavy metals like lead (49±21.5), nickel (20.74±7.64), cadmium (0.701±0.62), copper (44.28±7.30), and zinc (257.77±72.11) are very much below the suitable range. For Leachate characteristics of the soil-like materials, it can be said that concentration (mg/l) of the lead (1.04±0.58), nickel (0.60±0.45), copper (0.45±0.28), total chromium (0.75±0.42), mercury (0.00±0.00), arsenic (0.01±0.00), cadmium (0.02±0.02), zinc (5.58±3.06), iron (10.13±4.82), manganese (10.13±4.82) are within the range. Exception is the mercury concentration (0.00±0.00) which is almost negligible.

Biomining and Biocapping are the two options of bioremediation techniques. By conducting a cost comparison, stakeholders can make informed decisions, optimize resources and ensure this sustainability of legacy waste management project. Cost comparison is required (i) to determine the cost effective approach for legacy waste management, ensuring optimal use of resources, (ii) to establish a realistic budget for the project considering the cost of different approaches, (iii) to inform decision makers about the financial implications of different options, enabling him to make informed choices, (iv) to prioritise projects or activities based on their cost effectiveness and potential impact, (v) to evaluate the financial performance of different approaches and identify areas for improvement, (vi) to compare costs with industry standards, benchmarks, or other similar projects (vii) to identify opportunities for cost reduction or optimization without compromising environmental or social benefits, (viii) to communicate costs and benefits to stakeholders, ensuring transparency and accountability, (ix) to identify and mitigate potential costs related risks associated with different approaches, (x) to ensure that the chosen approach is sustainable in the long term considering both environmental and financial aspects. The comparative cost analysis of biomining and biocapping for legacy waste management reveals (i) biomining is more cost effective approach with a total cost of Rs. 260 crores compared to biocapping which costs Rs. 115 Crores including the 5 years operation and maintenance cost (ii) Biomining offers significant saving of Rs. 1800 Crores due to the recovery of valuable resources and reduced landfill costs, along with the cost of land recovered after biomining (iii) biocapping, while more expensive, provides a higher level of environmental protection & safety.

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LIST OF ABBREVIATIONS

i. APHA – American Public Health Association
ii. AAS – Atomic Absorption Spectrometry
iii. AAQ – Ambient Air Quality
iv. ANOVA – Analysis of Variance
v. BMC – Bombay Municipal Corporation
vi. Br-XV – Borough XV
vii. BH – 6 – Borehole – 6`
viii. CPCB – Central Pollution Control Board
ix. C/N Ratio – Carbon to Nitrogen Ratio
x. CSE – Centre for Science and Environment
xi. CPHEEO – Central Public Health and Environmental Engineering Organization
xii. C&D Waste – Construction & Demolition Wastes
xiii. ESIC – Employees' State Insurance Corporation
xiv. EPA – Environmental Protection Agency
xv. EURELCO – European Consortium for Landfill Mining
xvi. EIC – Export Inspection Council
xvii. FOD – First Order Decay Model
xviii. GHG – Greenhouse Gas
xix. HDPE – High-Density Polyethylene
xx. IPCC – Intergovernmental Panel on Climate Change
xxi. ICP – Inductively Coupled Plasma
xxii. KMC – Kolkata Municipal Corporation
xxiii. LFM – Landfill Mining
xxiv. LFG – Landfill Gas
xxv. MT – Metric Ton
xxvi. MOEFCC – Ministry of Forest, Environment and Climate Change
xxvii. NGT – National Green Tribunal
xxviii. NHDES – New Hampshire Department of Environmental Sciences
xxix. ORGI – Office of the Registrar General & Census Commissioner, India
xxx. PWM Rules, 2016 – Plastic Waste Management Rules, 2016
xxxi. PPPs – Public-Private-Partnerships
xxxii. RDF – Refused Derived Fuel
xxxiii. SWM – Solid Waste Management
xxxiv. SLM – Soil Like Materials
xxxv. SPSS – Statistical Package for Social Sciences (SPSS)
xxxvi. TOC – Total Organic Carbon
xxxvii. TPD – Ton Per Day
xxxviii. THM – Total Heavy Metals
xxxix. TCLP – Toxicity Characteristics Leaching Procedure

xl. ULB – Urban Local Body
xli. USEPA – United States Environmental Protection Agency
xlii. WBPCB – West Bengal Pollution Control Board

CHAPTER-I: INTRODUCTION

1.1 ORIGIN OF LEGACY WASTE & ITS MANAGEMENT

Open dumping is the major problem associated with most of the Asian cities. Continuous negligence and lack of awareness for sustainable and scientific treatment of municipal solid wastes has forced us to open dumpsites. In India, uncontrolled dumping of mixed municipal waste aided by flawed laws has created around 3,159 dumpsites (CSE, 2020). Continuous changing in the nature of the municipal solid wastes also played an important role in this issue. The term legacy wastes generally referred to the aged municipal wastes dumped in open dumpsites. Since there are no proper criteria which a waste has to fulfil in order to be called a legacy waste, it has been decided that the waste will be considered a legacy waste if it is 15 years older or more than that. As per Swachh Bharat Mission Toolkit for Legacy waste management, the composition and characteristics of the legacy waste is completely different when compared with fresh municipal waste generated on daily basis. The management of solid waste in cities or town is influenced by two prime factors: (i) the handling of the daily constant flow of solid waste, and (ii) dealing with the legacy of neglect that has led to accumulation of waste at dumpsites which are intended for waste processing.

Thus, it is needed to reclaim the existing open dumping grounds in many Asian cities by adopting the landfill remediation measures like Biomining. Biomining is advantageous than Biocapping of legacy dumpsites in terms of reducing the greenhouse gas emissions, reducing the footprint area of the landfill, avoiding the surface water and groundwater contamination, improving reuse and recycling concepts. From the financial perspective, Biomining also reduces the post-closure operation and maintenance cost which raises the need of biomining concepts. Materials recovered from MSW can be turned into raw materials useful for other purposes and allied industries. Globally, in legacy waste the soil or organic fraction is very less in case of developed countries and the metal and plastic fraction remain considerably high. Before mining an MSW dumpsite or a non-engineered landfill, a thorough analysis is necessary, especially to assess the cost effectiveness of the project. Therefore, determining the project's economic viability is crucial when making decisions. However upto this point, very few studies have specifically addressed the economics of landfill mining. In order to ensure that projects producing significant social benefits are not overlooked, a thorough approach for evaluating the economic viability of landfill mining should consider both the direct cost and revenues for the private investor as well as the social benefits.

1.2 INDIAN SCENARIO OF LEGACY WASTE MANAGEMENT

Lack of appropriate technology and its improper implementation & management, the existing technology and its associated impact lead to accumulation of waste in a different shape in designated and non-designated places of each urban local bodies (Mandpe et al., 2019). As per Press Information Bureau (PIB), at present nearly 60 million tonnes of waste are generated in India which are primarily mixed wastes (CPCB, 2019). In India, a very few percentages of scrap metal enter the landfills as it is sold directly to scrap dealers or kawariwala from household or collected from landfill by rag pickers. Due to the mixing of street sweeping and drain cleansing waste at the dumpsite, the organic contents are slightly lower than the collected waste composition from the residential, institutional and commercial areas.

In India, increased growing rate of waste generation has acquires huge land area by converting virtual mountains of age-old legacy waste. These old landfills are possessing real threat to the environment in terms of contaminating air, water and land. Emission of greenhouse gases like Methane, Carbon Dioxide, Ammonia, Hydrogen Sulphide and Volatile Organic Carbon (VOCs) from the decomposition of the legacy wastes, persistence of heavy metals to vegetation, groundwater and surface water due to leaching of toxic leachate, emission of carcinogenic compounds, Hydrocarbons, Dioxins, and Furans from landfill fires are all such aspects not only deteriorating environmental standards but also inculcating human and ecological risks. In India, nearly 10,000 hectares of urban land is locked in these open dumpsites. As per IPCC 2001, the Methane gas produced from the open dumpsites has a share of (3-4) % of the annual global man-made greenhouse gas emissions. From 2014 onwards, the Swachh Bharat Mission (SBM) has been giving importance on dumpsite reclaimation and minimization of adverse environmental impact adhering to the Solid Waste Management Rules, 2016. As per SBM manual, the simplest and the quickest method to reduce India's emissions and protect the neighbouring villages from polluted water sources, smoke, odour etc. is to remove these mountains of age-old legacy waste.

Recently, Hon'ble National Green Tribunal (NGT) has directed a committee to determine the extent of the damage caused in the dumpsite and also recommends the clearing of dumpsite by implementing Standard Operating Procedure (SOP) also known as Biomining and Bioremediation under the supervision of Central Pollution Control Board (CPCB, 2019). The NGT has directed that the remediation of these dumpsites be carried out in accordance with Clause "J" of Schedule-I of the Solid Waste Management Rules, 2016, i.e., the observation being made regarding the adoption of the desired landfill measure with respect to its suitability as per waste characterization including the environmental and economic feasibility of the adopted measure. From the engineering perspective, the option of the Biocapping of legacy wastes, which has severe negative impacts on the environment and human health, is not considered with the exception of inert materials, which must once again be disposed of in a scientific landfill.

1.3 PROCESS OF BIOMINING OF LEGACY WASTE AND ITS PHASES

Biomining also referred as Landfill Mining refers to the process of digging out the previously dumped/disposed materials from a landfill to recover metal, plastic, glass, combustibles, soil, C&D waste and other fine materials. It also refers to clearing the open dumpsites by segregating the prevailing waste into different constituents and converting the biodegradable portion into compost, methane gas or bio-diesel and the remaining non-recyclable plastics as Refused Derived Fuels, which in turn can be used as an alternate fuel in industries. The compostable fraction of the waste is separated through screening and sold for use in landscaping or as a soil enhancer or fertilizer. The major factors which have contributed to the rising need of biomining concepts are reducing the greenhouse gas emissions, avoiding the surface water and groundwater contamination due to open dumps since it is unlined, reducing the footprint area of landfill i.e., increasing land value and economic costs associated with it, rising energy demand, improved reuse and recycling concepts especially the variety of metals available which have a market value and reducing the post-closure operation and maintenance costs (Mohan & Joseph, 2020). The process of the Biomining of Legacy Waste generally consists of 3 phases which are explained below:

Phase I: Waste Stabilization

Initially the dumping site is converted into equal-sized windrows and turned frequently; bio-culture is added into it. This stage eliminates pathogens, lessens moisture and flies, and removes odour. The addition of bio-culture increase the rate of the decomposition of waste to carbon dioxide and water vapour and produces biological heat inside of it which helps to dry up the waste and reduce its volume by 35-40%. In this process (termed as bioremediation), the waste material is dried out enough for screening. The waste is regarded as stable when there is no longer any production of heat, landfill gas, or leachate.

Phase II: Sorting and Segregation

In this stage, stabilized excavated landfill waste is separated to obtain soil, stones, and combustibles and other type of waste fraction. The aggregates and other heavy construction debris are separated using a series of trommels and manpower.

Phase III: Disposal of Segregated Waste

In this phase, the non-combustible fractions including soil and stones are disposed off for further processing into finer aggregates or used as earth-fill; metals, glasses are sent for recycling facility. The combustible fractions, often termed as Refuse Derived Fuel (RDF), are generally delivered for co-processing in cement industries.

1.4 COMPOSTION OF LEGACY WASTE

The age of the landfill is the main factor which influences the legacy waste composition since more is the age of landfill, more time the microbes will get to decompose the complex organic masses. The microbial decomposition led to the formation of Fines which is a mixture of decomposed and mineralized organic waste along with silt, sand and fine fragments originated from the construction and demolition activities. So, it can be said that more is the age of the landfill, more will be the proportion of fines. Through research it has been proved that fine comprises near about 40-60 percent of legacy waste. From the research works (Chandel et al., 2022), it has been that a typical Indian dumpsite mainly consists off the following components although legacy waste composition differs according to the region and landfill age: Significant proportion of fine soil like material contributing near about 60-65%. Combustible materials comprising off plastics, paper, cardboard and textiles constitute another 15-20 percent. Coarser materials comprising off broken bricks, masonry, and stones constitute nearly 20 percent along with 1-5 percent of the miscellaneous fraction comprising off broken glass, metallic fractions like razors, needles, sanitary wastes etc. Besides, the recyclable quantity mainly depends on the activities of informal sectors associated with recyclables extraction (Datta et al., 2021).

1.5 FACTORS RESPONSIBLE FOR SUCCESSFUL DUMPSITE REMEDIATION

1. From Engineering Aspect: Main factor which is considered for any dumpsite remediation project to be successful is maximum and proper utilization of the mixed legacy waste fraction which in turn will serve two purposes i.e. the reclaimation of maximum land and to minimize the amount of the residual waste which are about to reach the sanitary landfill. It must also be taken care of the fact that standards have to be developed for purposeful utilization of recovered legacy waste fraction. It is also very essential to enhance the capacity building of Urban Local Bodies, and other authorized bodies with proper understanding and assessments of all aspects of biomining. Construction of sanitary landfill and its sustainable operation must be built in order to dispose of non-recyclable and non-treatable legacy waste fractions which are recovered from biomining.

2. From Human Resource & Labour Welfare Management aspect: The execution of projects of legacy waste biomining/bioremediation can only be considered to be completed based on humanitarian ground when all the workers involved has been enrolled under Employees' State Insurance Corporation and they are provided all sorts of proper safety equipment and kits. Such projects should be a part of regulatory compliances of environmental protection under Plastic Waste Management Rules, 2016. Local bodies shall ensure insurances of workers working at the bioremediation/biomining projects at the desired dumpsites for any hazards due to fire, radiation or explosion. Small scale laboratory testing for monitoring the parameters of the biomining/bioremediation project shall be done with proper measures in authorized places and by authorized personnel only. The cost for carrying out the test will be included in the operational expenditures.

CHAPTER II: LITERATURE REVIEW

2.1 IMPORTANT OBSERVATIONS MADE AFTER REVIEWING OF LITERATURES OF LANDFILL MINING IN WORLD

According to Krook et al., (2012), landfills have serving as a final way or the destination of storing waste around the world at minimum cost. Most regions have accumulated a considerable number of old or still active landfills throughout the years, each storing vast amounts of obsolete materials and products, some of which are more valuable than others (Lifset et al., 2002). Due to current global conditions, such as increased resource competition, rising raw material prices, limited natural reservoirs for valuable resources and rising environmental issues, resource extraction from alternate sources is a realistic option (Kapur, 2006; Halada, 2009; Krook et al., 2012). The annual global generation rate of MSW was forecasted to reach 2200 million tons by the year 2025 (Al-Yaqout and Hamoda, 2020; Durmusoglu and Yilmaz, 2006; Liu et al., 2022). Such possibilities questioned the present understanding of landfills as waste disposal facilities and indicate the birth of a new landfill mining approach, focussing on valuable material extraction and energy resource recovery (Krook et al., 2012). According to Krook et al., 2012, landfill mining is defined as a process for extracting materials or other solid natural resources from waste materials that had previously been disposed of by burying them underground.

The potential extraction of waste materials has been conceptualised through different mining ideas, for example urban mining, biomining and waste mining (Ayres et al., 2001; Brunner, 2011; Johansson et al., 2013). Landfill is one such concept that can be defined as a strategy to recover secondary resources from an active or closed landfill with the help of unit operations like excavation, screening, sorting and processing (Hogland et al., 2004; Jones et al., 2013; Krook et al., 2012; Quaghebeur et al., 2013). Landfill mining was first conceptualised in Israel in 1953 to excavate the waste of Hiriya landfill and process the soil fraction to be used as compost (Savage, 1994). Until the early 1980s, this initiative remained the single documented study of landfill mining. Increased concerns over the limitations of space and environmental footprints marked the stage for further landfill mining initiative (Cossu et al., 1996; Hogland et al., 1995). In the European Union, landfilled waste was reduced from 68 to 38, contributing from 141 million tons to 96 million tons during 1995 and 2010, respectively (Mönkäre, Palmroth, and Rintala, 2016).

Since the commencement of the landfill mining concept in the 1950s, the scope of the landfill mining has emerged, addressing different drivers such as land reclaimation, material recovery, regain in landfill capacity, landfill remediation, pollution mitigation, generation of alternative fuel, and saving closure costs (Hernández Parrodi, Höllen, and Pomberger 2018). Over the past three decades, more than 60 landfill mining projects have been studied (Zhou et al., 2015). Detailed investigations have been carried out for characterising the fine materials recovered from different landfill sites. The main ingredient recovered from the landfill mining projects is coarse particles of greater than 50mm, consisting of stones and debris; combustible fractions comprising of textiles, paper, wood, and plastic; recyclable materials such as glass, and metals; and soil-like particles. In the previous studies, the previous characterisation involves categorising the waste according to its size fraction, mainly of coarser particles (Hogland, Marques, and Nimmermark, 2004; Hull, Krogmann, and Strom, 2005; Kurian et al., 2003). Moreover, landfill waste possesses a methane production potential of 50 Nm³ per ton of municipal solid waste (Themelius and Ulloa, 2007; Alidoust et al. 2021). Landfill mining prevents the massive generation of such methane emissions as well (Jurado et al., 2020; Palm et al., 2022).

The characterisation of mined waste from landfill has been done by screening the waste into different particle size fractions and subsequent analysis on screened fractions (Hogland, 2002; Hull et al., 2005; Kurian et al., 2003; Prechthai et al., 2008; Quaghebeur et al., 2013). One of the most critical aspects of the landfill mining is the end term utility of the mined product (Masi et al., 2014). One of the major hurdles in the success of the landfill mining operations is the difference between resource potential and technical potential, that is for technical, economical and ecological reasons, it is not possible to convert the complete deposited resources into markable recyclables (Frändegård et al., 2013). The recoverable fractions from landfill mining primarily includes metals, combustibles and possibly soil-like materials which requires extensive study, not only about the overall composition, but also about the pre-treatment before use (Kaartinen et al., 2013).

In general, the ration of soil-like materials (SLM) to the total recovered material from landfill mining is on an average of 40-60%, which is contributed by daily soil cover material (Kaartinen, Sormunen, and Rintala 2013; Burlakovs et al., 2016). Prechthai et al. (2008) also found major concentration of fine fraction and plastic in the waste comprising about (19-39) and (35-51) per cent respectively. Rong et al. (2017) also identified major concentration of fine fraction (52.4%), plastic (13.9%) and stone (13.2%) respectively. Similar trends for high amount of fine fraction, plastic and stone was found in other studies as well (Kaartinen et al., 2013; Quaghebeur et al., 2013). Old landfill sites can be the primary target for landfill mining projects since due to absence of any clear segregation policies, most of the resources are directly dumped in the landfills. Landfills mainly consist of fine fraction accounting for almost 50% of total dumped waste although the landfill waste composition varies with the location and topography of the region (Jones et al., 2013; Burlakovs et al., 2016; Kurian et al., 2003; Mönkäre et al., 2016).

Studies have been conducted to discuss the fine fractions' physical and chemical characteristics (Hernández Parrodi et al., 2018). According to literature studies, fine fraction is primarily a collection of decomposed organic matter (humic substances), cover soil, and street sweepings with few percentages of materials like wood and plastics (Zhou et al., 2015). Besides, it contains high amounts of nutrients like nitrogen, phosphorus and potassium compared to soil (Manfred et al., 1997; Quaghebeur et al., 2013). From the elaborate literature review, it has been observed that heavy metals have been reported as major contaminants in soil-like materials which has limited its use in offsite applications (Quaghebeur et al., (2013); Masi et al., (2014); Mönkäre et al., (2016). However, Oettle et al. (2010) and Wanka et al. (2017) have suggested the use of soil-like materials for offsite applications in roads and in embankments after washing and blending respectively. Geotechnical properties of soil-like materials have been studied by Song et al. (2003); Oettle et al. (2010) and Hyun et al. (2011). The strength properties of soil-like materials have been found acceptable by all, except Song et al. (2003) who reported a reduction in strength with an increase in organic content. Concerns regarding long-term settlements due to high organic content have been indicated by Oettle et al. (2010).

Based on the physicochemical characteristics of fine fractions, researchers have proposed its utilisation as compost. Till now, only two international studies have been carried out to understand the fine fraction impact on plant growth (Zhou et al., 2015; Rong et al., 2017). From the studies it has been observed that the germination test depends on the type of plant species used for the study (Cesaro et al., 2015) and the germination index was calculated using relative seed germination and root length (Miaomiao et al. 2009; Cesaro et al. 2015). In these studies, Tomato was selected as the test species as it is susceptible to heavy metal toxicity and the test was terminated when the control seeds at least 200mm root length (Courtney and Mullen, 2009; Pan and Chu, 2016). The study by Zhou et al. (2015) showed that sewage sludge and other compost significantly increase the plant growth for landscaping (Chu et al. 2018; Milinković et al., 2019). However, inadequate level of nutrients have been reported by Prechthai et al. (2008) and Zhou et al. (2015) whereas satisfactory level of nutrient in soil-like material have been observed before its use as compost (Scheu, 1997).

The total content of heavy metal can be defined as the concentration of metal in the soil or soil-like material determined after acid digestion. Previous researches on heavy metals in soil-like material have mainly focused on their total content. A thermodynamic equilibrium is maintained between the three phases, with insoluble precipitates being the predominant species (Gonzalez Henao and Ghneim-Herrera, 2021). Previous studies have shown that heavy metal toxicity to the ecosystem is mainly caused by the reactive fractions of metals in the soil (Ferrans et al., 2021). The exchangeable phase of heavy metals, which includes water-soluble metals, is much more bioavailable and reactive than the other precipitated phases. Metals in reducible and oxidizable phases might leach under extreme conditions, whereas those in the residual phase are almost inert (Kim et al., 2015). Hölzle et al. (2022) have reviewed the total heavy metal content in soil-like materials of 59 landfills/dumpsites located across the world although their investigation does not find any potential for metal recovery from soil-like materials.

Esakku et al. (2005) have analysed heavy metals in soil-like materials from different depths considering bioavailability. Xiaoli et al. (2007) have reported heavy metal specification in landfilled waste of different ages. Burlakovs et al. (2018) have investigated the recovery potential of metals from soil-like materials through sequential extraction for its suitability as a methane oxidation substrate. Prechthai et al. (2008) have studied the bioavailability of heavy metals in SLM for its usage as compost and metal recovery potential. In addition, their study sought concentrations in soil-like materials of different grain sizes. Hee et al. (2022) have assessed the influence of dissolved organic matter content on the specification and migration of heavy metals in soil-like materials. The most significant source of heavy metals in the soil-like materials can be associated with different materials, such as nickel/cadmium batteries, impurities in several products, including phosphorus-based fertilizers, pesticides and detergents and refined petroleum products (Jani et al., 2016; Parrodi et al., 2016).

The total heavy metals measurement is not a good indicator of the contamination, as it overcomes the bioavailability of a heavy metal (Yang et al., 2017). In addition to total heavy metals, mobility and bioavailability of heavy metals are required to be assessed to gauge the potential impact of contamination from fine fraction. Sequential extraction is widely used method to evaluate the mobility of heavy metals (Ukiwe and Nwoko, 2011). The benefit of sequential extraction lies in the fact that it differentiates the heavy metals between available, potentially bioavailable and residual fraction (that is likely to be unavailable) (Burlakovs et al., 2016; Zhu et al., 2014). Pollution indices like contamination factor (CF), enrichment factor (EF) and ecological risk assessment have become a popular tool to assess the contamination in sediment, soil and compost with respect to background levels (Duodu et al., 2016; Borah et al., 2020; Ihedioha et al., 2017). From the studies, it has been observed that the exchangeable and acid-soluble fraction of heavy metal is a mobile fraction that tends to be readily bioavailable. Further, the reducible and oxidizable fraction will be only available at extreme oxidizing and reducing conditions while the residual fraction is an immobile and non-bioavailable fraction that is attached to the mineral lattice (Esakku et al., 2005; Lu et al., 2005).

Studies have shown that increase in the organic matter of soil made cadmium less bioavailable due to its high affinity towards organic substances to produce organometallic complexes (Hanć et al., 2008). Humification of organic matter produces a stable copper complex of humic substances (Achiba et al., 2009; Hee et al., 1995; Zheljazkov and Warman, 2004). The solubility of heavy metals in water is dependent on various factors like pH, organic matter, ion-exchange capacity and humic acid content. This low solubility of heavy metals can be attributed to the fact that the absorption of heavy metals in fine fraction due to the high pH and organic matter, resulted in decreased solubility of heavy metals in water (Mor et al., 2006; Xiaoli et al., 2007). The deviation of recovery rates in some cases can be attributed to the high level of Iron in the soil-like materials. Spectral interferences with a high level of iron have been observed in previous studies as mentioned by Ferrans et al. (2021). The difference in the mobility of heavy metals in soil-like materials was caused by the solubility of respective hydroxides, sulphides, or other precipitates, as well as the degree and mode of forming complex compounds with organic matter (Bozkurt et al., 1999).

Leachate pH and alkalinity gave an idea of the conditions under which leachate is formed from the waste. The typical range of pH for leachate at MSW landfill reported in the literature is 5.8-8.5 (Kjeldsen et al., 2002; Kulikowska and Klimiuk, 2008). Limited researches available on the leaching behaviour of fine fraction have reported pH to range from 7.1 to 8.3 (Kaczala et al. 2017). The alkaline pH observed in the current studies is the reflection of the aged solid wastes in the dumpsites that have already achieved a complete methanogenic phase, which is in accordance with the findings of Slomczyńska and Slomczyński (2004). Bernard and Gerard (1995) reported ammonia and alkalinity as the most important factors to contribute to the toxicity of the leachate. Electrical conductivity is affected by the dissolved organics and inorganics present in the water (Jani et al., 2018). Water with high TDS can limit the growth and may also lead to the death of aquatic species. High concentration of TDS in leachate accumulated near the dumpsites is well reported in the literatures (Kjeldsen et al., 2002; Moody and Townsend, 2017; Somani et al., 2019). Presence of colour in the water affects the consumers' acceptance towards drinking water because some people aesthetically do not accept coloured water (Marañŏn et al., 2010). It may be due to the presence of high amount of volatile dissolved solids present in the leachate.

High concentration of chloride in water is usually considered as a major source for the contamination of groundwater (Loizidou and Kapetanios, 1993). Calcium, magnesium, sodium and potassium are few major cations typically found in landfill leachate. Calcium and magnesium are major cations associated with the hardness of water (Harmsen, 1983). The presence of ammoniacal nitrogen is probably due to the domination of amino acids during the decomposition of organic compounds. High concentration of ammoniacal nitrogen in leachate around landfills has been reported in previous studies (Bernard and Gerard, 1995; Naveen et al., 2017). The presence of sodium in high concentration can pose risk to persons suffering from cardiac, renal and circulatory diseases (Mor et al., 2006). COD is a very rapid test to determine the extent of organic matter present in the wastewater. COD in the range of 10,000 to 25,000 mg/l is generally observed in the leachate accumulated around the dumpsites (Kjeldsen et al., 2002). High concentration of sulphates and chlorides in the range of 1,000 to 2,500 mg/l and 4,000 to 8000 mg/l have been reported in leachate around landfills by Kjeldsen et al., (2002), Mor et al., (2006). High values of colour in the order of 5,000 to 8,000 true colour units (TCU) are reported in the literature (Amuda 2006; Aziz et al. 2007).

Van Der Zee et al. (2004) evaluated the advantages and expenses of landfill reclamation. The expenses are primarily broken down into capital cost and operational costs. In most of the cases, the capital and operational cost exceed the revenue generated from extracted materials (Van Passel et al., 2012; Frändegård et al., 2015; Maheshi et al., 2015; Wolfsberger et al., 2016). In developed European countries, more than 150000 landfills are present and it has been reported that from 60 landfill mining projects, metals to be recovered (2.5% volume) is responsible for a significant cost reduction in regard to landfill mining costs (Vossen, 2013). In China, the average cost of landfill mining was 12.7USD/ton and a net positive benefit between 1.92 million USD to 16.63 million USD (Zhou et al., 2015). More importantly, particularly in developing economies, improved waste management systems may be more expensive than what society can afford (Damigos et al., 2016b). The willingness to pay (WTP) for a benefit and the willingness to accept compensation (WTA) for a cost are the actual metrics used to measure preferences (Pearce et al., 2006).

2.2 IMPORTANT OBSERVATIONS MADE AFTER REVIEWING OF LITERATURES OF LANDFILL MINING IN INDIA

Open dumpsites had been a popular municipal solid waste (MSW) disposal choice in India. Most of the towns, villages and cities practised open dumping in the sites that had no to very few sanitary measures (Joshi and Ahmed, 2016; Kumar et al., 2017). This dumped waste has a negative impact on the environmental and societal level. The decomposition of waste in dumpsites generates harmful gases like methane, ammonia, and mercaptans as well as leachate, which contains heavy metals and organic pollutants. Studies have indicated the percolation of leachate infiltration from landfills in groundwater in India (Pujari and

Despande, 2005; Mor et al., 2006). In India, most of the dumpsites/landfills have exhausted their capacity and are serving beyond their operational life (Sharholy et al., 2008).

Sites like Deonar in Mumbai, Ghazipur, Bhalswa and Okhla in Delhi have exhausted their capacity a long time ago, but are still operational due to lack of landfill space (Kumar, 2013). Over dumping of the waste in such sites leads to problems like slope instability, which can cause the slope failure leading to landfill collapse (Koelsch et al., 2005). The maximum permissible limit for the height of the garbage dump in Indian is 20m above the ground level, which most of the landfills have already crossed. For example, Ghazipur landfill in Delhi stands at the height of more than 50m, which is way above the permissible limit (Vyawahare, 2018). The increasing municipal solid waste generation requires more land for waste disposal, stating that the land requirement for unscientific dumping of MSW will not continue in the future (Kumar et al., 2017).

One of the solutions to mitigate environmental issues from open dumps is capping. The capping of Gorai and Malad dumpsite in Mumbai, has been carried out in past. However, leakage of harmful gases like methane and mercaptans were reported for Malad dumpsite, which was developed into a residential area after capping (Chandel et al., 2020). Capping along with a bottom liner may be a better option; however the entire waste requires to be excavated to install a bottom liner and provide further sanitary provisions which in turn would increase the remediation cost (Dubey et al., 2016). Landfill mining of unscientifically created landfills/dumpsites and engineered landfills is being advocated to meet a huge demand for land to meet the infrastructural requirements of an ever-growing population, within the municipal limits (Chandana et al., 2021). Multiple pressures drive the re-excavation of such sites including resource recovery and the management of various impacts on environmental and human receptors (Krook et al., 2012; Somani et al., 2018). To reduce the accumulated legacy waste at dumps and reclaim the site for other purposes, so-called landfill mining can be a viable option (Somani et al., 2020).

Recently, the National Green Tribunal (NGT), India directed that mining of more than three thousand old MSW dumpsites should be undertaken to reduce the height of these, often unlined, 50-60m high facilities (Datta et al., 2023). However, the suitability of landfill mining as a sustainable strategy for the cities and towns is still being debated owing to the absence of proper guidelines for characterization and utilization of landfill mined residues (like landfill-mined-soil-fraction, inert, C&D waste) (Chandana et al., 2021; Goli et al., 2021b; Singh & Chandel, 2020). It is important to know that this landfill mined soil-like materials is the major fraction of the total landfill mining residues since it contributes to approximately 40-70% by weight. Hence, consumption of the soil-like materials is crucial for approving the landfill mining as an appropriate strategy to fulfil the requirements of sustainable development goals (Chandana et al., 2021; Singh et al., 2022).

The mining of excavated waste presents a lot of opportunities in term of recovery of the valuables discarded earlier due to the mismanagement or non-availability of technology at the time (UNEP, 2021). The other potential prospect may be the elimination of possibility of further pollution from an unlined waste dumps. It is especially important for the developing countries where these dumps are posing a hazard in terms of groundwater contamination (Kumar et al., 2019), surface water contamination (Kumar et al., 2016), air contamination (Kumar et al., 2017), an explosion from methane gas (Kumar et al., 2018) and other such hazards. Similar environmental benefits can also be observed by excavating an old dump and rehabilitating the site for waste disposal by installing liner in its (Datta et al., 2016; Widyarsana et al., 2019). In other cases, the land has been used as Public Park or other recreational purposes after performing waste mining (Joseph et al., 2008).

The first reported initiative for landfill mining in India was for Deonar dumpsite, which was a trial project to recover fine fraction to be used as compost and increase landfill space (Manfred and Bhattacharya, 1995). Kurian et al., (2003) studied the degradation status in Kodungaiur and Perungudi landfill using physicochemical parameters analysis. Ranjan et al., (2014) studied the potential use of mined waste for refuse-derive fuel production. While Somani et al., (2018) assessed the use of fine fraction as cover material or geotechnical application. In Panchvati (Maharashtra), a project for waste stabilization was carried out by spreading bio-culture on aerobic windrow prepared from mined waste for waste volume reduction (NSWAI, 2010). In Kumbakonam (Tamil Nadu) waste stabilisation and segregation of dumped waste was carried out to clear the dumpsite (Patel, 2015).

From the landfill mining studies done in the past irrespective of places, it has been observed that soil-like materials commonly referred as fine fraction used as filler/cover material, for geotechnical purposes, for energy generation, and as compost or soil enricher (Mönkäre et al., 2017; Singh and Chandel, 2018). However, old dumpsites are collection of heterogeneous waste, especially in countries like India where no segregation of waste occurs, leading to the infusion of various impurities in the fine fraction. These infused impurities severely affected the utilization of fine fraction. The potential application of fine fraction would depend on its physicochemical characteristics (Datta et al., 2021). However, characteristic requirement differs from one application to another; for example organic matter is a contaminant for fine fraction application as a construction material but is important for use as compost. So, according to the characterisation of fine fraction with its potential application technology defines its valorization route (Singh and Chandel, 2023).

The compositional analysis of the excavated waste obtained during the landfill mining operation of the four legacy waste heaps at the Boragaon dumpsite in north-east India revealed that the proportion of combustible and non-combustible fractions decreases from the youngest heap to the oldest heap due to variations in the consumption habits of the local community and the inadequate recycling of recyclable materials (Kartha et al., 2023). While studying the effect of age on the SLM characteristics, it has been observed that proportion of fine fraction shows an increasing trend from youngest heap to oldest heap, suggesting enhanced biodegradation of easily degradable waste over the years. The proximate and energy content analysis suggests that refused-derived fuel preparation is the most suitable valorization option for the combustible fractions since surface defilements are too high for good quality material recovery (Ghosh et al., 2023).

Another study was carried out at Bhalswa dumpsite at Delhi in order to study the effect of the depth of landfill on the SLM characteristics. In this study, total unit weight, organic content, water content, and the particle size distribution of the total MSW were analysed for different depths to understand the matrix of the waste mass accumulated inside the dump (Somani et al., 2022). It has been observed that total unit weight of MSW slightly increased, whereas organic content slightly decreased in the lower sections of the boreholes. An increase in the percentage of soil-like materials was also observed with an increase in the depth of the waste. It has also been observed that the total heavy metal concentration of chromium, lead and zinc increased with depth. The leachable heavy metal concentration of chromium and nickel were also found to increase with depth (Datta et al., 2023).

Another study was carried out by Ramana et al., (2023) in order to examine the feasibility of using the soil-like materials (SLM) less than 4.75mm size, recovered by the mining of old waste from four municipal solid waste dumps of India as an earth-fill for embankments, low-lying areas etc. and as compost for agricultural applications. In this study, the contamination levels of soil-like materials for reuse were analysed on the basis of heavy metals, organic contents, soluble salts, and release of dark coloured leachate. The reused feasibility of soil-like materials as compost was assessed on the basis of nutrient levels (like total organic carbon, nitrogen, phosphorus and potassium) (Datta et al., 2023). The presence of high levels of organic matter, heavy metals and soluble salts indicates the importance of treatment before off-site reuse. This study also reveals that the reuse of mined soil-like materials should be restricted to non-agricultural applications owing to the presence of excess heavy metals after supplementing the total organic carbon (Somani et al., 2023).

Another study was also carried out by Chandel et al., (2022) to evaluate the mobility and chemical speciation of heavy metals in fine fraction collected from municipal solid waste dumpsite located in Mumbai, India to assess the reclaimation feasibility. In this study, it has been observed that concentration of heavy metals exhibits an increasing trend with the waste age. Besides this, the chemical speciation is observed to be different for all assesse heavy metals along with a significant change with age (Singh et al., 2022). It has also been observed that heavy metals are dominant in non-bioavailable forms except for cadmium that had significant distribution in all forms. According to pollution assessment and chemical speciation results, cadmium was identified as the most polluting and mobile heavy metal. Though this study, it has been observed that although the mobile forms of heavy metal is low and is required to be considered while deciding the remediation measures (Singh & Chandel, 2021).

Another study was carried by Datta et al., (2019) with the objective to study the leaching characteristics of soil-like fraction (finer than 4.75mm) of aged municipal solid waste excavated from three old dumps of India. The leaching behaviour of this soil-like fraction was assessed to examine its use as an earthfill. The total dissolved solids (TDS), chemical oxygen demand (COD); release of colour, and ammoniacal nitrogen in the leachate from soil-like materials were observed to be significantly more in comparison with the water extract of local soil. Relatively elevated concentration of arsenic, chromium, copper, cobalt and nickel were observed in the leachate from soil-like material in comparison to the water extracted from soils of surrounding region (Somani et al., 2019). The low value of COD observed the above studies reflects the age of waste and also small amount of biodegradable fraction available in the waste (Ramana et al., 2019). As explained in Somani et al., (2019), COD in the leachate collected from Delhi, Hyderabad and Kadapa landfill was found to have 680 to 21,500 mg/l which corresponds to the leachate accumulated near the landfills in the leachate ponds.

In order to study the economic feasibility of the landfill mining projects, it is necessary to consider the excavation, material sorting, transport, recovery/treatment plants and plant operations and maintenance account for the majority of the costs associated with landfill mining projects. Considering waste characteristics under Indian context, major revenue sources would be landfill space recovery and combustible fraction (Dubey et al., 2016; Mandpe et al., 2019). One of the major revenue sources reported in most of the literatures was metal fraction, which is very low in case of Indian dumpsite (Singh & Chandel, 2019). However, Bir et al., (2022) has suggested some revenue generation options for the Kolkata landfill that include compost products, anaerobic digester, power generation and recycling products which will enhance the economy to meet the sustainable circularity solution.

ANOVA (Analysis of Variance) is a statistical technique used to analyse the effect of one or more factors on a response variable (Kutner et al., 2005). In Biomining, ANOVA can be used to evaluate the impact of different factors (e.g. pH, temperature, microbial consortia, and metal extraction efficiency (Brierly & Brierly, 2013). Studies have employed ANOVA to optimize biomining conditions such as identifying the most effective microbial strains or nutrient combination (Rawlings & Johnson, 2007). Correlation matrices are used to examine the relationship between multiple variables e.g. metal concentration, microbial population, and environmental factors (Johnson & Wichem, 2007). In Biomining, correlation matrices can help identify key factors including metal extraction, such as correlation between microbial population and metal concentrations (Sand et al., 2001). Researches have used correlation matrices to identify patterns and relationships in complex biomining system, informing strategies for process optimization (Brierly & Brierly, 2013).

2.3 INFERENCE FROM LITERATURE REVIEW

Landfill mining presents a number of opportunities e.g., resource recovery, elimination of the possibility of further pollution and reuse of the land for public purposes. However, it becomes important to understand the main challenges to take advantage of these opportunities. These challenges consist mainly in terms of the quality of recovered material. For soil-like fraction, it may be high concentrations of heavy metals. For combustibles, it may be in terms of low calorific value and high value of ash content. Future researches for landfill mining should be directed to determine the effect of various factors such as climate, waste type buried in the landfills on the materials recovered. The effect of excavation and processing mechanism also need to be investigated systematically in detail.

From the current experimental findings, it can be concluded that the soil-like materials recovered from the landfill dumpsites depicts a tremendous potential for reuse in earth-fill applications. Their bulk availability makes it more essential for identifying its reuse potential. However until now, the primary focus is on the physicochemical characterisation of soil-like materials concerning the heavy metal concentration, release of dark-coloured leachate, soluble solids, moisture content, and organic content only. Other parameters which need to be kept in the future scope of the study are pathogenic organism activity, mechanical properties such as shear strength, and long term settlement, which illustrates a crucial in deciding the suitability of earth-fill material.

Developed countries have minimised the quantities of wastes to be open landfilled by implementing a combination of recycling, composting, anaerobic digestion, recycling, engineered landfills etc. However, in developing countries like India, there is no strong policy framework to provide a proper direction and thrust to environmentally sound waste management. Policies and other measures have been adopted to promote waste minimization recycles, and the scope of recovery is rather lean. In Indian context, environmental policies are ‘discharge and control’ based rather than shifting to ‘source end control’ based approach and till now, there is no national target to deal with these MSWM issues in line with the nation’s economic development. However, in Indian and other Asian countries, biomining and bioreactor concepts are becoming the popular MSWM concept adopted to reclaim the old landfills.

Economic feasibility and social justification are crucial aspects of making decisions regarding the biomining projects over conversion of open landfills considering the cost associated with the closure and post closure management. However, a very few studies have been done so far regarding the economic issue of conversion of open landfills to biomined landfill and with respect to West Bengal, the result is very relatively insignificant. There is a fundamental misconception that the economic incentive will not be adequate for private landfill mining operators, despite the social or public benefits of landfill mining being extraordinarily high. Therefore, proper economic feasibility analysis is required for checking sustainability and the cost effectiveness of the landfill mining projects.

CHAPTER III

OBJECTIVE

The main objective of the study is the characterisation and component analysis of the soil-like materials which is mined from municipal solid waste dumps. This research work offers a great opportunity to study the potentiality of the soil-like material to perform as a effective construction materials. The objective of the present study is limited to the determination of contaminants including heavy metals (both total and leachable), soluble solids along with the release of the dark coloured leachate. The contaminants which play a key role in determining the environmental feasibility of the coarser fraction of the soil-like material have not been brought into light. Besides, the greenhouse gases emissions generated during this entire bio-mining process is also an emerging concern and can act as a scope of future study.

SCOPE OF PRESENT STUDY

- Study of the existing Bio-mining project at Dhapa disposal site.
- Secondary Data Collections from different sources.
- Study of the depthwise variation of the physical characteristics of the soil-like materials using Correlation Matrix and ANOVA Model.
- Study of the seasonwise variation of the physical characteristics of the soil-like materials using Correlation Matrix and ANOVA Model.
- Study of the depthwise variation of the chemical characteristics of the soil-like materials using Correlation Matrix and ANOVA Model.
- Study of the seasonwise variation of the chemical characteristics of the soil-like materials using Correlation Matrix and ANOVA Model.
- Cost analysis of Biocapping of landfill site at Dhapa.
- Cost analysis of Biomining of legacy waste at Dhapa.
- Cost comparison of Biomining and Biocapping of landfill site at Dhapa.

CHAPTER IV: LEGACY WASTE CHARCTERIZATION AND DETAILED METHODOLOGY OF EXISTING BIOMINING PROJECT

4.1 STUDIES OF EXISTING LANDFILL SITES IN KOLKATA, WEST BENGAL

Kolkata, a metropolitan city of India, has a population of 8 million generates about 3000MT of municipal solid waste per day (Chattopadhyay et al., 2007). Without any prior treatment, bulk of the generated solid waste is disposed on the open/uncontrolled landfill site at Dhapa, Kolkata. Two municipal corporations and seven municipalities cover the whole area of Kolkata metropolitan city. Solid waste management is a statutory function and all municipal corporations are responsible for the management of municipal solid waste generated in the city (Hazra et al., 2023). No source segregation is practiced, except the rag pickers who segregated the recyclable components in an unorganized, hazardous and unhygienic way (Chattopadhyay et al., 2009). Due to variation in both geographic origin and the socio-economic conditions, the compositions of municipal solid waste are likely to be different in various regions. Kolkata Municipal Corporation is no exception from this case. The city generates about 3000 tons of municipal solid waste (MSW) daily at a rate of 450-500gm per capita per day (Chattopadhyay et al., 2009).

There are three disposal sites in the Kolkata Municipal Corporation area at Dhapa, Garden Reach and Noapara of which Dhapa is the most important one (Hazra et al., 2009). On an average, it has been assessed that there is a huge gap between the waste production and waste processing which creates several environmental issues. In Kolkata, source segregation is not 100% practiced and after collection, the wastes are primarily dumped into Dhapa landfill site after covering it with a nominal daily cover, without any treatment creating severe geo-environmental and health problems as the land adjacent to Dhapa is mainly used for agricultural purposes and both the adjacent surface and the ground water bodies are utilized for aquaculture (Hazra et al., 2023).

4.1.1 Study Area: Dhapa Dumping Ground, Kolkata, West Bengal

Dhapa is located on the eastern part of Kolkata at latitude 22° 32’ north and longitude 88° 26’ east. Dhapa having around 24.71 ha of landfill area is situated on the western part of East Kolkata Wetlands (EKW) (Hazra and Goel, 2009). The landfill site is operational since 1981 and consists of an eastern dumping area or mound (active) and a western dumping area or mound (closed since 2009) (USEPA, 2010). An area of about 800 ha adjacent to Dhapa landfill site are used for cultivation (Patra et al., 2001). The landfill site is non-engineered, unlined, open dump without any arrangements for leachate collection and treatment system with nominal daily cover. In Dhapa, MSW is disposed on the level ground whose permeability is less than the permeability of the dumped solid waste (KEIP, 2005). Moreover, as the landfill site is without any leachate collection system or confined by earthen embankments, major portion of the leachate flows out laterally from the waste heap. This generated leachate severely pollutes the surrounding groundwater via percolation and thereby affecting the surrounding ecosystem (Maiti et al., 2016).

Recently, West Bengal government has revealed details of its plan for biomining at Dhapa, which will help reducing the 35m tall virtual mountain of garbage accumulated at the decade-old dumpsite. The recovered waste will be sent to recycling units, creating more space for future dumping at the 60-acre Dhapa dumpsite. To study the application of biomining technique for legacy waste reclaimation, Nagpur model was adopted by the West Bengal government for a period of time (Debsarkar et al., 2023). Currently, the closed western mound of area 12.14 ha has been biocapped as per SWM rule, 2000 and active eastern dumping mound of area 24.20 ha which consists of 40 lakh MT of legacy waste is being treated with Biomining (Banerjee et al., 2022).

Fig 4.1 Location of Closed & Active Dumpsite at Dhapa, Kolkata

4.2 STEPS INVOLVED IN THE BIOMINING/BIOREMEDIATION OF LEGACY WASTE PROCESS

Step I: Pre-feasibility Assessment: It is considered to be one of the first and most primary steps in booming operations. The main objective to perform a thorough pre-feasibility assessment is to get an idea regarding chances of completing the biomining project successfully within the stipulated timeline. Besides this, it also helps in the execution of operations with sound technology and economically viable manner (CPCB 2019).

Step II: Excavation of Legacy Waste: Excavation of legacy waste is the process by which excavation and treatment of waste from an inactive landfill or dumpsite with bio-organisms or natural elements like air and sunlight so that the biodegradable elements in the waste break down over time, for one or more of the purposes such as conservation of landfill area, elimination of the potentially contaminated source of pollution, mitigation of an existing source of contamination etc. (CPCB 2019).

Step III: Bioremediation of Excavated Waste: After the excavation and loosening of legacy waste, windrows are formed so as to dry the leachate through solar exposure and aeration. During this process, all the entrapped methane is removed from the heap. Stabilizing the legacy waste, exposure to air is needed as much as possible. To speed up the stabilization process, Bio-cultures are added for rapid decomposition and biological heat generation. Composting Bio-cultures are added to dry out and reduce the waste volume by 35-40% through loss of moisture and by decomposition of some of the aerated waste to carbon dioxide and water vapour (CPCB 2019).

Step IV: Processing of Excavated Fraction: Excavated wastes are required to undergo shredding, screening, air classification and ferrous separation. Screen sizes which are generally used as per the CPCB guidelines in the process of biomining and bioremediation are 150mm, 80-100mm, 24-50mm, 12-16mm, and 4-6mm. Cyclone separators are generally used in conjunction with air classifier for the removal of the light separated fraction. Ballistic separators are used to separate stones, soil and humus where magnetic separators are used to separate ferrous materials (CPCB 2019).

Step V: Utilization of Processed Fraction: According to the size, excavated legacy wastes are classified into various fractions. The finest fraction mainly composed of soil and sand, are generally very rich in organic material. It can generally be used for improving the soil fertility. The coarsest fraction includes bricks, stones, coconut sheets, etc. whereas the lighter mid-fractions includes mostly plastics which can be shredded as per industry requirement to be used in bitumen hot mix plants or as RDF for co-processing in cement kilns. The fractions whose sizes are less than 50mm are not subjected to shredding to be used as RDF (CPCB 2019).

4.3 EQUIPMENT REQUIRED FOR THE PROCESSING OF LEGACY WASTE

As per CPCB 2019, the major equipment that can be used for processing of legacy waste fall under the following heads of processes like excavation, shredding, screening, air classification, and ferrous separation. Appropriate choices should be made as per the suitability and requirement of process, site conditions and economy.

4.3.1 Handling Equipment

- **Excavator & Loader (Front Load):** The old waste dump contains leachate at different layers and various gases and odour-causing substances. Before starting the excavation process, it is necessary to vent out these gases and drain out the leachate. An excavator or front end loader may be used to dig up and transport the dumped material to elevator conveyor belts, then to the sorting machinery.
- **Loader:** A loader is a heavy equipment machine used in Biomining operations to move or load materials such as legacy waste, soil, rock, sand, Construction &

Demolition waste, etc. into or onto another type of machinery such as dump truck, conveyor belt, feed-hopper, or railroad car.

- **Dumpers:** A dumper is a vehicle designed for carrying bulk materials in the biomining operations such as legacy waste, RDF, C&D waste, coarser fraction, bio-earth etc. Dumpers can tip to dump the load and are normally diesel powered.
- **Elevators and Conveyor Belts:** Belt conveyors system is utilized for effectively transporting materials up steep inclines and is extremely versatile.

4.3.2 Shredding Equipment

- **Solid waste shredders**: are state-of-the-art devices used to reduce the size of materials in a wide range of recycling applications. The shredder machines can perfectly process the waste material of various types including wood, paint, hazardous waste, tire, rubber, and paper, plastic, agriculture waste and other.

4.3.3 Screening Equipment

- **Ballistic Separator:** Ballistic Separators are designed for sorting waste materials. A ballistic separator, as the name indicates is a high load segregating device that separates out wastes of different kinds. Waste products having similar shapes and sizes are separated out from the rest in two or three fractions like C&D waste and other recyclable products along with RDF while the rest materials are separated out.
- **Trommels**: In Trommels different size sieves separate the soil material, combustibles and inert etc. The rotating cylindrical screens are inclined at a downward angle with the horizontal. Material is fed into the trommel at the elevated end and the separation occurs while the material moves down the drum. Screen sizes commonly used are one or more of the following: 150mm, 80 to 100mm, 24 to 50mm, 12-16mm and 4-6mm.
- **Air Density Separator/Classifier:** Air classification is utilized to separate light materials like papers, plastics, etc. from heavier materials such as stones, bricks, etc. through the use of an air stream of sufficient velocity to carry away the lighter materials. A cyclone separator may be used in conjunction with the air classifier to remove the lighter separated fraction from the air stream after it exits the classifier throat.

Weighbridge is used to weigh entire vehicles and their contents. By weighing the vehicle both empty and when loaded, the load carried by the vehicle can be calculated. Weighbridge can be surface mounted with a ramp and the weighing equipment underneath or they can be pit mounted with the weighing equipment and platform in a pit so that the weighing surface is level with the road.

4.4 BIOREMEDIATION PROCESSES ADOPTED FOR WASTE STABILISATION

Bioremediation is an environment-friendly technique to separate soil and recyclables from the legacy wastes. The process involves stimulating the growth of microorganisms and degrading the target pollutants without the use of any toxic chemicals to alter the environmental conditions in the legacy waste dumpsite. Exposing the legacy waste to air to stabilize it with the process of forming long low waste heaps of about 2-2.5m height called windrows to achieve maximum surface area to volume. Repeated turning is necessary to ensure that the innermost waste in windrows also gets exposed to air. Usually 3-4 turnings of legacy waste are necessary to stabilize it. As per CPCB, the common bioremediation processes which are mainly adopted and applied in Indian scenario are Bioremediation through windrow method for spacious landfill sites and through thin layer spreading method.

4.5 CONSIDERATIONS FOR THE PROCESSED WASTE FRACTIONS DERIVED AND THEIR PREFERRED USE

Waste fractions which are recovered during the biomining process have to be tested in order to find the presence of toxic metals and harmful organic matter. Assessing the potential of the scrap combustion fraction present in the processed waste is very important and is one of the critical aspects. Besides this, the calorific value of the waste must be greater than or equal to 2,500 Kcal/kg. Ash content must be less than or equal to the 20 percent and the moisture content of the processed legacy waste must be less than or equal to 30 percent. Along with this, it is also important to identify the end-users where the screened fractions are to be utilized. For example, the nearest industries using the solid waste fraction as fuels or the plastic roads in road tenders can be used as the final disposal alternatives for all sort of processed waste fractions containing plastic fraction to a large extent. An offsite aggregation space has to be planned for different waste fractions and waste types which are produced from screening. Along with this, the transporting agencies have to be hired who can take the responsibility of transporting different fractions out on their return tips. The processed waste fractions and their preferred use are listed as follows:

- **Construction & Demolition Materials (C&D)**: preferably be used as construction and filling materials.
- **Refused Derived Fuel (RDF)**: preferably be used as combustion fuels in Waste-to-Energy facilities and also for co-processing in the industries.
- **Recyclables**: preferably to be sent to the authorized recycling industries/vendors for recycling the materials.
- **Coarser fraction of sand, gravel and some coarse fraction of organics**: preferably be used as road shoulders, for plinth filling, for road sub-grade and in the construction industry.
- **Bio-earth / Soil improver**: preferably be used for compost materials if it passes the FCO standards otherwise it can be used as landscaping or gardening or road medians and can also be used as soil enricher.
- **Process rejects (maximum 5-10% of the Total)**: This waste can be sent to scientific landfill for disposal or to be used as daily cover materials at the waste disposal site.

CHAPTER-V: PHYSICAL CHARACTERISTICS OF COARSER FRACTION OF SOIL-LIKE MATERIALS

5.1 PHYSICAL CHARACTERISTICS & ITS ROLES IN REUSABILITY OF SOIL-LIKE MATERIALS

As landfill mining has gained major attention in the recent past in India, the characterization of waste accumulated inside the dumpsite is a primary step to assess the feasibility of reuse of the excavated materials (Datta et al., 2022). However, the potential of landfill mining depends on the resource recovery from the lying resources in a landfill. Hence, for developing any landfill mining project, it is imperative to conduct a preliminary characterization study to have an in-depth analysis of the dumpsite at Dhapa, Kolkata. Landfill waste composition varies with the location and topography of the region. Beside this, old landfills can be the primary target of a landfill mining project due to the absence of clear segregation policies in the past, resulting direct dumping of most of the resources in the landfills. Landfills mainly consist of soil-like materials accounting for almost 50% of the total dumped waste at Dhapa, Kolkata.

Soil-like materials resembles a soil but due to its origins the nature of the grains will differ substantially with particles of plastics, wood, glass and other typical waste categories expected to be present. As a result, the interaction of chemical contaminants, and their fate and transport may differ from behaviour in soil. A major use of mined soil-like materials has been as a cover material at the landfill site at Dhapa. There are opportunities for the reuse of soil-like materials in agricultural applications and geotechnical applications i.e. as fill materials. The suitability of soil-like material may also act as a buffering material. Soil electrical conductivity is a measure of the amounts of salts in soil. Physical characteristics are necessary for evaluating the feasibility of the soil-like materials to be used for different useful purposes. For example, determining the capacity of recovery and recycling facility, bulk density is an important parameter. Similarly, the moisture content of excavated waste is crucial to determine the valorization route (thermal, recycling or biological treatment) of the waste fraction and depends on several parameters such as location, climatic conditions, leachate generation and waste type.

Beside this, the particle size distribution is an important parameter for the utilization of landfill mine soil-like materials as structural fill material for embankments and low lying areas at Kolkata and its adjoining areas. The organic content is another important characteristic which is considered the limiting factor in deciding the reusability of soil-like materials in earth-fill and subgrade in the roadwork pavements. Even though the presence of organic content in soil-like materials is not labelled as a contaminant, their quantity has to be determined to assess the long-term settlement. Water holding capacity is primarily controlled by soil texture and organic matter. Soil with smaller particles like silts and clay has a larger surface than those with larger sand particles. More is the surface area; more will be its capacity for holding water. So, as the soil depth increases, the size of the particle is smaller which indicates an increment in water holding capacity.

5.2 SAMPLING AREA AND SAMPLING COLLECTION PROCEDURES FOLLOWED

The soil-like materials investigated in this study was collected from age-old MSW dumpsite of India located in Kolkata. Aged samples were excavated from trial pits using a backhoe excavator. In order to understand the variation of nature of Physical characteristics, samples have been collected from different locations at 1-2m depth interval upto the depth of 20m from the top. This sampling procedure is mainly followed to understand the effect of depth upon the characteristics of soil-like materials. The selection of the location of the trial pits is mainly done on the basis of the age of dumpsite as being informed by the operators working onsite. Sometimes, the location for sample collection has been changed consecutively keeping the depth from top (m) constant for understanding the variation in characteristics in detail. This is because it has been observed from municipal records, that there is a high chance of irregular dumping in Dhapa during its operational phase. Composite samples have been prepared by coning and quartering to produce laboratory samples.

Generally, each composite sample was prepared from excavated waste of four test pits. The initial moisture content was measured and the waste was then dried on-site for 1-2 weeks until the moisture content was reduced below 10%. The dried MSW was then sieved through screens of sizes 80mm, 50mm, 20mm, and 4.75mm which were selected from the grain size distribution mentioned in IS 2720-IV (BIS 1985). The soil-like fraction was then collected and sealed in separated pre-cleaned airtight polythene bags and transported to the laboratory. All the samples were stored in cooling cabinets at a temperature of 4°C to prevent degradation till the chemical analyses.

5.3 EXPERIMENTAL METHODS FOLLOWED & RELEVANT PRINCIPLES

A table has been provided below containing the list of the important physicochemical characteristics which have been considered for this research work. Besides this, in this table, the Test method for each parameter are listed which will give a clear idea about the methods of experiments adopted for this project work (Datta et al., 2018):

Table 5.1: Physical Parameters & Relevant Experimental Methods used

Serial No.	Parameters	Test Method
01	pH at 25ºC	IS 2720 (Part-26) (RA 2011)
02	Elect. Conductivity (mS/cm) at 25ºC	IS 14767:2000; RA 2016
03	Texture	Chemical Analysis SOP No. TPM/QLS/E/S/MA based on Soil & Plant Analysis; C.S. Piper
04	Sand%	
05	Silt%	

06	Clay%	
07	Water Holding Capacity%	SOP No. TPM/QLS/E/S/MA based on Soil & Plant Analysis; C.S. Piper
08	Bulk Density (gm/cm³)	IS 2720 (Part-29) 1975; RA 2005
09	Nitrogen (as N) (mg/kg)	IS 14684 (1999) RA-2014
10	Potassium (as K) (mg/kg)	Soil Analysis (Soil Science Society for America) Part-II
11	Organic Matters%	IS 2720 (Part-22) 1972 RA 2015
12	Calcium (as Ca)%	Methods of Soil Analysis (Soil Science Society for America) Part-II
13	Magnesium (as Mg)%	Methods of Soil Analysis (Soil Science Society for America) Part-II
14	Phosphorus (as P) (mg/kg)	SOP No. TPM/QLS/E/S/P based on Methods of Soil Analysis (Soil Society for America) Part-II [Pg. 1040-1041]
15	Sodium (as Na) (mg/kg)	SOP No. TPM/QLS/E/S/Na based on Methods of Soil Analysis, (Soil Society for America) Part-II [Pg. 1033]

Analysis of the physicochemical properties of excavated was carried out to understand the effect of ageing. To determine bulk density, pH and moisture content of excavated waste, airtight bagged sample were used (Chandel et al., 2020). Determination of particle size distribution is done by sieve analysis after washing the soil-like materials (Datta et. al., 2021b). The pH and EC were measured in triplicate using a pH meter and a conductivity meter, respectively following IS 2720 (Part 26):1987 (RA 2011). During the pH test, the sample is mixed with reagent water and the pH of the resulting aqueous solution is measured. To measure the electrical conductivity, samples are to be analysed at 25ºC. Unless a temperature correction routine is used by the instrument, samples of different temperatures must be equilibrating to and results must be obtained at 25ºC. Moisture content was estimated by heating the waste at 60ºC to a constant mass (36-48 hours). Organic content was determined by loss on ignition at 550ºC (±20ºC) which is in accordance with Zekkos et al., (2010) and Mönkäre et al., (2016).

For estimating the water holding capacity of the soil-like material, pressure force must be applied to the soil sample and the amount of water must be measured. In this case, the water holding capacity is measured by Drip Loss Method. In this method, the pressure is created by gravity and the fact that the sample material shrinks as it is stored. The method is time consuming since it involves cutting, mixing, and weighing. For Calcium and Magnesium, Titrimetric method has been done. For Sodium & Potassium, Flame Photometric method has been done. For Nitrogen, experiment has been done via Expandable Ion Analyser (EA 940). All the measurements were carried out in triplicate and the mean value were found to be within ±5% error limit. All the reagents are of Merck Analytical Grade (AR). Analytical instruments got standardized by calibration with standard spiked solutions. Blank and standards were run after five analyses to recalibrate the instrument. All the blanks, standards, and analytical reagent solutions were prepared as pre-standard method guidelines (APHA). Statistical analyses are also taken into consideration for the necessary error analysis.

5.4 STATISTICAL METHODS FOLLOWED & THEIR PRINCIPLES

In order to study the multiple inter-relationships among the analysed parameters, a descriptive statistical analysis was carried out for the analysed parameters using OriginPro 2021. Pearson correlation coefficient was calculated with the help of Correlation matrix separately for both Depthwise and Seasonal variation of the physicochemical characteristics of the soil-like materials samples separately in order to get a better understanding. Correlation Matrix is a preliminary descriptive method which is primarily used to estimate the degree or intensity of association between the two variables. If the correlation coefficient value is not in the range of ±0.5 to ±1 then the parameters will be considered to be weakly correlated. In correlation matrix, then the coefficient value is negative then the desired parameters are assumed to be inversely related and vice-versa. Besides this, more closer is the correlation coefficient value to ±1; more the parameters are positively or negatively correlated.

The seasonal variation for both the total heavy metals and leachate characteristics for the soil-like materials has been examined 1-way Analysis of Variance (ANOVA) at $p<0.05$ significance level. Here, 1-way ANOVA method has been adopted as it gives a proper idea about the variation of relation upon comparing one category of an independent variable with three or more other categorical variables. After performing the analysis, sources of variation for both 'between groups' and 'within groups' is obtained. The F[statistic] is the test statistic in the 1-way ANOVA method. If the F[statistic] is greater than F[critical] value; then the test is significant one and vice-versa. For p-value, if the $p\geq.0.05$ then null hypothesis will be considered which means there is no difference between the means of the considered three groups. Similarly, if $p\leq0.05$ then alternative hypothesis will be considered which means there is no difference between the means of the considered three groups.

5.5.1 Statistical Inference from Correlation Matrix Analysis on Depthwise Variation of Physical Characteristics of Coarser Fraction of Soil-like Materials

Based on the available data from KMC (2022), shown in Table 5.2, statistical analysis of the Depthwise variation of Physical Characteristics of the coarser fraction of soil-like materials have been studied using the Correlation Matrix method which is shown in Table 5.4 respectively. Statistical analysis was applied using OriginPro 2018 software. The data was checked thoroughly before the analysis.

Table 5.2: Physicochemical Characteristics of Coarser Fraction of Soil-like Materials

Sl. No.	Test Parameter	Jul-21	Mar-22	Apr-22	May-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23
	Depth from top (m)	0	7	8	18	18	15	12	12	19	17	17	8	18	16	10	20
1	pH at 25°C	8.22	8.21	8.06	7.96	7.81	7.86	7.67	7.59	7.48	7.39	7.26	7.38	7.49	7.45	7.37	7.29
2	Electrical Conductivity, mS/cm at 25 °C	16.4	18.8	26.6	5	1.28	1.21	1.09	0.92	0.81	0.84	0.84	1.32	1.18	1.04	1.12	1.07
3	Sand, %	55	62	60	62	56	52	56	50	52	53	51	63	91	46	62	52
4	Silt, %	15	10	12	11	10	9	11	19	21	18	17	14	3	25	8	25
5	Clay, %	9	8	11	10	8	9	5	7	8	4	9	10	0	10	10	11
6	Gravel, %	21	20	17	17	26	30	28	24	19	25	23	13	6	19	20	12
7	Water Holding capacity, %	34	42	38	42	39.4	37.8	41.8	39.2	40.1	41.5	42.5	38.7	40.4	43.2	42.8	40.4
8	Bulk Density, gm/cm3	1.07	1.32	1.33	1.29	1.18	0.78	0.81	0.85	0.79	0.82	0.81	0.89	1.37	1.43	1.41	1.47
9	Nitrogen (as N) in mg/kg	164	536	836	844	1344	1356	1624	1092	1176	1316	1372	1176	616	828.2	1176	1470
10	Potassium (as K), in mg/kg	104	124	131	138	148	122	148	131	144	161	224	182	105	116	288	264
11	Organic Matters, %	4.24	4.8	5.2	5.6	5.6	4.12	2.93	2.25	1.98	1.62	1.93	1.75	1.67	3.55	2.41	2.26
12	Calcium (as Ca) in %	0.22	0.34	0.4	0.48	0.34	0.27	0.24	0.21	0.22	0.25	0.22	0.27	0.24	0.28	0.3	0.26
13	Magnesium (as Mg) in %	0.08	0.14	0.26	0.28	0.24	0.11	0.07	0.05	0.04	0.04	0.06	0.06	0.08	0.06	0.11	0.08
14	Phosphorus (as P) in mg/kg	96.2	136.4	128.4	132	116	94	81	70.2	58.2	44.7	51.4	44.3	38.6	44.8	112	98
15	Sodium (as Na) in mg/kg	110	180	182	188	104	76	73	79	62	58	76	54	53	61	87	79

Table 5.3: Depthwise Variation of Physicochemical Characteristics of Coarser SLM

Physical Characteristics (Depthwise Variation)											
Depth from Top (m)	**0**	**7**	**8**	**10**	**12**	**15**	**16**	**17**	**18**	**19**	**20**
pH at 25°C	8.22	8.21	7.72	7.37	7.63	7.86	7.45	7.33	8.72	7.48	7.29
Elect. Conductivity	16.40	18.80	13.96	1.12	1.01	1.21	1.04	0.84	2.80	0.81	1.07
Sand%	55.00	62.00	61.50	62.00	53.00	52.00	46.00	52.00	78.38	52.00	52.00
Silt%	15.00	10.00	13.00	8.00	15.00	9.00	25.00	17.50	9.00	21.00	25.00
Clay%	9.00	8.00	10.50	10.00	6.00	9.00	10.00	6.50	6.75	8.00	11.00
Gravel%	21.00	20.00	15.00	20.00	26.00	30.00	19.00	24.00	18.38	19.00	12.00
Water Holding Capacity%	34.00	42.00	38.35	42.80	40.50	37.80	43.20	42.00	45.68	40.10	40.40
Bulk Density (gm/cm³)	1.07	1.32	1.11	1.41	0.83	0.78	1.43	0.82	1.44	0.79	1.47
Nitrogen (mg/kg)	164.00	536.00	1006.00	1176.00	1358.00	1356.00	828.20	1344.00	1051.50	1176.00	1470.00
Potassium (mg/kg)	104.00	124.00	156.50	288.00	139.50	122.00	116.00	192.50	146.63	144.00	264.00
Organic Matters%	4.24	4.80	3.48	2.41	2.59	4.12	3.55	1.78	4.83	1.98	2.26
Calcium%	0.22	0.34	0.34	0.30	0.23	0.27	0.28	0.24	0.40	0.22	0.26
Magnesium%	0.08	0.14	0.16	0.11	0.06	0.11	0.06	0.05	0.23	0.04	0.08
Phosphorus (mg/kg)	96.20	136.40	86.35	112.00	75.60	94.00	44.80	48.05	107.48	58.20	98.00
Sodium (mg/kg)	110.00	180.00	118.00	87.00	76.00	76.00	61.00	67.00	129.38	62.00	79.00

Table 5.4: Correlation Matrix of Depthwise Variation of Physicochemical Characteristics

Physical Parameters Correlation Matrix (Depthwise Variation)																
	Depth from Top (m)	pH at 25°C	EC (mS)	Sand %	Silt %	Clay %	Gravel %	WHC%	Bulk Density gm/cm³	Nitrogen mg/kg	Potassium mg/kg	Org. Matter%	Cal-cium%	Mag-nesim%	Phosp-horus mg/kg	Sodi-um mg/kg
Depth from Top (m)	1															
pH at 25°C	-0.348	1														
EC (mS-cm)	-0.814	0.508	1													
Sand%	-0.109	0.724	0.255	1												
Silt%	0.429	-0.570	-0.310	-0.674	1											
Clay%	-0.116	-0.332	0.140	-0.223	0.256	1										
Gravel%	-0.101	0.086	-0.198	-0.223	-0.411	-0.548	1									
WHC%	0.576	0.018	-0.436	0.408	-0.036	-0.271	-0.175	1								
Bulk Density (gm/cm³)	0.002	0.173	0.130	0.401	0.051	0.481	-0.675	0.477	1							
Nitrogen (mg/kg)	0.774	-0.541	-0.804	-0.140	0.137	-0.093	0.111	0.346	-0.230	1						
Potassium (mg/kg)	0.291	-0.540	-0.396	0.080	0.046	0.352	-0.392	0.298	0.368	0.529	1					
Organic Matters%	-0.433	0.878	0.593	0.507	-0.501	-0.012	0.088	-0.044	0.313	-0.625	-0.593	1				
Calcium%	0.008	0.581	0.258	0.822	-0.515	0.078	-0.320	0.552	0.615	-0.115	0.026	0.620	1			
Magnesium%	-0.129	0.740	0.340	0.907	-0.656	0.010	-0.221	0.312	0.462	-0.158	-0.045	0.696	0.932	1		
Phosphorus (mg/kg)	-0.424	0.551	0.524	0.624	-0.660	0.143	-0.137	-0.002	0.441	-0.292	0.163	0.568	0.555	0.649	1	
Sodium (mg/kg)	-0.521	0.722	0.806	0.666	-0.560	-0.067	-0.209	0.063	0.377	-0.568	-0.222	0.727	0.671	0.706	0.798	1

5.5.1.1 Parameter: pH at 25ºC

From the correlation matrix, it has been found that correlation coefficient between **pH at 25ºC & Depth from Top (m)** is **-0.348** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

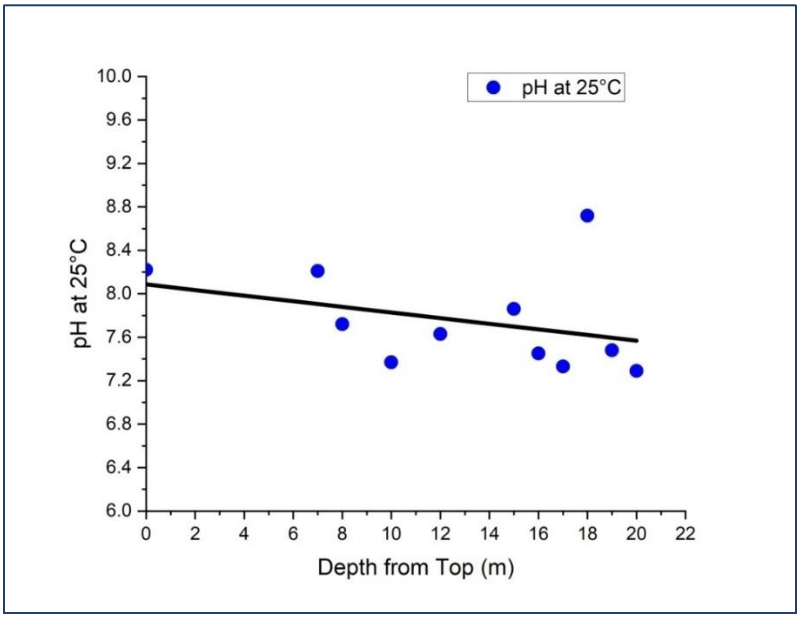

Fig 5.1: Depthwise Variation of pH at 25°C

5.5.1.2 Parameter: Soil EC at 25ºC

From the correlation matrix, it has been found that correlation coefficient between **Soil EC at 25ºC & Depth from Top (m)** is **-0.815** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Soil EC at 25ºC & pH at 25ºC** is **+0.508** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

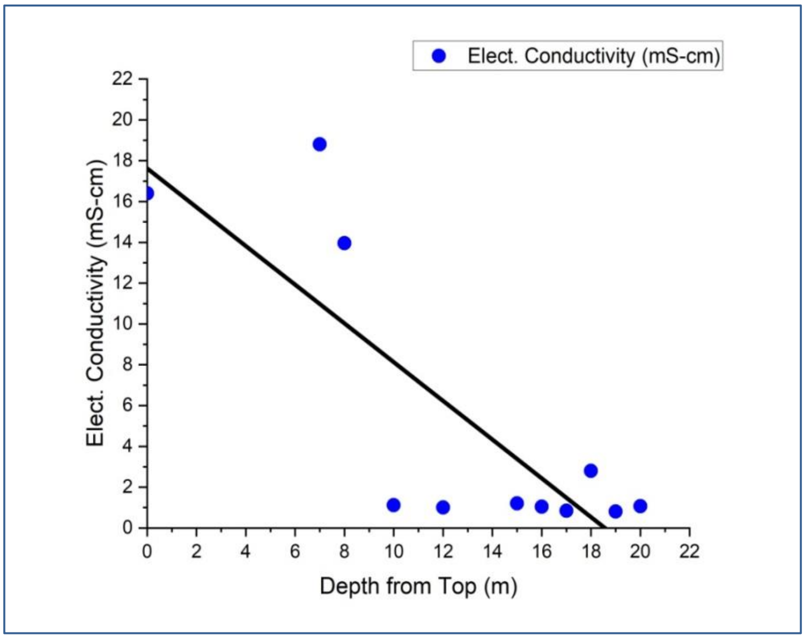

Fig 5.2: Depthwise Variation of Electrical Conductivity (mS-cm)

5.5.1.3 Parameter: Sand%

From the correlation matrix, it has been found that correlation coefficient between **Sand% & Depth from Top (m)** is **-0.109** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sand% & pH at 25°C** is **+0.724** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sand% & Soil EC** is **+0.255** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

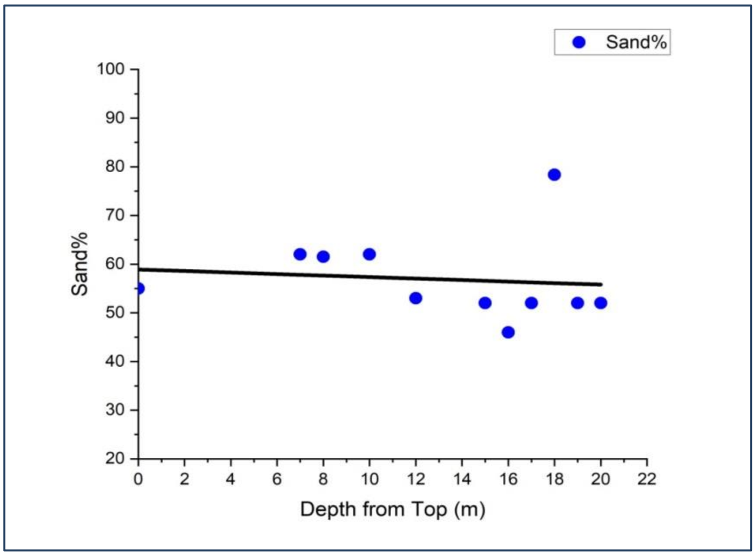

Fig 5.3: Depthwise Variation of Sand%

5.5.1.4 Parameter: Silt%

From the correlation matrix, it has been found that correlation coefficient between **Silt% & Depth from Top (m)** is **+0.429** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Silt% & pH at 25ºC** is **-0.570** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Silt% & Soil EC** is **-0.310** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Silt% & Sand%** is **-0.674** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

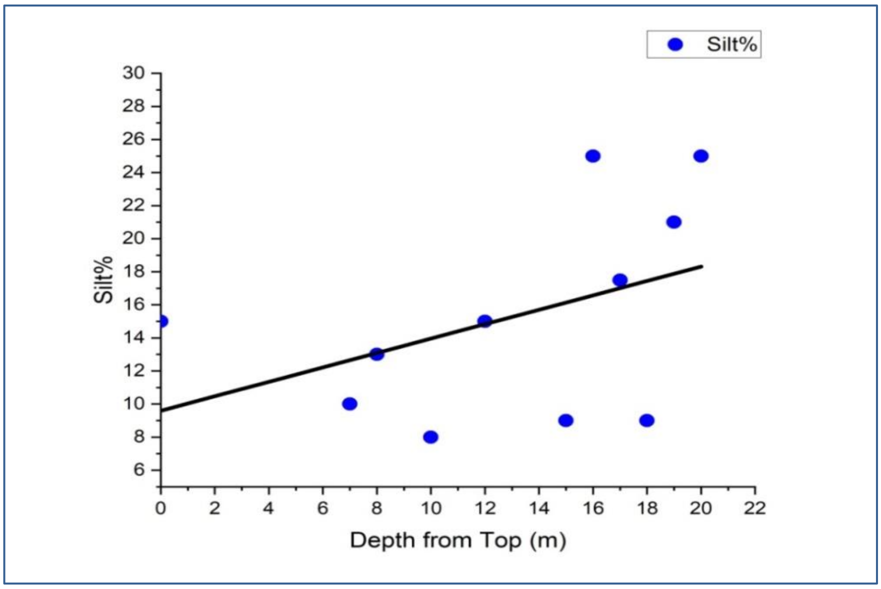

Fig 5.4: Depthwise Variation of Silt%

5.5.1.5 Parameter: Clay%

From the correlation matrix, it has been found that correlation coefficient between **Clay% & Depth from Top (m)** is **-0.116** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Clay% & pH at 25°C** is **-0.332** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Clay% & soil EC (mS)** is **+0.140** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Clay% & Sand%** is **-0.223** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Clay% & Silt%** is **+0.256** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

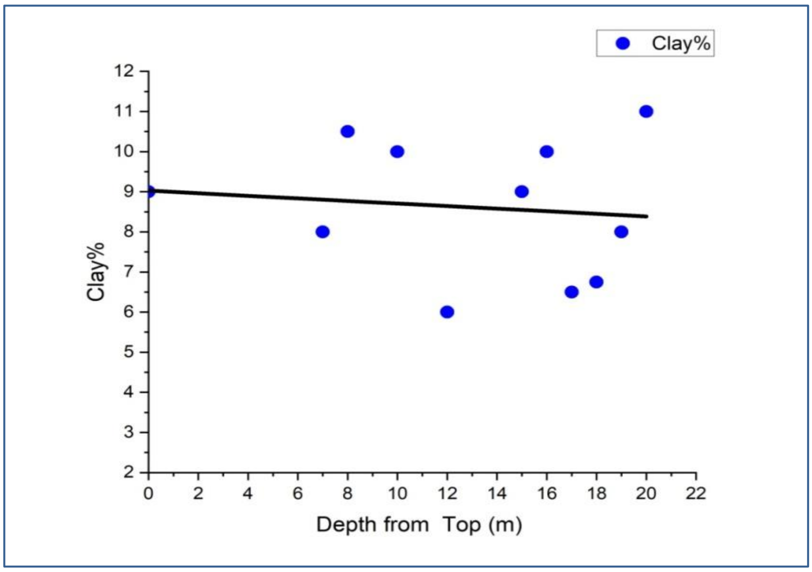

Fig 5.5: Depthwise Variation of Clay%

5.5.1.6 Parameter: Gravel%

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & Depth from Top (m)** is **-0.101** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & Soil EC** is **-0.198** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & Sand%** is **-0.223** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & Silt%** is **-0.411** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & Clay%** is **-0.548** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

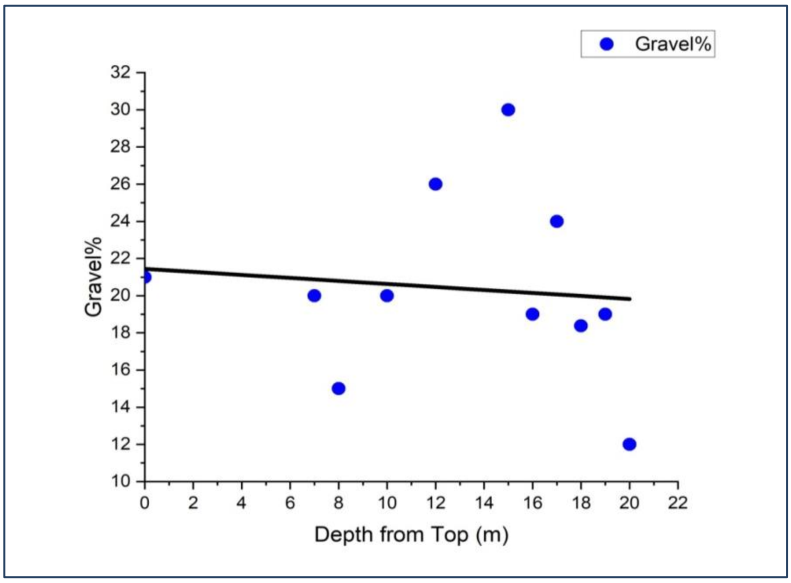

Fig 5.6: Depthwise Variation of Gravel%

5.5.1.7 Parameter: Water Holding Capacity%

From the correlation matrix, it has been found that correlation coefficient between **Water Holding Capacity% & Depth from Top (m)** is **+0.576** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Water Holding Capacity% & Soil EC** is **-0.436** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Water Holding Capacity% & Sand%** is **+0.408** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Water Holding Capacity% & Clay%** is **-0.271** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Water Holding Capacity % & Gravel%** is **-0.175** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

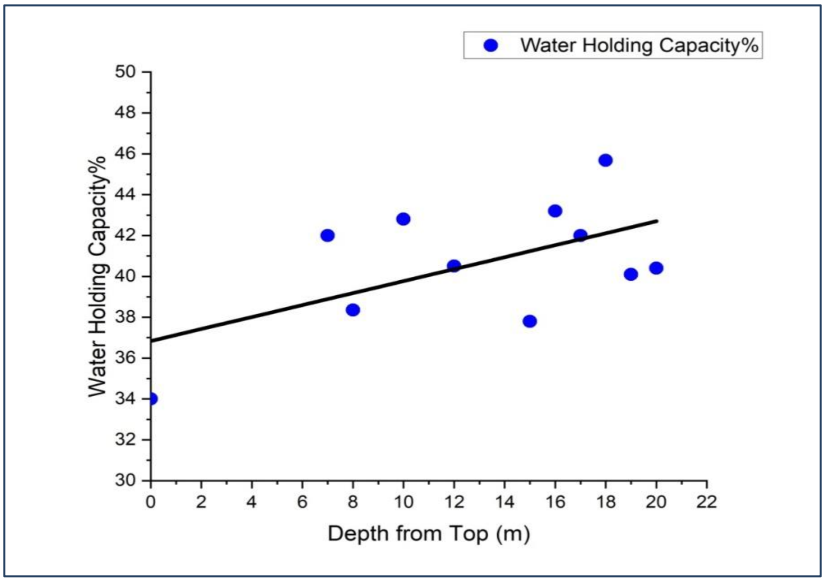

Fig 5.7: Depthwise Variation of Water Holding Capacity%

5.5.1.8 Parameter: Bulk Density (gm/cm³)

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & pH at 25ºC** is **+0.173** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & soil EC** is **+0.130** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Sand%** is **+0.401** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Clay%** is **+0.481** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Gravel%** is **-0.675** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Water Holding Capacity%** is **+0.477** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

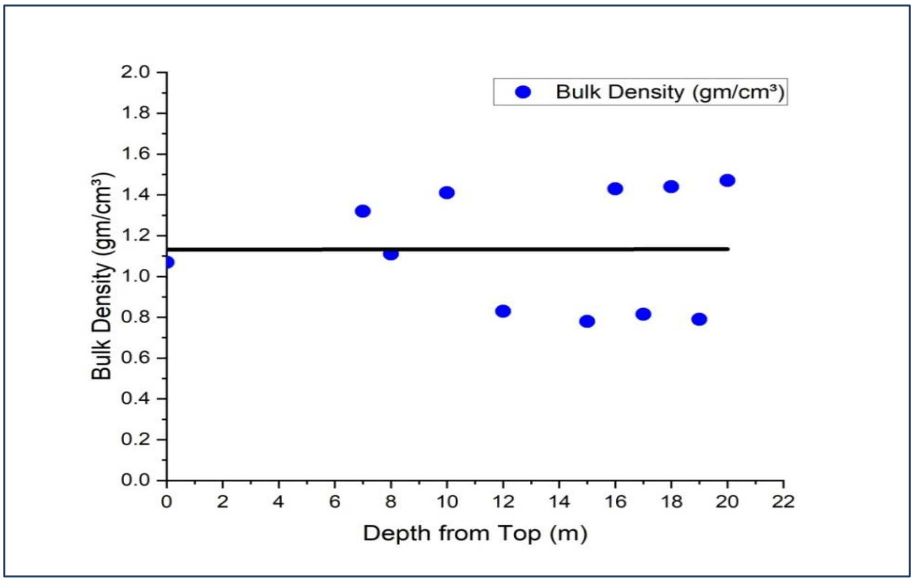

Fig 5.8: Depthwise Variation of Bulk Density (gm/cm³)

5.5.1.9 Parameter: Nitrogen (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Depth from Top (m)** is **+0.774** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & pH at 25ºC** is **-0.541** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Soil EC** is **-0.804** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Sand%** is **-0.140** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Silt%** is **+0.137** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Gravel%** is **+0.111** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Water Holding Capacity%** is **+0.346** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Bulk Density (gm/cm^3)** is **-0.230** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

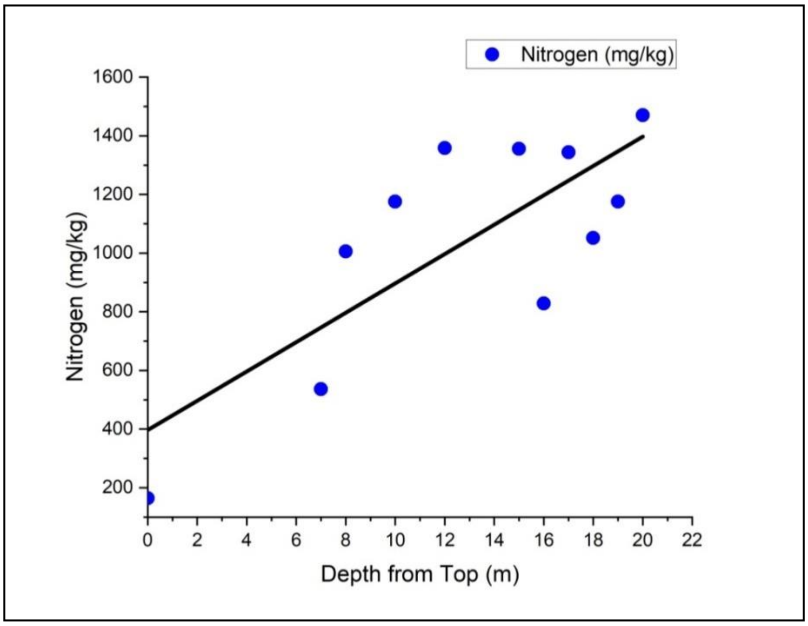

Fig 5.9: Depthwise Variation of Nitrogen (mg/kg)

5.5.1.10 Parameter: Potassium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Depth from Top (m)** is **+0.291** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & pH at 25ºC** is **-0.540** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Soil EC** is **-0.396** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Clay%** is **+0.352** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Gravel%** is **-0.392** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Water Holding Capacity%** is **+0.298** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Bulk Density (gm/cm^3)** is **+0.368** which indicates that these two parameters are

weakly positively correlated. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Nitrogen (mg/kg)** is **+0.529** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

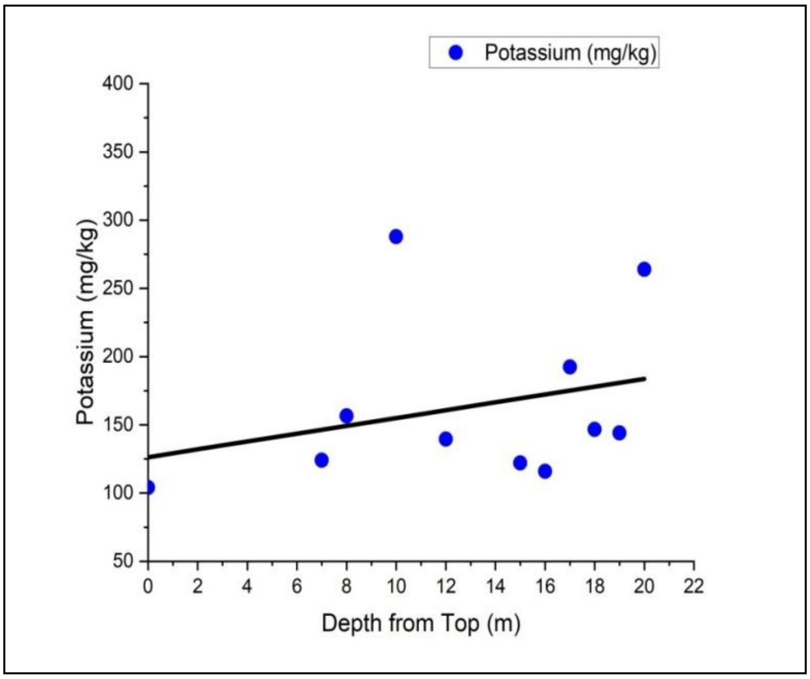

Fig 5.10: Depthwise Variation of Potassium (mg/kg)

5.5.1.11 Parameter: Organic Matter%

From the correlation matrix, it has been found that correlation coefficient between **Organic Matter% & Depth from Top (m)** is **-0.433** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic Matter% & pH at 25ºC** is **+0.878** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Soil EC** is **+0.593** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Sand%** is **+0.507** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Silt%** is **-0.501** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Bulk Density (gm/cm^3)** is **+0.313** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Nitrogen (mg/kg)** is **-0.647** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Potassium (mg/kg)** is **-0.593** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

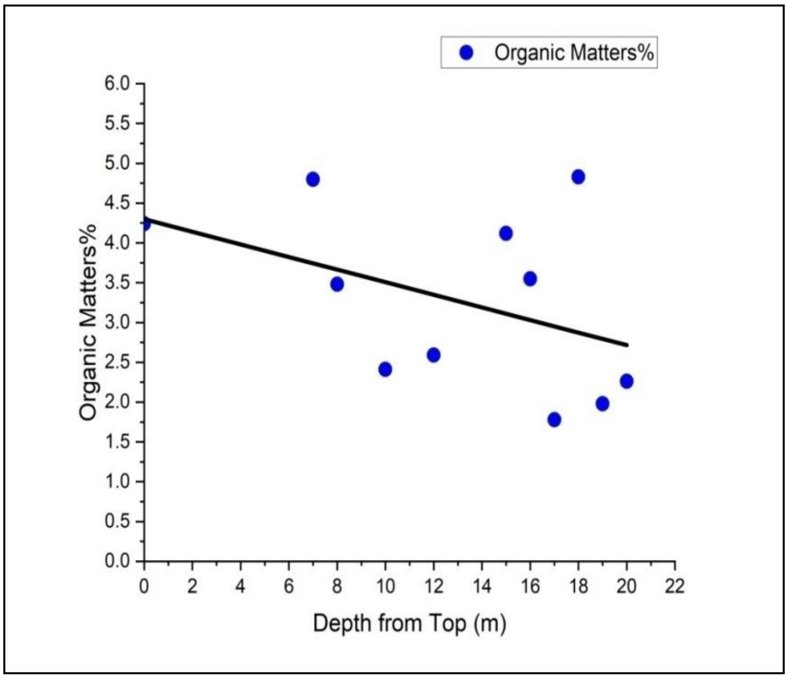

Fig 5.11: Depthwise Variation of Organic Matter%

5.5.1.12 Parameter: Calcium%

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & pH at 25ºC** is **+0.581** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Soil EC** is **+0.258** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Sand%** is **+0.822** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Silt%** is **-0.515** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Gravel%** is **-0.320** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Water Holding Capacity%** is **+0.552** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Bulk Density (gm/cm^3)** is **+0.615** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Nitrogen (mg/kg)** is **-0.115** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Organic Matter%** is **+0.620** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

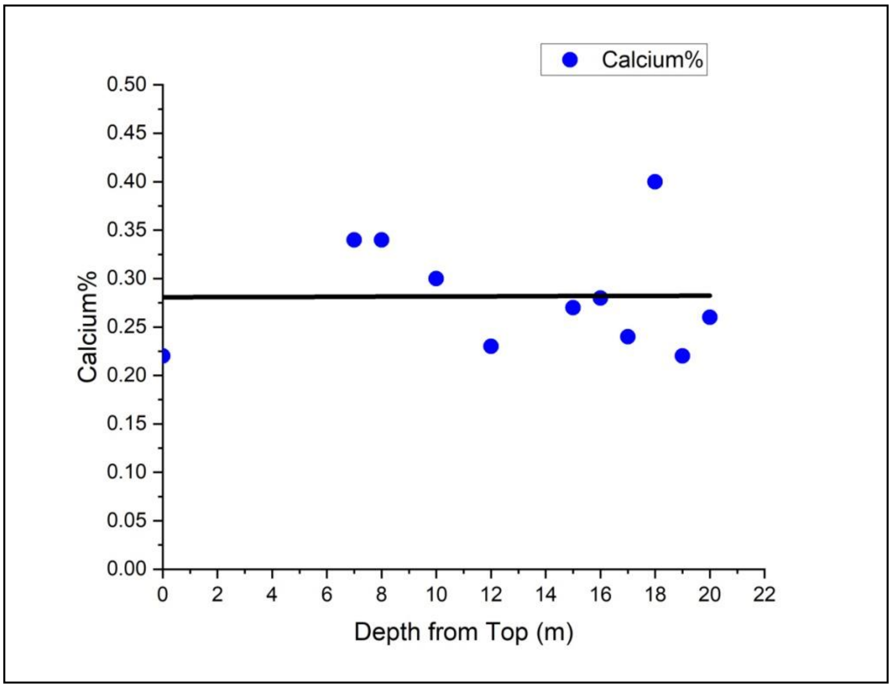

Fig 5.12: Depthwise Variation of Calcium%

5.5.1.13 Parameter: Magnesium%

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Depth from Top (m)** is **-0.129** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & pH at 25ºC** is **+0.740** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Soil EC** is **+0.340** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Sand%** is **+0.907** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation

between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Silt%** is **-0.656** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Gravel%** is **-0.221** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Water Holding Capacity%** is **+0.312** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Bulk Density (gm/cm^3)** is **+0.462** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Nitrogen (mg/kg)** is **-0.158** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Organic Matter%** is **+0.696** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Calcium%** is **+0.932** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

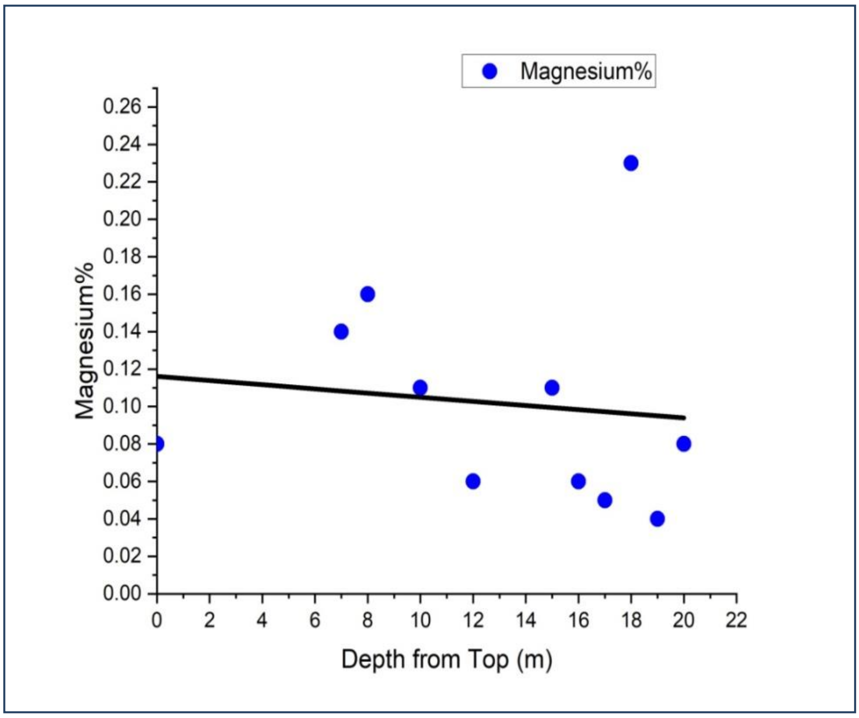

Fig 5.13: Depthwise Variation of Magnesium%

5.5.1.14 Parameter: Phosphorus%

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus% & Depth from Top (m)** is **-0.424** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & pH at 25°C** is **+0.551** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Soil EC** is **+0.524** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to

+1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg)& Sand%** is **+0.624** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Silt%** is **-0.660** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Clay%** is **+0.143** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg)** & **Gravel%** is **-0.137** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus% & Bulk density (gm/cm^3)** is **+0.441** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus% & Nitrogen (mg/kg)** is **-0.292** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus% & Potassium (mg/kg)** is **+0.163** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus% & Organic Matter%** is **+0.568** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus% & Calcium%** is **+0.555** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus% & Magnesium%** is **+0.649** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

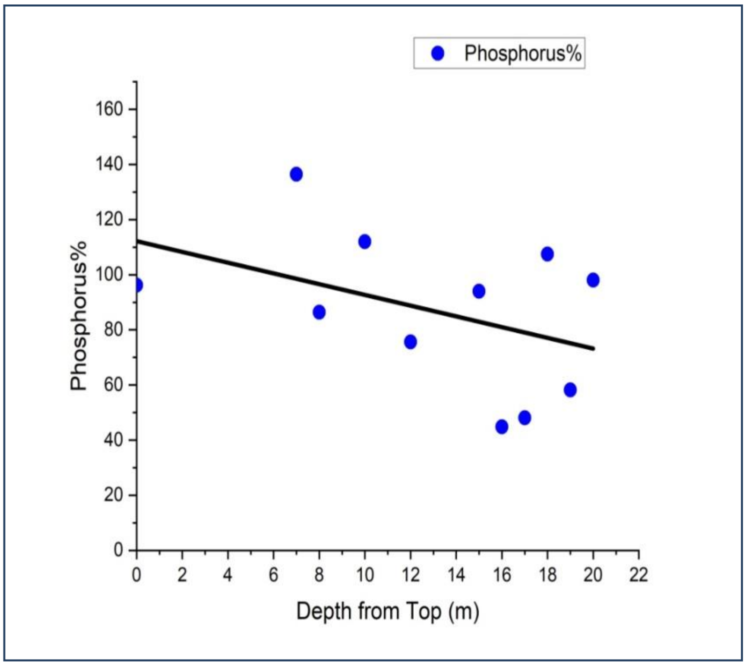

Fig 5.14: Depthwise Variation of Phosphorus%

5.5.1.15 Parameter: Sodium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Depth from Top (m)** is **-0.521** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & pH at 25ºC** is **+0.722** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Soil EC** is **+0.806** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Sand%** is **+0.666** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Silt%** is **-0.560** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Gravel%** is **-0.209** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Bulk density (gm/cm^3)** is **+0.377** which indicates that these two parameters are

weakly positively correlated. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Nitrogen (mg/kg)** is **-0.568** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Potassium (mg/kg)** is **-0.222** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Organic matter%** is **+0.727** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Calcium%** is **+0.671** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Magnesium%** is **+0.706** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Phosphorus%** is **+0.798** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

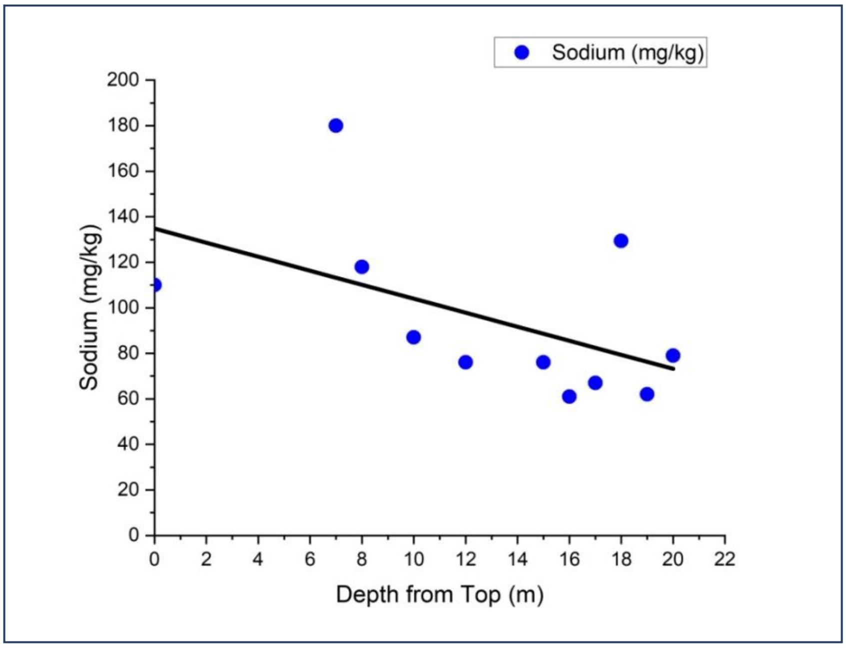

Fig 5.15: Depthwise Variation of Sodium (mg/kg)

5.5.2 Statistical Inference from Correlation Matrix Analysis on Seasonwise Variation of Physical Characteristics of Coarser Soil-like Materials

Based on the available data from KMC (2022) shown in Table 5.2, Seasonal variation of Physical Characteristics of Coarser fraction of Soil-like Materials have been studied using the Correlation Matrix method which has been shown in Table 5.6 and Table 5.5 respectively. The data was checked thoroughly before the analysis. Pearson correlation coefficient has been used to study the relationship between the different physicochemical characteristics. Pearson correlation coefficient was mainly employed to detect the patterns in different parameters. The correlation coefficient varies between -1 and +1 and indicates negative and positive correlation between two analysed physical parameters of soil-like materials.

Table 5.5: Seasonwise Variation of Physicochemical Characteristics

Physical Parameters (Seasonwise Variation)																
Seasons	**Summer**							**Monsoon**					**Winter**			
Months	**S -1**	**S – 2**	**S - 3**	**S - 4**	**S - 5**	**S - 6**	**S - 7**	**S - 8**	**S - 9**	**S - 10**	**S - 11**	**S -12**	**S - 13**	**S -14**	**S - 15**	**S - 16**
pH at 25°C	8.21	8.06	7.96	7.39	7.26	7.38	7.49	8.22	7.81	7.45	7.37	7.29	7.86	7.67	7.59	7.48
EC (mS)	18.8	26.6	5	0.84	0.84	1.32	1.18	16.4	1.28	1.04	1.12	1.07	1.21	1.09	0.92	0.81
Sand, %	62	60	62	53	51	63	91	55	56	46	62	52	52	56	50	52
Silt, %	10	12	11	18	17	14	3	15	10	25	8	25	9	11	19	21
Clay, %	8	11	10	4	9	10	0	9	8	10	10	11	9	5	7	8
Gravel, %	20	17	17	25	23	13	6	21	26	19	20	12	30	28	24	19
WHC, %	42	38	42	41.5	42.5	38.7	40.4	34	39.4	43.2	42.8	40.4	37.8	41.8	39.2	40.1
Bulk Density (gm/cm^3)	1.32	1.33	1.29	0.82	0.81	0.89	1.37	1.07	1.18	1.43	1.41	1.47	0.78	0.81	0.85	0.79
Nitrogen (mg/kg)	536	836	844	1316	1372	1176	616	164	1344	828.2	1176	1470	1356	1624	1092	1176
Potassium (mg/kg)	124	131	138	161	224	182	105	104	148	116	288	264	122	148	131	144
Organic Matters %	4.8	5.2	5.6	1.62	1.93	1.75	1.67	4.24	5.6	3.55	2.41	2.26	4.12	2.93	2.25	1.98
Calcium %	0.34	0.4	0.48	0.25	0.22	0.27	0.24	0.22	0.34	0.28	0.3	0.26	0.27	0.24	0.21	0.22
Magnesium%	0.14	0.26	0.28	0.04	0.06	0.06	0.08	0.08	0.24	0.06	0.11	0.08	0.11	0.07	0.05	0.04
Phosphorus (mg/kg)	136.4	128.4	132	44.7	51.4	44.3	38.6	96.2	116	44.8	112	98	94	81	70.2	58.2
Sodium (mg/kg)	180	182	188	58	76	54	53	110	104	61	87	79	76	73	79	62

Table 5.6: Correlation Matrix of Seasonwise Variation of Physicochemical Characteristics

Physical Characteristics Correlation Matrix (Seasonwise Variation)															
	pH at 25°C	EC (mS)	Sand %	Silt %	Clay %	Gra-vel %	WHC %	Bulk Density gm/cm³	Nitro-gen mg/kg	Potas-sium mg/kg	Org. Matter%	Calc-ium%	Magne-sium mg/kg	Phosph-orus mg/kg	Sod-ium mg/kg
pH at 25°C	1														
EC (mS)	0.772	1													
Sand, %	0.067	0.098	1												
Silt, %	-0.386	-0.189	-0.733	1											
Clay, %	0.140	0.274	-0.572	0.391	1										
Gravel, %	0.209	-0.101	-0.647	0.026	0.085	1									
WHC, %	-0.490	-0.404	-0.003	0.089	-0.107	-0.038	1								
Bulk Density (gm/cm³)	0.136	0.309	0.353	-0.092	0.209	-0.587	0.221	1							
Nitrogen (mg/kg)	-0.606	-0.626	-0.366	0.195	0.038	0.390	0.368	-0.412	1						
Potassium (mg/kg)	-0.612	-0.333	-0.150	0.182	0.361	-0.103	0.381	0.157	0.531	1					
Organic Matters %	0.827	0.579	-0.090	-0.280	0.391	0.245	-0.218	0.341	-0.342	-0.398	1				
Calcium %	0.482	0.426	0.160	-0.319	0.377	-0.122	0.167	0.503	-0.187	-0.079	0.756	1			
Magnesium%	0.587	0.484	0.177	-0.424	0.324	-0.019	-0.063	0.438	-0.176	-0.143	0.851	0.917	1		
Phosphorus (mg/kg)	0.701	0.587	-0.032	-0.327	0.465	0.161	-0.120	0.423	-0.190	0.051	0.802	0.714	0.783	1	
Sodium (mg/kg)	0.768	0.768	0.071	-0.279	0.381	-0.017	-0.064	0.404	-0.434	-0.199	0.805	0.820	0.817	0.856	1

5.5.2.1 Parameter: Soil EC

From the correlation matrix, it has been found that correlation coefficient between **Soil EC (mS) & pH at 25°C** is **+0.772** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

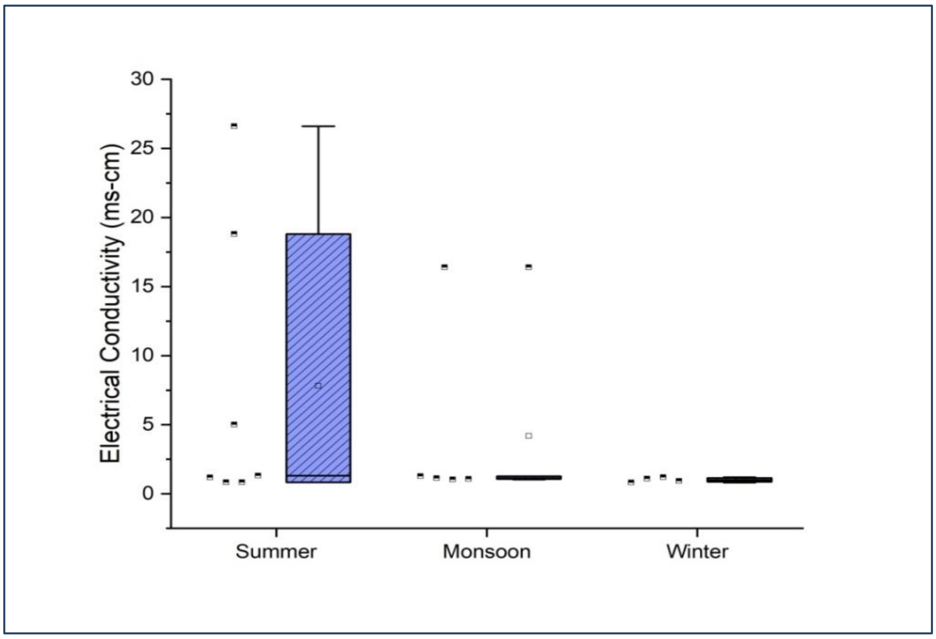

Fig 5.16: Seasonwise Variation of Electrical Conductivity

5.5.2.2 Parameter: Silt%

From the correlation matrix, it has been found that correlation coefficient between **Silt% & pH at 25°C** is **-0.386** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Silt% & Soli EC** is **-0.189** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Silt% & Sand%** is **-0.732** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

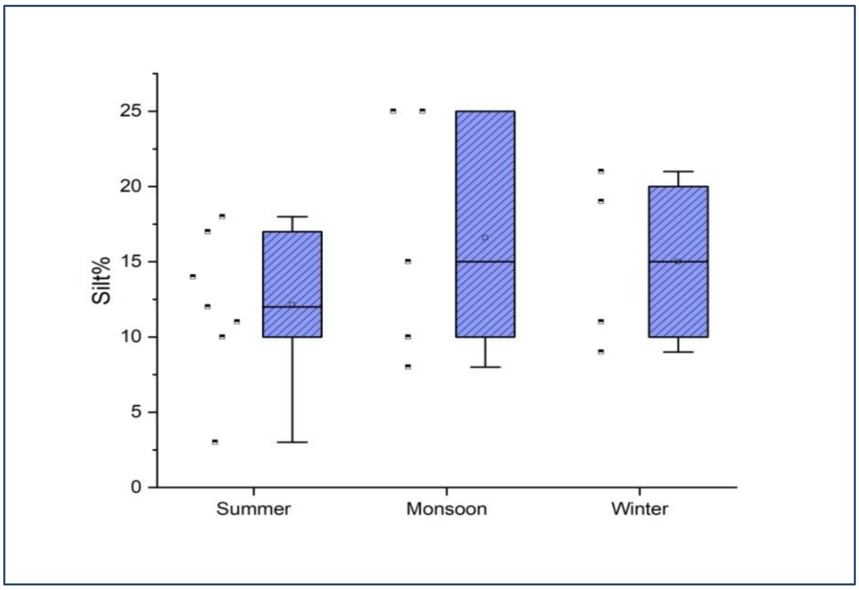

Fig 5.17: Seasonwise Variation of Silt%

5.5.2.3 Parameter: Clay%

From the correlation matrix, it has been found that correlation coefficient between **Clay% & pH at 25°C** is **+0.140** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Clay% & Soil EC** is **+0.274** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Clay% & Sand%** is **-0.572** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Clay% & Silt%** is **+0.391** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

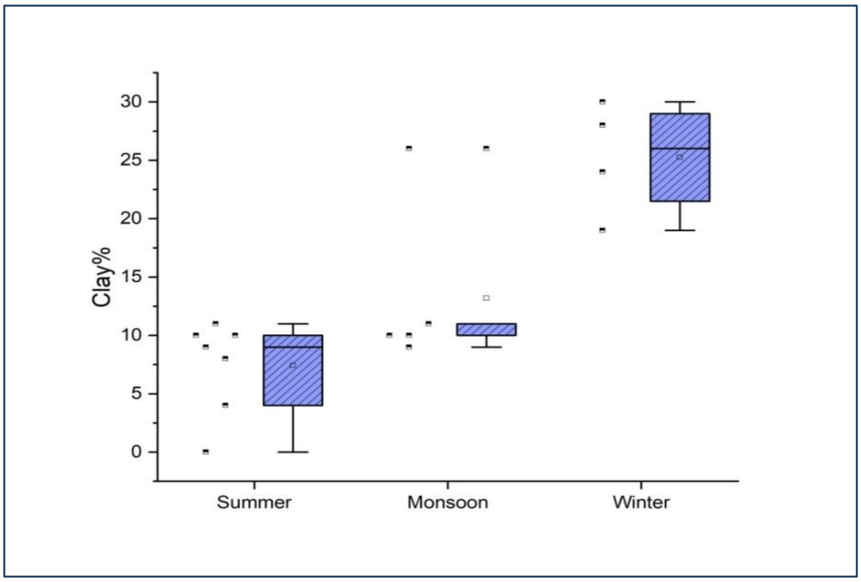

Fig 5.18: Seasonwise Variation of Clay%

5.5.2.4 Parameter: Gravel%

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & pH at 25ºC** is **+0.209** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & Soil EC** is **-0.101** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Gravel% & Sand%** is **-0.647** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

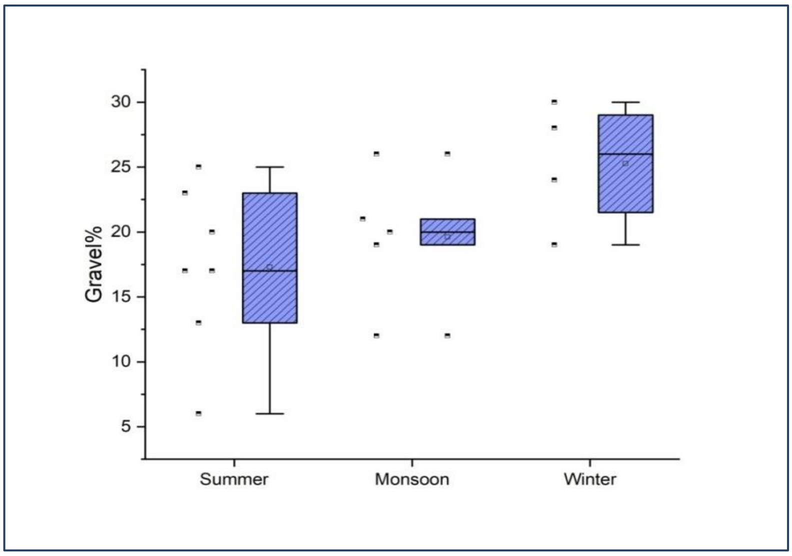

Fig 5.19: Seasonwise Variation of Gravel%

5.5.2.5 Parameter: Water Holding Capacity%

From the correlation matrix, it has been found that correlation coefficient between **Water Holding Capacity% & pH at 25ºC** is **-0.490** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Water holding capacity% & Soil EC** is **-0.404** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Water holding capacity% & Clay%** is **-0.107** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

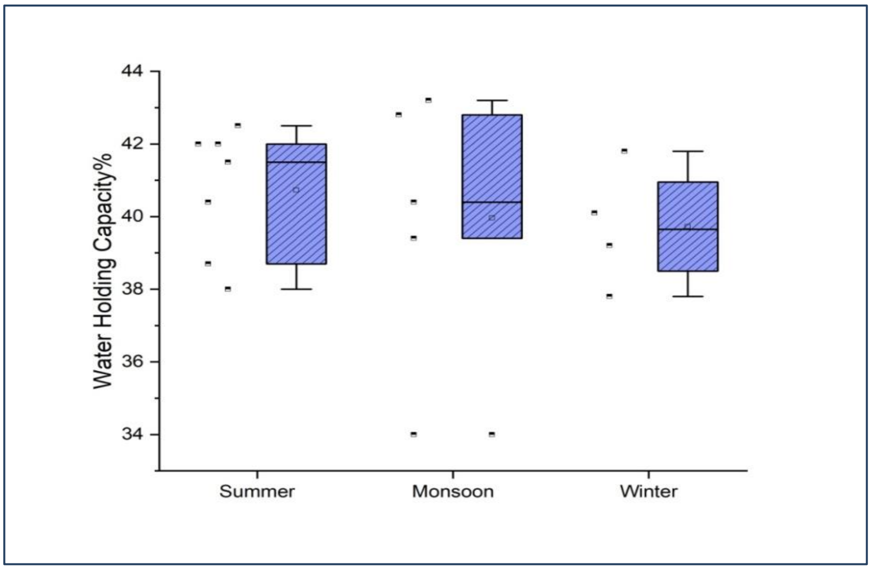

Fig 5.20: Seasonwise Variation of Water Holding Capacity%

5.5.2.6 Parameter: Bulk Density (gm/cm³)

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & pH at 25ºC** is **+0.136** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Soil EC** is **+0.309** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Sand%** is **+0.352** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Clay%** is **+0.208** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Gravel%** is **-0.587** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Bulk Density & Water holding capacity%** is **+0.221** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

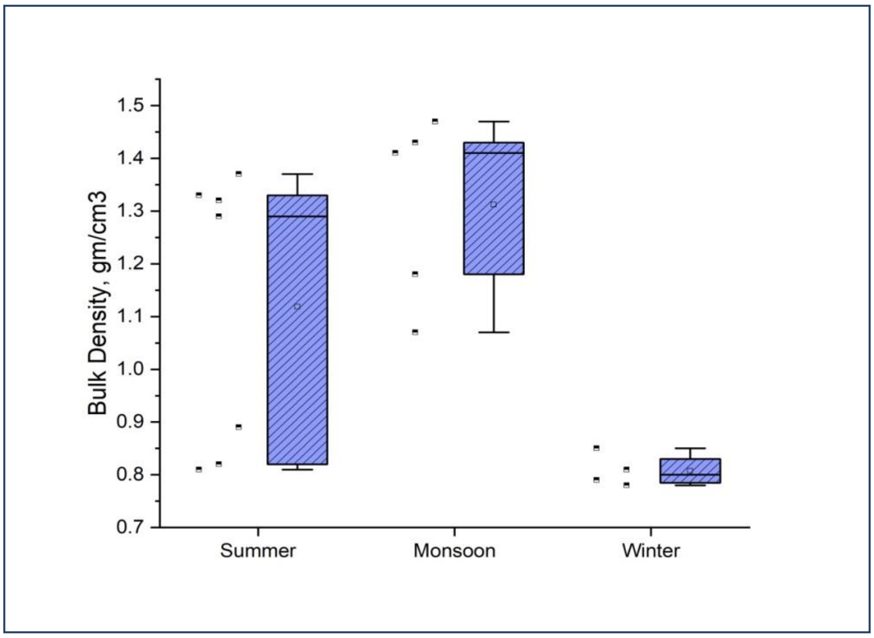

Fig 5.21: Seasonwise Variation of Bulk Density (gm/cm³)

5.5.2.7 Parameter: Nitrogen (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & pH at 25ºC** is **-0.605** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Soil EC** is **-0.626** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Sand%** is **-0.365** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Silt%** is **+0.195** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Gravel%** is **+0.389** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Water holding capacity%** is **+0.367** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nitrogen (mg/kg) & Bulk Density (gm/cm^3)** is **-0.412** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

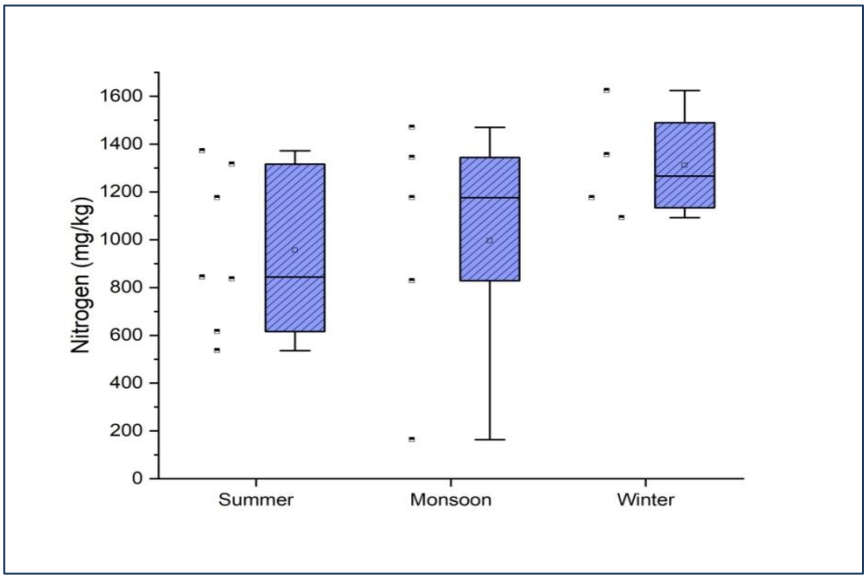

Fig 5.22: Seasonwise Variation of Nitrogen (mg/kg)

5.5.2.8 Parameter: Potassium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & pH at 25ºC** is **-0.612** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Soil EC** is **-0.333** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Sand%** is **-0.151** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Silt%** is **+0.182** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Clay%** is **+0.361** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Gravel%** is **-0.103** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Water holding capacity%** is **+0.381** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Bulk density (gm/cm^3)** is **+0.157** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Potassium (mg/kg) & Nitrogen (mg/kg)** is **+0.531** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

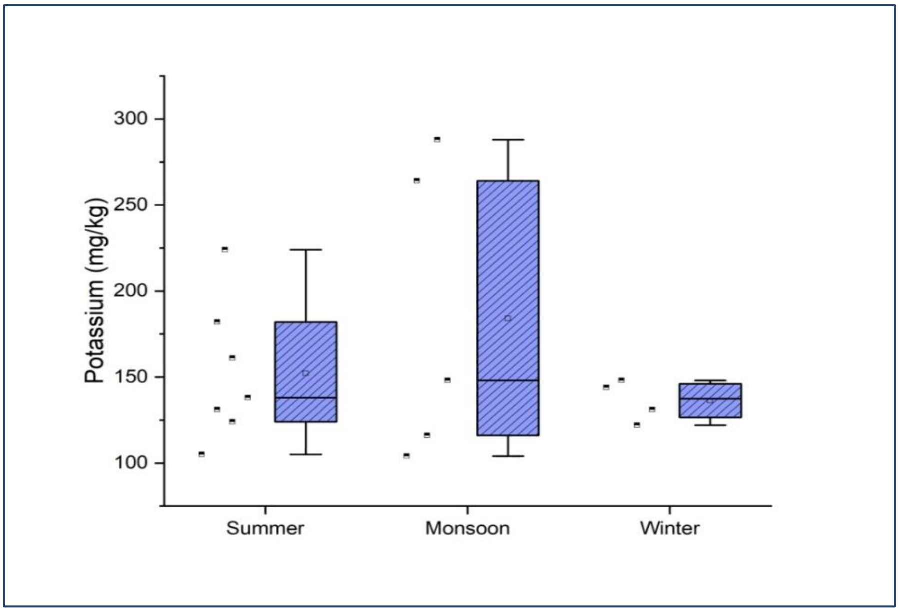

Fig 5.23: Seasonwise Variation of Potassium (mg/kg)

5.5.2.9 Parameter: Organic Matter%

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & pH at 25ºC** is **+0.826** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Soil EC** is **+0.579** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Silt%** is **-0.280** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Clay%** is **+0.391** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Gravel%** is **+0.245** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Water holding capacity%** is **-0.217** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Bulk density (gm/cm³)** is **+0.341** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Nitrogen (mg/kg)** is **-0.342** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Organic matter% & Potassium (mg/kg)** is **-0.397** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

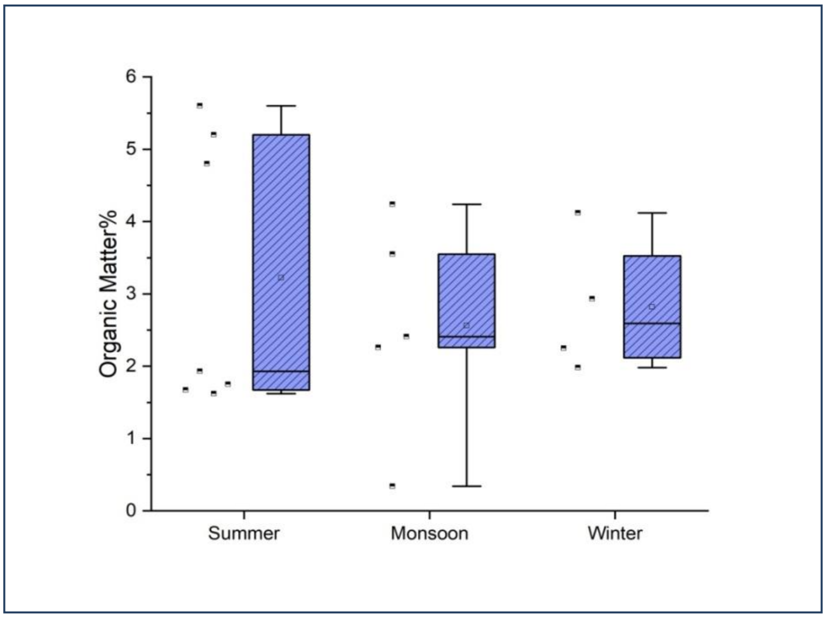

Fig 5.24: Seasonwise Variation of Organic Matter%

5.5.2.10 Parameter: Calcium%

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & pH at 25ºC** is **+0.482** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Soil EC** is **+0.426** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Sand%** is **+0.160** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Silt%** is **-0.318** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The

negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Clay%** is **+0.376** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Gravel%** is **-0.122** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Water holding capacity%** is **+0.167** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Bulk density (gm/cm^3)** is **+0.503** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Nitrogen (mg/kg)** is **-0.187** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Calcium% & Organic matter%** is **+0.756** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

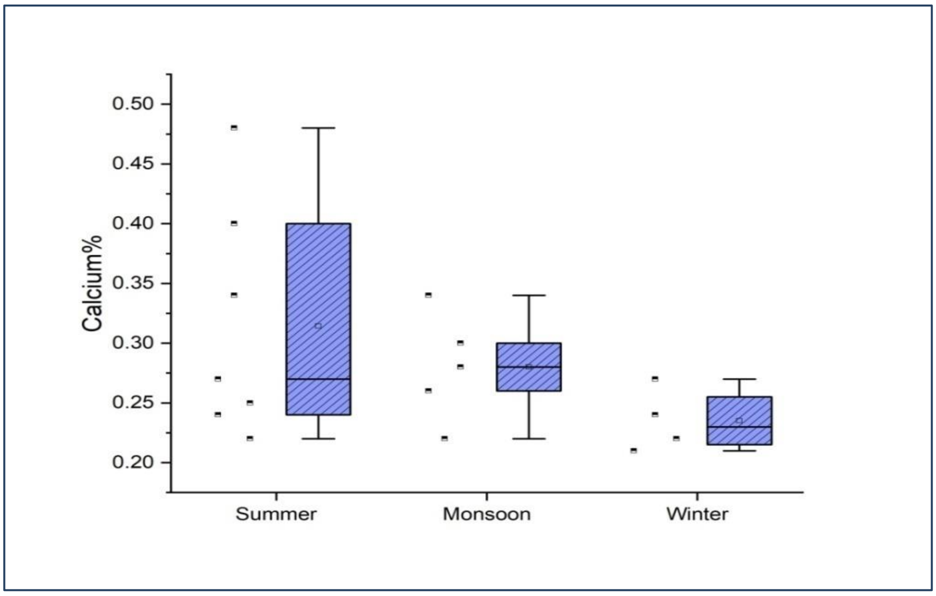

Fig 5.25: Seasonwise Variation of Calcium%

5.5.2.11 Parameter: Magnesium%

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & pH at 25ºC** is **+0.587** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Soil EC** is **+0.483** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Sand%** is **+0.176** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Silt%** is **-0.424** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Clay%** is **+0.324** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Bulk density (gm/cm^3)** is **+0.438** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Nitrogen (mg/kg)** is **-0.176** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Potassium (mg/kg)** is **-0.143** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Organic matter%** is **+0.851** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Magnesium% & Calcium%** is **+0.917** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

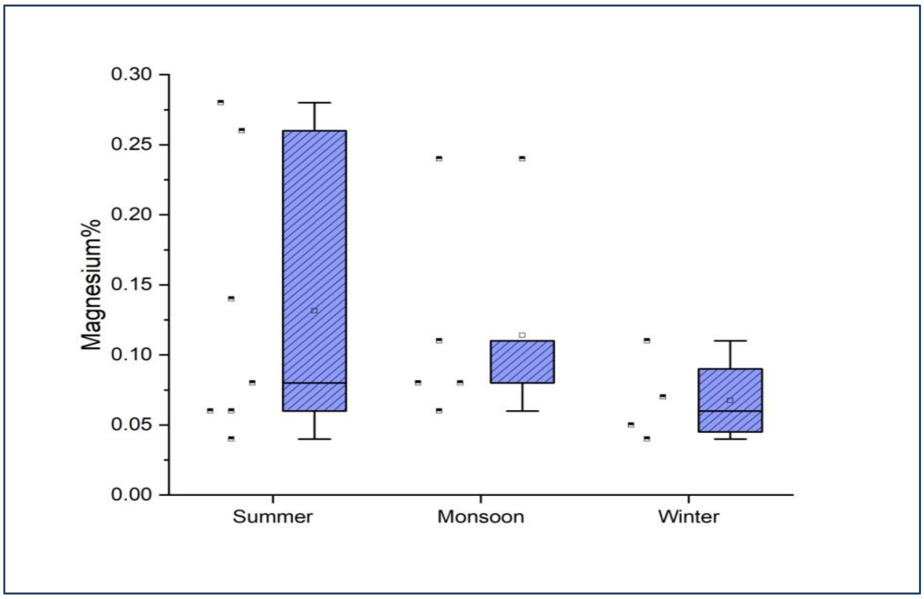

Fig 5.26: Seasonwise Variation of Magnesium%

5.5.2.12 Parameter: Phosphorus (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & pH at 25ºC** is **+0.701** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Soil EC** is **+0.586** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Silt%** is **-0.327** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Clay%** is **+0.465** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Gravel%** is **+0.161** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Water holding capacity%** is **-0.120** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Bulk density (gm/cm^3)** is **+0.423** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Nitrogen (mg/kg)** is **-0.189** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Organic matters%** is **+0.802** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Calcium%** is **+0.714** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Phosphorus (mg/kg) & Magnesium%** is **+0.783** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

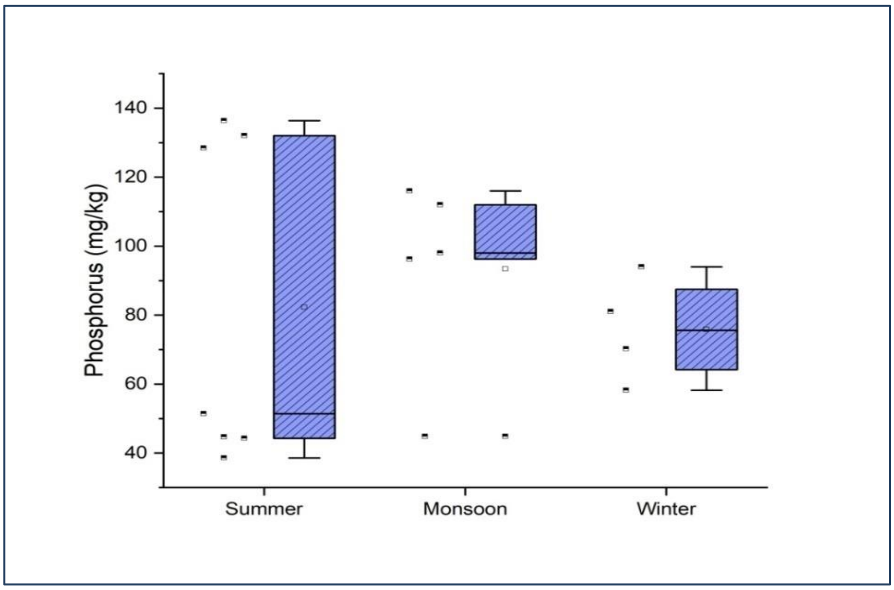

Fig 5.27: Seasonwise Variation of Phosphorus (mg/kg)

5.5.2.13 Parameter: Sodium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & pH at 25ºC** is **+0.768** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Soil EC** is **+0.767** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Silt%** is **-0.279** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Clay%** is **+0.381** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5

to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Bulk density (gm/cm³)** is **+0.404** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Nitrogen (mg/kg)** is **-0.434** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Potassium (mg/kg)** is **-0.199** which indicates that these two parameters are **weakly negatively correlated**. Moreover the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is a weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Organic matter%** is **+0.805** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Calcium%** is **+0.820** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Magnesium%** is **+0.817** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Sodium (mg/kg) & Phosphorus (mg/kg)** is **+0.856** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

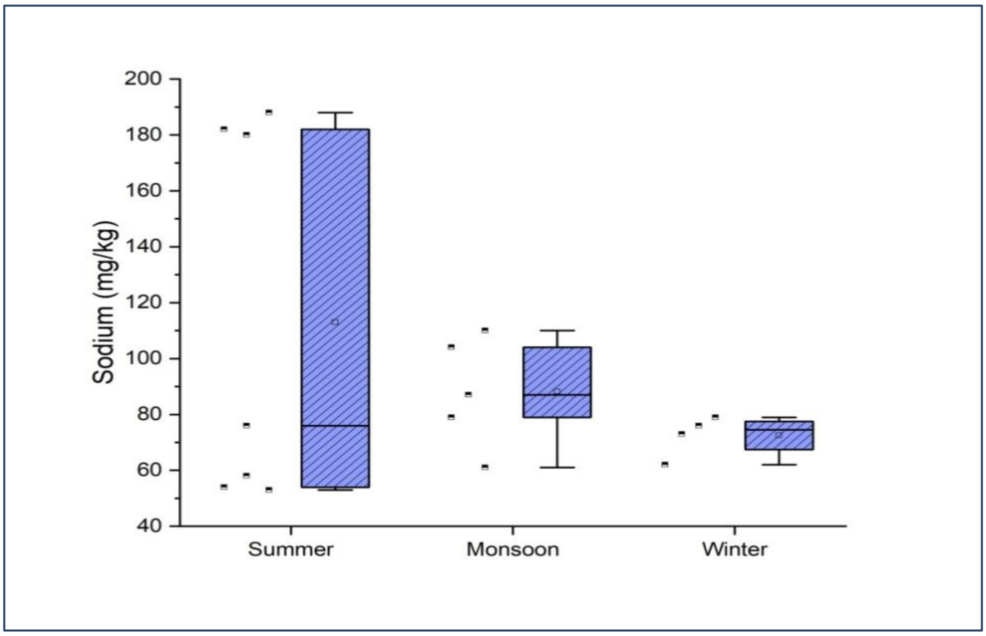

Fig 5.28: Seasonwise Variation of Sodium (mg/kg)

5.5.3 Statistical Inference from 1-way ANOVA Analysis on Seasonal Variation of Physical Characteristics of Coarser Soil-like Materials

Based on the available data from KMC (2022) shown in Table 5.5, statistical analysis of the Seasonal variation of the Physical Characteristics of coarser fraction of soil-like materials have been studied further using the 1-way ANOVA analysis method considering the $p<0.05$ significance level which has been shown in Table 5.7 respectively. The data was checked thoroughly before performing the analysis. The 1-way ANOVA (Analysis of Variance) is a descriptive statistical method which is mainly used to study the relationship between the physicochemical characteristics and observe the differences in mean values.

Table 5.7: Seasonwise 1-way Anova Analysis of Physicochemical Characteristics

Physical Parameters 1-way Anova Analysis [Seasonwise]						
Seasons	**Summer**	**Monsoon**	**Winter**	**F[Stat]**	**P-value**	**F [Crit.]**
pH at 25°C	53.75 ± 7.67	38.14 ± 7.63	30.6 ± 7.65	0.032	0.969	3.806
EC (mS)	54.58 ± 7.79	20.91 ± 4.18	4.03 ± 0.03	0.930	0.419	3.806
Sand, %	442 ± 173.14	271 ± 34.2	210 ± 52.5	2.050	0.168	3.806
Silt, %	85 ± 25.14	83 ± 65.30	60 ± 34.67	0.768	0.484	3.806
Clay, %	52 ± 15.95	66 ± 51.7	101 ± 23.58	14.108	0.001	3.806
Gravel, %	121 ± 40.90	98 ± 25.3	101 ± 23.58	2.533	0.118	3.806
WHC, %	285.1 ± 3.11	199.8 ± 13.65	158.9 ± 2.81	0.249	0.783	3.806
Bulk Density (gm/cm³)	7.83 ± 0.07	6.56 ± 0.03	3.23 ± 0.001	6.830	0.009	3.806
Nitrogen (mg/kg)	6696 ± 111666.3	4982.2 ± 274640	5248 ± 55392	1.173	0.340	3.806
Potassium (mg/kg)	1065 ± 1632.47	920 ± 7384	545 ± 142.92	0.901	0.430	3.806
Organic Matters %	22.57 ± 3.48	12.8 ± 2.21	11.28 ± 0.91	0.268	0.769	3.806
Calcium %	2.2 ± 0.01	1.4 ± 0.002	0.94 ± 0.001	1.584	0.242	3.806
Magnesium%	0.92 ± 0.009	0.57 ± 0.005	0.27 ± 0.001	0.815	0.464	3.806
Phosphorus (mg/kg)	575.8 ± 2207.4	467 ± 811.92	303.4 ± 233.13	0.275	0.764	3.806
Sodium (mg/kg)	791 ± 4391.67	441 ± 387.7	290 ± 55	1.048	0.379	3.806

The statistical inferences from the 1-way ANOVA Analysis on Seasonal Variation of Physical Characteristics are described as follows:

5.5.3.1 Parameter: pH at 25°C

Analysis of Variance is performed for checking the effect of three seasons on mean of **pH at 25°C**. The average soil pH is (53.75 ± 7.67) at summer, (38.14 ± 7.63) at monsoon, (30.6 ± 7.65) at winter indicating that soil pH is maximum in summer and minimum in winter. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in pH according to the seasonal variation.

5.5.3.2 Parameter: Electrical Conductivity (mS/cm) at 25°C

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Electrical Conductivity (mS/cm).** The average electrical conductivity of the soil sample has been (54.58 ± 7.79) % in summer, (20.91 ± 4.18) in monsoon,(4.03 ± 0.03) in winter respectively. It indicates that soil EC (mS-cm) is maximum in summer and is minimum in winter. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in electrical conductivity according to the seasonal variation.

5.5.3.3 Parameter: Sand%

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Sand%**. The average sand% of the soil sample has been (442 ± 173.14) in summer, (271 ± 34.2) in monsoon, (210 ± 52.5) in winter respectively. It has been found that the average sand% is maximum in summer and is minimum in winter season respectively. After performing the analysis, we find the F[statistic] is lesser than the F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in sand% according to the seasonal variation.

5.5.3.4 Parameter: Silt%

Analysis of Variance is performed for checking the effect of the three seasons on the mean of the silt%. The average silt% of the soil sample has been (85 ± 25.14) at summer, (83 ± 65.30) at monsoon, and (60 ± 34.67) at winter. It indicates that Silt% is maximum in summer & minimum in winter. After performing the analysis, we find the F[statistic] is lesser than the F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in silt% according to the seasonal variation.

5.5.3.5 Parameter: Clay%

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Clay%**. The average clay% of the soil sample has been (52 ± 15.95) at summer, (66 ±

51.7) at monsoon, and (101 ± 23.58) at winter. It has been found clay% is maximum in winter and is minimum in summer. After performing the analysis, we find the F[statistic] is greater than F[critical], so the test is a significant one. As $p<0.05$, alternative hypothesis considered which implies that the result has found significant difference in clay% according to the seasonal variation.

5.5.3.6 Parameter: Gravel%

Analysis of Variance is performed for checking the effect of the three seasons on the mean of the **Gravel%**. The average gravel% is (121 ± 40.90) in summer, (98 ± 25.3) in monsoon, and (101 ± 23.58) in winter respectively. It has been found that the average gravel% is maximum in summer whereas in monsoon it is minimum. After performing the analysis, we find the F[statistic] is lesser than the F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in gravel% according to seasonal variation.

5.5.3.7 Parameter: Water Holding Capacity%

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Water Holding Capacity%**. The average water holding capacity% is (285.1 ± 3.11) in summer, (199.8 ± 13.65) in monsoon, and (158.9 ± 2.81) in winter respectively. It has been found that the average water holding capacity% is maximum in summer whereas remains minimum in winter. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p> 0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in water holding capacity% according to seasonal variation.

5.5.3.8 Parameter: Bulk Density (gm/cm³)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Bulk Density (gm/cm³)**. It indicates that Bulk Density of soil is (7.83 ± 0.07) in summer, (6.56 ± 0.03) in monsoon, and (3.23 ± 0.001) in winter respectively. It has been found that the average soil bulk density is maximum in summer and minimum in winter. After performing the analysis, we find the F[statistic] is greater than F[critical], so the test is a significant one. As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in bulk density according to the seasonal variation.

5.5.3.9 Parameter: Nitrogen (as N), in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Nitrogen (mg/kg)**. The average nitrogen concentrations are (6696 ± 111666.3) in summer, (4982.2 ± 274640) in monsoon, (5248 ± 55392) in winter respectively. It has been found that the nitrogen concentration in summer is maximum whereas the concentration in monsoon is minimum. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in nitrogen concentration according to seasonal variation.

5.5.3.10 Parameter: Potassium (as K) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Potassium (mg/kg)**. The average potassium concentrations are (1065 ± 1632.47) in summer, (920 ± 7384) in monsoon, (545 ± 142.92) in winter respectively. It has been found that the average potassium concentration is maximum in summer whereas the concentration is minimum in winter. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in potassium concentration according to seasonal variation.

5.5.3.11 Parameter: Organic Matter%

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Organic Matter%**. The average organic matter concentrations are (22.57 ± 3.48) in summer, (12.8 ± 2.21) in monsoon, (11.28 ± 0.91) in winter respectively. It has been found that the average organic matter concentration in summer is maximum whereas in monsoon it is minimum. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in organic matter% according to seasonal variation.

5.5.3.12 Parameter: Calcium (as Ca) in %

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Calcium%**. The average calcium concentrations are (2.2 ± 0.01) in summer, (1.4 ± 0.002) in monsoon, and (0.94 ± 0.001) in winter respectively. It has been found that the average calcium concentration in summer is maximum whereas in winter, the concentration is minimum. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in calcium% according to seasonal variation.

5.5.3.13 Parameter: Magnesium (as Mg) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Magnesium (mg/kg)**. The average magnesium concentrations are (0.92 ± 0.09) in summer, (0.57 ± 0.005) in monsoon, and (0.27 ± 0.001) in winter respectively. It has been found average magnesium concentration is maximum in summer and minimum in winter. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in magnesium% according to seasonal variations.

5.5.3.14 Parameter: Phosphorus (as P) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Phosphorus (mg/kg)**. The average phosphorus concentrations are (575.8 ± 2207.4) in summer, (467 ± 811.92) in monsoon, and (303.4 ± 233.13) in winter respectively. It has been found that phosphorus concentration in summer is maximum and minimum in winter. After performing the analysis, we find the F[statistic] is lesser than the F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in phosphorus (mg/kg) according to seasonal variations.

5.5.3.15 Parameter: Sodium (as Na) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Sodium (mg/kg)**. The average sodium concentrations are (791 ± 4391.67) in summer, (441 ± 387.7) in monsoon, and (290 ± 55) in winter respectively. It has been found that the average sodium concentrations in summer is maximum and is minimum in winter. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in sodium percentage according to seasonal variation.

5.6 INFERENCES REGARDING ENVIRONMENTAL FEASIBILITY OF PHYSICAL CHARACTERISTICS OF COARSER FRACTION OF SOIL-LIKE MATERIALS

Assessment of the physical characteristics of the coarser fraction of the soil-like materials have been done in order to assess its suitability or feasibility of using the desired soil-like materials for the constructional purposes like road construction, embankment construction, lowland filling etc. From the data collection table 5.3, it is observed that the pH value of the soil sample is alkaline in nature with the average range of 7.65. The sources of the sand, silt, clay and gravel in the samples are mainly the temporary construction of roads with the purpose of easy transportation of waste along with the dumping of construction & demolition waste or rubbish generated from various constructional activities. Now focussing on the topic of organic matter% in the soil-like fractions, the fact which must be considered is if the soil is poor in organic matter% then it enhances the process of soil erosion.

As the organic matter% is within the desired range so the sample depicts that this coarser fraction of soil-like materials is very much suitable for the embankment purpose. The main effects of the dumpsite location, characteristics of municipal solid waste and dumpsite depth on some selected soil chemical properties are shown in above mentioned table 5.3 of the physicochemical characteristics of the coarser fraction of the soil-like materials. Upon performing the analysis on the organic components, it has been observed that the concentrations of some of the organic components present like nitrogen is much more than its desired concentration whereas other organic components like phosphorus, potassium etc. lies within the desired range. So, it is a known fact that nitrogen level affects the soil pH by increasing the chance of soil acidification.

More is the chance of soil acidification; lesser will be the chance of using it in the agricultural purposes. Analysing the results generated from the detailed analysis of the physical characteristics of the inorganic components, it has been found that the concentrations of some of the inorganic components present like calcium, magnesium, and sodium are very much above the maximum desired range. The three above mentioned components are very important from the viewpoint of soil fertility management since inorganic components like calcium, magnesium etc. play a key role as a potential factor for sustaining the soil productivity by reducing the soil acidity through its limiting affect.

After studying the data collected thoroughly, it can be concluded that the pH and the electrical conductivity of the processed soil-like materials from which the samples have been collected are within the permissible range showing that the acidity or alkalinity of SLM is a stable one. The physicochemical characteristics like water holding capacity and bulk density of the SLM are within the permissible limit which makes it a good soil sample. Although, the concentration of potassium, phosphorus, and organic matter are within the range, the concentrations of the three main constituents like calcium, magnesium, and nitrogen are below the permissible limit. As a result, this soil-like material will not be a good fertilizing soil, so this soil cannot be used for the agricultural purposes but this soil-like material can be used for constructional activities like road construction etc. To understand the environmental feasibility of physical parameters with respect to standards, mean and standard deviation has been calculated by taking the average of the sampling data of all the three seasons (summer, monsoon & winter) which have been collected (refer to Table 5.5).

Table 5.8: Environmental Feasibility of Physical Characteristics of SLM

PHYSICAL PARAMETERS ANALYSIS			
Parameters	**Mean ± SD**	**Range**	**Remarks**
pH at 25°C	7.66 ± 0.32	6 - 8.5	In range
Elect. Conductivity (μS)	4.97 ± 8.06	-	-
Sand%	57.69 ± 10.24	(45 – 60)%	In range
Silt%	14.25 ± 6.20	-	-
Clay%	8.06 ± 2.91	-	-
Gravel%	20.00 ± 6.22	-	-
Water Holding Cap. %	40.24 ± 2.38	(25 – 60)%	In range
Bulk density (gm/cm³)	1.10 ± 0.27	(1.0 – 1.8) gm/cm³	In range

Nitrogen (mg/kg)	1057.89 ± 390.19	25 – 125 (mg/kg)	Not in range
Potassium (mg/kg)	158.13 ± 54.94	101 – 300 (mg/kg)	In range
Organic matter %	3.24 ± 1.47	(3 – 6)%	In range
Calcium%	0.28 ± 0.07	(0.043 – 0.054)%	Not in range
Magnesium%	0.11 ± 0.08	(0.004 – 0.005)%	Not in range
Phosphorus (mg/kg)	84.14 ± 34.56	60 – 90 (mg/kg)	In range
Sodium (mg/kg)	95.13 ± 46.61	-	-

CHAPTER VI: CHEMICAL CHARACTERISTICS OF SOIL-LIKE MATERIALS

6.1 TOTAL HEAVY METALS AND ITS ROLE IN REUSABILITY OF SOIL-LIKE MATERIALS

Previous investigations have reported a significant presence of contaminants in soil-like material including heavy metals, organic pollutants, soluble salts etc. which hinders its reuse in offsite applications and poses environmental and human health risks (Burlakovs et al., 2016; Hölzle, 2019; Datta et al., 2021a; Somani et al., 2022; Orupöld et al., 2022). Using the total concentration of metal as a criterion to determine the potential effects of soil contamination may sometimes be misleading; it indicates that all forms of a given metal have an equal effect on the environment (Ferrans et al., 2021). However, this assumption does not consider that the risk of heavy metal contamination depends on their bioavailability and mobility (Somani et al., 2023). From the previous studies it has been proved that heavy metal toxicity to the ecosystem is mainly caused by the reactive fractions of metals in the soil (Ferrans et al., 2021). In contrast to the destruction of organic compounds in landfill environments, heavy metals remain in the waste until being released out by leaching (Jain et al., 2005). It has been reported that around one-third of the total heavy metals including copper, chromium, nickel, zinc, lead etc. from landfilled municipal solid waste were found to exist in bioavailable forms that can leach out easily. Therefore, sequential extraction analysis provides a suitable approach to determine the different forms of heavy metals (exchangeable, reducible, oxidizable, carbonatic, residual phase). It allows understanding the chemical distribution of heavy metals within their solid matrix. This analysis differentiates between easily leachable fraction and non-leachable fraction (Somani et al., 2023).

Heavy metals can be found in different phases within a solid matrix, including dissolved ions and organic complexes in soil solution, exchangeable ions that are adsorbed onto solid particles of a soil skeleton, and co-precipitate as part of soil solids. Heavy metals in reducible and oxidizable phases might leach under extreme conditions, whereas those in the residual phase are almost inert (Kim et al., 2015). With regard to the contaminant aspect, heavy metal thresholds for the reuse in earthworks served as references to assess the suitability of soil-like materials for construction purposes like backfilling, road sub-bases, noise barriers etc. Compost quality standards were taken to assess the compliance of soil-like materials with heavy metal thresholds in the dry matter (Hölzle et al., 2022). The cost standards of countries like Austria, Belgium, Bulgaria, Estonia etc. served as references (Foster and Prasad, 2021). Numerous factors that govern the characteristics of soil are responsible for the distribution of heavy metals in various phases. These factors include the availability of clay content, pH and redox potential of soil, Fe/Mn oxide content, availability of organic matter, and presence of other anions and cations in the soil (Srivastava & Chakma 2020). For a precise evaluation of the bioavailability of heavy metals in soil sediments, these governing factors need to be taken into the consideration. The mobility and the chemical speciation of heavy metals play important roles in determining the potential pollution risk of the soil-like materials thereby is essential in assessing its reclaimation feasibility (Chandel et al., 2022).

6.2 LEACHATE CHARACTERISTICS & ITS ROLE IN REUSABILITY OF SOIL-LIKE MATERIALS

Open dumpsites poses a number of threats to both environment and local inhabitants by polluting nearby soil layers, surface and groundwater sources as an outcome leachate plume migration (Fatta et al., 1999; Mor et al., 2006; Maiti et al., 2016). The leachate from the landfill generally contains toxic chemical including volatile organic compounds, nitrogen compounds, inorganic macro compounds (like sulfate, chloride etc.), heavy metals and xenobiotic organic compounds (like PCBs, dioxins) (Mor et al., 2006). It is essential to assess the leaching behaviour of soil-like materials reclaimed by landfill mining (finer than 4.75mm fraction) before using it as earthfill in embankments and the filling of low-lying areas (Ramana et al., 2019). The basic physicochemical characteristics such as total dissolved solids (TDS), chemical oxygen demand (COD), ammoniacal nitrogen, cations, anions and leachable heavy metals were analysed in order to assess the leachate characteristics released from the soil-like fraction. Generally, the concentration of constituents of the leachate released from reclaimed waste was compared with those of the water released from the local soil (Somani et al., 2019). Leachate pH and alkalinity gave an idea of the condition under which leachate was formed from the waste. The alkaline pH observed is the reflection of the aged solid wastes in the dumpsites that have already achieved a complete methanogenic phase. Alkalinity is primarily caused by the presence of bicarbonates that are produced by the biodegradation of organic matter present in the waste (Ramana et al., 2019). The alkalinity of actual MSW leachate collected from site of Indian landfills has been reported in the concentrations of 10.000 – 15,000 mg/l in previous studies (Maiti et al., 2016; Mor et al., 2006). Electrical conductivity is affected by the dissolved organics and inorganics present in the leachate whereas TDS reflects the presence of inorganic salts and some amounts of organic matter that are dissolved in the leachate.

High concentration of TDS in leachate accumulated near the dumpsite damages the growth even causing the death of aquatic species (Somani et al., 2019). COD in leachate from soil-like materials was found to be lower in comparison to the leachate accumulated around the base dumpsites which may be because of lower amounts biodegradable materials present in the soil-like materials (Somani et al., 2019b). The presence of the ammoniacal nitrogen is mainly due to the domination of amino acids during the decomposition of organic compounds. Presence of colour is one of the important physical characteristics of water released from soil-like materials since it has a strong public perception. Leaching of the coloured water may contaminate the surrounding water resources (Somani et al., 2019). The principle source of inorganic anions like sulphates in leachate released from soil-like materials is the decomposition of organic matter, soluble waste such as ash, detergents, and inert waste such as sediments of dredged river (Datta et al., 2019). High concentration of chloride in leachate generated from soil-like materials is another prime inorganic anion acts as a major source for the contamination of groundwater (Loizidou & Kapetanios 1993). To understand the mobility of heavy metals which arise from different sources into the water, leaching ratio of each metal has been estimated. The low leaching of metals can be attributed to the alkaline nature of the leachate (Datta et al., 2019).

6.3 SAMPLING AREA AND SAMPLING COLLECTION PROCEDURES FOLLOWED

The soil-like materials investigated in this study was collected from age-old MSW dumpsite of India located in Kolkata. Aged samples were excavated from trial pits using a backhoe excavator. In order to understand the variation of nature of heavy metal characteristics, samples have been collected from different locations at 1-2m depth interval upto the depth of 20m from the top. This sampling procedure is mainly followed to understand the effect of depth upon the characteristics of soil-like materials. The selection of the location of the trial pits is mainly done on the basis of the age of dumpsite as being informed by the operators working onsite. Sometimes, the location for sample collection has been changed consecutively keeping the depth from top (m) constant for understanding the variation in characteristics in detail. This is because it has been observed from municipal records, that there is a high chance of irregular dumping in Dhapa during its operational phase. Composite samples have been prepared by coning and quartering to produce laboratory samples.

Generally, each composite sample was prepared from excavated waste of four test pits. The initial moisture content was measured and the waste was then dried on-site for 1-2 weeks until the moisture content was reduced below 10%. The dried MSW was then sieved through screens of sizes 80mm, 50mm, 20mm, and 4.75mm which were selected from the grain size distribution mentioned in IS 2720-IV (BIS 1985). The soil-like fraction was then collected and sealed in separated pre-cleaned airtight polythene bags and transported to the laboratory. All the samples were stored in cooling cabinets at a temperature of 4°C to prevent degradation till the chemical analyses.

6.4 EXPERIMENTAL METHODS USED & RELEVANT PRINCIPLES

Table 6.1 has been provided below containing the list of the important Total Heavy Metals which have been considered for this research work. Similarly, another Table 6.2 has also been provided containing the list of the Leachable Heavy Metals which have been considered for this research work has been shown. Besides this, in this table the test methods for each parameter are listed which will provide a clear idea about the experimental methods followed:

Table 6.1: Total Heavy Metals and relevant Experimental Methods used

Total Heavy Metals in Coarser Fraction		Test Methods followed
01	Iron (as Fe) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
02	Lead (as Pb) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)

03	Arsenic (as As) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
04	Nickel (as Ni) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
05	Cadmium (as Cd) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
06	Total Chromium (as Cr) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
07	Copper (as Cu) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
08	Mercury (as Hg) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
09	Zinc (as Zn) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)
10	Manganese (as Mn) in mg/kg.	AAS Method (APHA 3111B:2012); ICP Method (APHA 3120B:2012)

Table 6.2: Leachate Characteristics & relevant Experimental Methods used

TCLP test for Leachability of Coarser Fraction		**Hazardous Waste Management TCLP Limits (mg/lt.)**
Lead (Pb) in mg/lt.	USEPA - 1311, July 1992	5
Nickel (Ni) in mg/lt.	USEPA - 1311, July 1992	20
Copper (Cu) in mg/lt.	USEPA - 1311, July 1992	25
Total Chromium (Cr) in mg/lt.	USEPA - 1311, July 1992	5

Mercury (Hg) in mg/lt.	USEPA - 1311, July 1992	0.2
Arsenic (As) in mg/lt.	USEPA - 1311, July 1992	5
Cadmium (Cd) in mg/lt.	USEPA - 1311, July 1992	1
Zinc (Zn) in mg/lt.	USEPA - 1311, July 1992	250
Iron (Fe) in mg/lt.	USEPA - 1311, July 1992	-
Manganese (Mn) in mg/lt.	USEPA - 1311, July 1992	10

In the case of testing the samples collected for total heavy metals analysis, we followed the experimental method mentioned in the manuals of American Public Health Association (APHA 3111B:2012). All the Heavy Metal tests have been done following the AAS Method (APHA 3111B:2012) and ICP Method (APHA 3120B:2012). In the case of testing the samples collected for Leachate Characteristics, Toxicity Characteristics Leaching procedure Test has been done in order to analyse the characteristics of the leachate generating from the soil-like materials. The experiments have been done as per the guidelines prescribed in the USEPA Method 1311, July 1992. It is applicable to the determination of mobility of leachable metals and semi-volatile organic compound in solids. If the total analysis of solid demonstrates that analytic interest is not detected or is present in such a low concentrations that regulatory leachate limits cannot be exceeded, then it is unnecessary to carry out the desired leaching experiments.

Determination of metals involves two steps like digestion of samples and determination of metals by Flame AA method. Digestion of samples is generally an acid digestion procedure used to prepare the samples foe analysis of metals by atomic absorption spectrophotometer technique. In this method, a representative of 1 to 2 gm (wet weight) sample is digested in nitric acid and hydrogen peroxide. The digestate is then refluxed with either nitric acid or hydrochloric acid which is used as the final reflux acid for Flame AA analysis. Although, methods have been reported for the analysis of solids by atomic absorption spectroscopy, the technique generally is limited to metals in solution or solubilized through some form of sample processing. In direct aspiration atomic absorption spectroscopy, a sample is aspirated and atomized in a flame. A light beam from a hollow cathode or an electrode less discharge lamp is directed through the flame into a monochromator, and onto a detector that measures the amount of absorbed light. Since the wavelength of the light beam is characteristic of only the metals being determined, the light energy absorbed by the flame is a measure of the concentration of that metal in the sample

6.5 STATISTICAL METHODS USED & THEIR PRINCIPLES

In order to study the multiple inter-relationships among the analysed parameters, a descriptive statistical analysis was carried out for the analysed parameters using OriginPro 2021. Pearson correlation coefficient was calculated with the help of Correlation matrix separately for both Depthwise and Seasonal variation of Total heavy metals and Leachate characteristics of the soil-like materials samples separately in order to get a better understanding. Correlation Matrix is a preliminary descriptive method which is primarily used to estimate the degree or intensity of association between the two variables. In correlation matrix, then the coefficient value is negative then the desired parameters are assumed to be inversely related and vice-versa. Besides this, more closer is the correlation coefficient value to ±1; more the parameters are positively or negatively correlated with each other.

The seasonal variation for both the total heavy metals and leachate characteristics for the soil-like materials has been examined 1-way Analysis of Variance (ANOVA) at $p<0.05$ significance level. Here, 1-way ANOVA method has been adopted as it gives a proper idea about the variation of relation upon comparing one category of an independent variable with three or more other categorical variables. After performing the analysis, sources of variation for both 'between groups' and 'within groups' is obtained. The sum of squares quantifies the variability between or within the groups. Besides this, degrees of freedom and mean squares are calculated for both the categories i.e. ''between groups' and 'within groups'. The F[statistic] is the test statistic in the 1-way ANOVA method. If the F[statistic] is greater than F[critical] value; then the test is significant one and vice-versa. For p-value, if the $p \geq .0.05$ then null hypothesis will be considered which means there is no difference between the means of the considered three groups. Similarly, if $p \leq 0.05$ then alternative hypothesis will be considered which means there is no difference between the means of the considered three groups.

6.6.1 Statistical Inference from Correlation Matrix Analysis on Depthwise Variation of Total Heavy Metal Characteristics of Soil-like Materials

Based on the available data from KMC (2022) shown in Table 6.3, statistical analysis of the Depthwise variation of the Total Heavy Metal Characteristics of coarser fraction of soil-like materials have been studied using the Correlation Matrix method which is shown in Table 6.5 respectively. The data was checked thoroughly before performing the statistical analysis respectively.

Table 6.3: Total Heavy Metals Characteristics of Soil-like Materials

Total Heavy Metals										
Month	**Dec-22**	**Jan-23**	**Feb-23**	**Mar-23**	**Apr-23**	**May-23**	**Jun-23**	**Jul-23**	**Aug-23**	**Sep-23**
Depth from top (m)	**12**	**12**	**19**	**17**	**17**	**8**	**18**	**16**	**10**	**20**
Iron (as Fe) in mg/kg	366.2	304.1	381.6	561	463	252.3	230.4	1035	926	843
Lead (as Pb) in mg/kg	89.7	76.1	33.9	50.4	34.7	66	35.8	42.2	33.4	27.8
Arsenic (as As) in mg/kg	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Nickel (as Ni) in in mg/kg	14	24.4	28.4	22.5	27.3	10.2	7.53	28.7	20.2	24.2
Cadmium (as Cd) in mg/kg	2.1	1.2	0.53	0.2	0.2	1.2	0.52	0.5	0.26	0.3
Total Chromium (as Cr) in mg/kg	69.3	54.7	61.1	84.6	68.6	53.2	46.2	89.1	71.3	59.7
Copper (as Cu) in mg/kg	52.1	39.3	44.7	45	31.9	47.8	39.7	57.1	46.9	38.3
Mercury (as Hg) in mg/kg	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Zinc (as Zn) in mg/kg	378.9	327.4	308.3	285.5	239.3	169.7	153.8	289	217.4	208.4
Manganese (as Mn) in mg/kg	240	183.7	107.8	165	89.4	119.2	93.1	74.3	63.4	71.6

Table 6.4: Depthwise Variation of Total Heavy Metals

THM (Depthwise Variation)								
Depth from Top (m)	**8**	**10**	**12**	**16**	**17**	**18**	**19**	**20**
Iron (mg/kg)	252.3	926	335.15	1035	512	230.4	381.6	843
Lead (mg/kg)	66	33.4	82.9	42.2	42.55	35.8	33.9	27.8
Arsenic (mg/kg)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Nickel (mg/kg)	10.2	20.2	19.2	28.7	24.9	7.53	28.4	24.2
Cadmium (mg/kg)	1.2	0.26	1.65	0.5	0.2	0.52	0.53	0.3
Total Chromium (mg/kg)	53.2	71.3	62	89.1	76.6	46.2	61.1	59.7
Copper (mg/kg)	47.8	46.9	45.7	57.1	38.45	39.7	44.7	38.3
Mercury (mg/kg)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Zinc (mg/kg)	169.7	217.4	353.15	289	262.4	153.8	308.3	208.4
Manganese (mg/kg)	119.2	63.4	211.85	74.3	127.2	93.1	107.8	71.6

Table 6.5: Total Heavy Metal Correlation Matrix (Depthwise Variation)

THM Correlation Matrix (Depthwise Variation)											
	Depth from Top (m)	Iron mg/kg	Lead mg/kg	Arsenic mg/kg	Nickel mg/kg	Cadmium mg/kg	Tot. Chromium mg/kg	Copper mg/kg	Mercury mg/kg	Zinc mg/kg	Manganese mg/kg
Depth from Top (m)	1										
Iron (mg/kg)	0.109	1									
Lead (mg/kg)	-0.624	-0.474	1								
Arsenic (mg/kg)	#DIV/0!	#DIV/0!	#DIV/0!	1							
Nickel (mg/kg)	0.430	0.613	-0.311	#DIV/0!	1						
Cadmium (mg/kg)	-0.539	-0.538	0.941	#DIV/0!	-0.374	1					
Total Chromium (mg/kg)	0.021	0.745	-0.123	#DIV/0!	0.749	-0.328	1				
Copper (mg/kg)	-0.426	0.400	0.257	#DIV/0!	0.235	0.254	0.551	1			
Mercury (mg/kg)	-0.023	-0.088	0.182	#DIV/0!	0.042	0.111	0.065	-0.089	1		
Zinc (mg/kg)	0.100	0.109	0.371	#DIV/0!	0.680	0.321	0.498	0.308	0.181	1	
Manganese (mg/kg)	-0.263	-0.607	0.866	#DIV/0!	-0.140	0.810	-0.184	-0.091	0.258	0.564	1

6.6.1.1 Parameter: Iron (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/kg) & Depth from Top (m)** is **+0.108** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

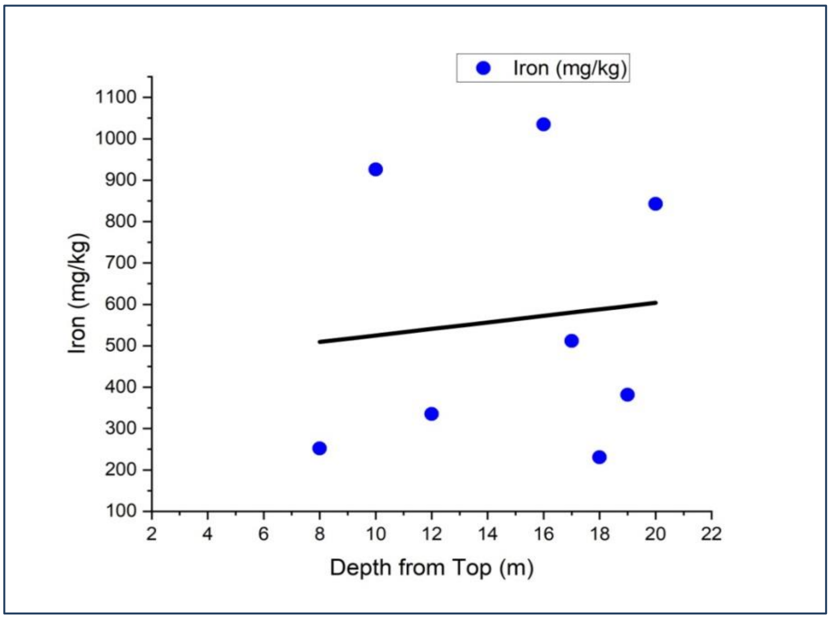

Fig 6.1: Depthwise Variation of Iron (mg/kg)

6.6.1.2 Parameter: Lead (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Lead (mg/kg) & Depth from Top (m)** is **-0.623** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Lead (mg/kg) & Iron (mg/kg)** is **-0.474** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

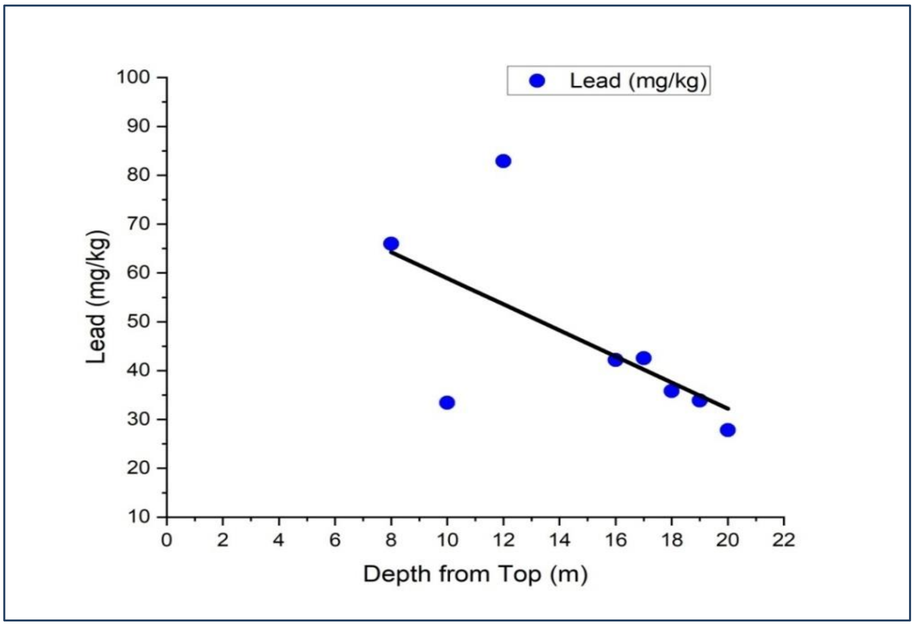

Fig 6.2: Depthwise Variation of Lead (mg/kg)

6.6.1.3 Parameter: Nickel (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Nickel (mg/kg) & Depth from Top (m)** is **+0.429** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nickel (mg/kg) & Iron (mg/kg)** is **+0.612** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nickel (mg/kg) & Lead (mg/kg)** is **-0.311** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to-1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

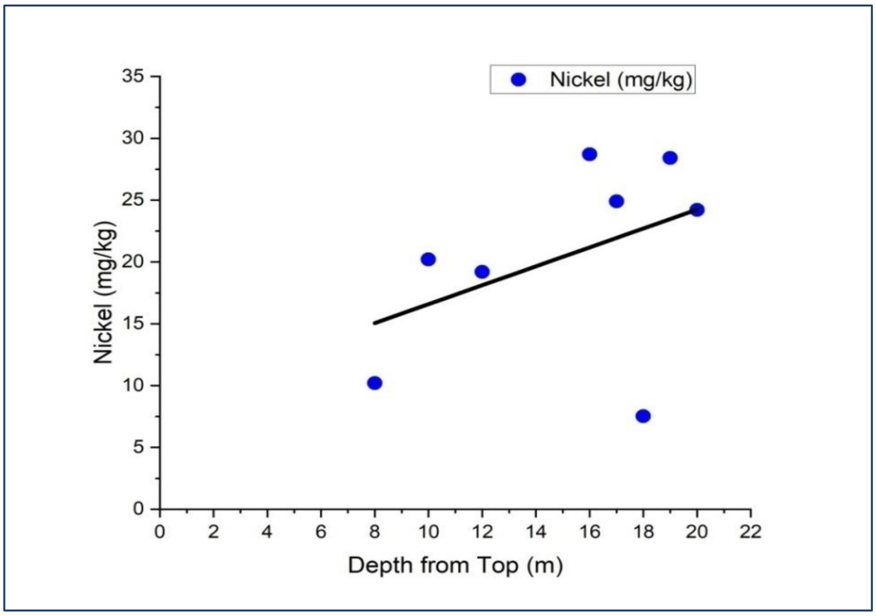

Fig 6.3: Depthwise Variation of Nickel (mg/kg)

6.6.1.4 Parameter: Cadmium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/kg) & Depth from Top (m)** is **-0.538** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/kg) & Iron (mg/kg)** is **-0.537** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/kg) & Lead (mg/kg)** is **+0.941** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/kg) & Nickel (mg/kg)** is **-0.374** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The

negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

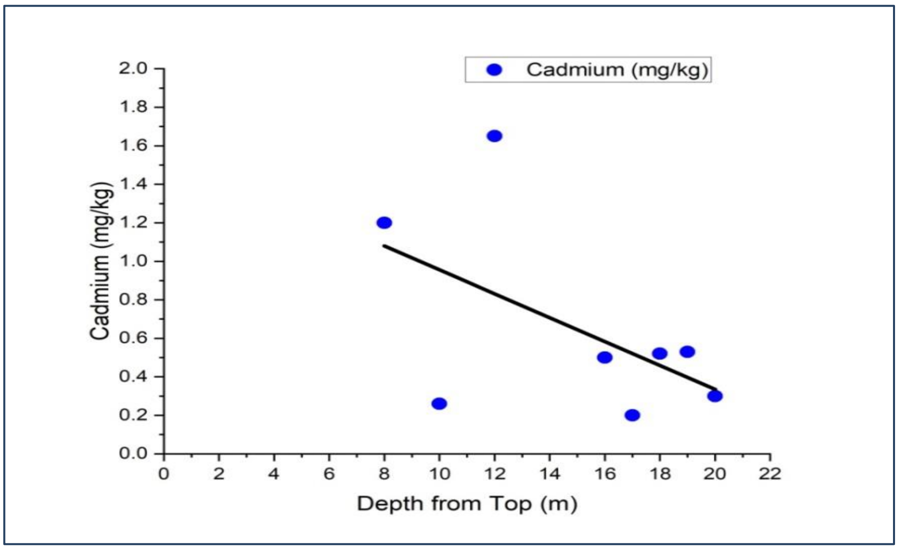

Fig 6.4: Depthwise Variation of Cadmium (mg/kg)

6.6.1.5 Parameter: Total Chromium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/kg) & Iron (mg/kg)** is **+0.744** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/kg) & Lead (mg/kg)** is **-0.123** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/kg) & Nickel (mg/kg)** is **+0.748** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/kg) & Cadmium (mg/kg)** is **-0.328** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

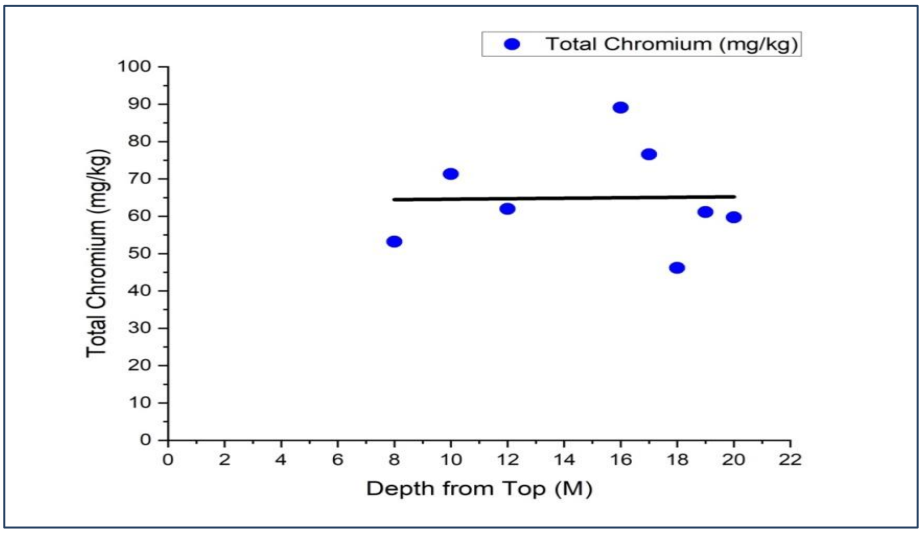

Fig 6.5: Depthwise Variation of Total Chromium (mg/kg)

6.6.1.6 Parameter: Copper (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Depth from Top (m)** is **-0.425** which indicates that these tree parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Iron (mg/kg)** is **+0.401** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Lead (mg/kg)** is **+0.256** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Nickel (mg/kg)** is **+0.235** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Cadmium (mg/kg)** is **+0.254** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Total Chromium (mg/kg)** is **+0.551** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

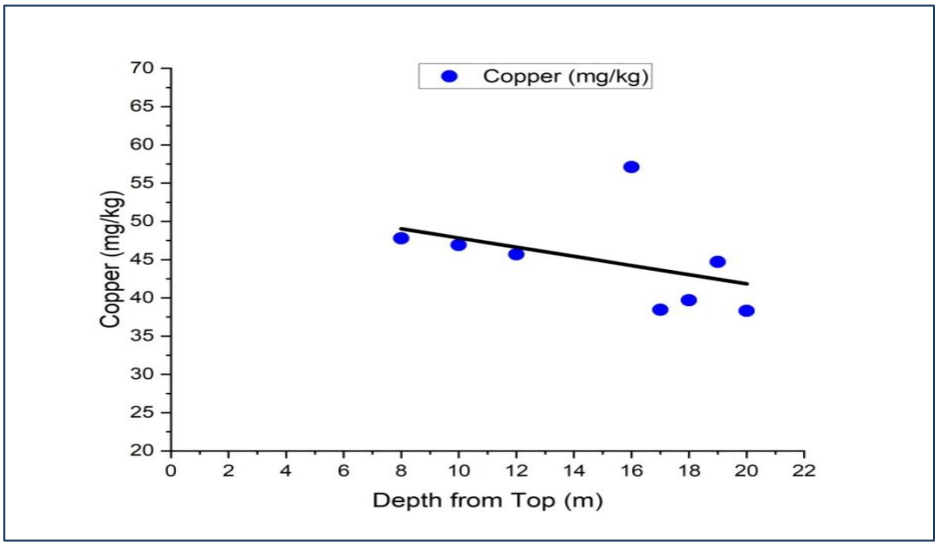

Fig 6.6: Depthwise Variation of Copper (mg/kg)

6.6.1.7 Parameter: Mercury (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/kg) and Lead (mg/kg)** is **+0.182** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/kg) and Cadmium (mg/kg)** is **+0.111** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

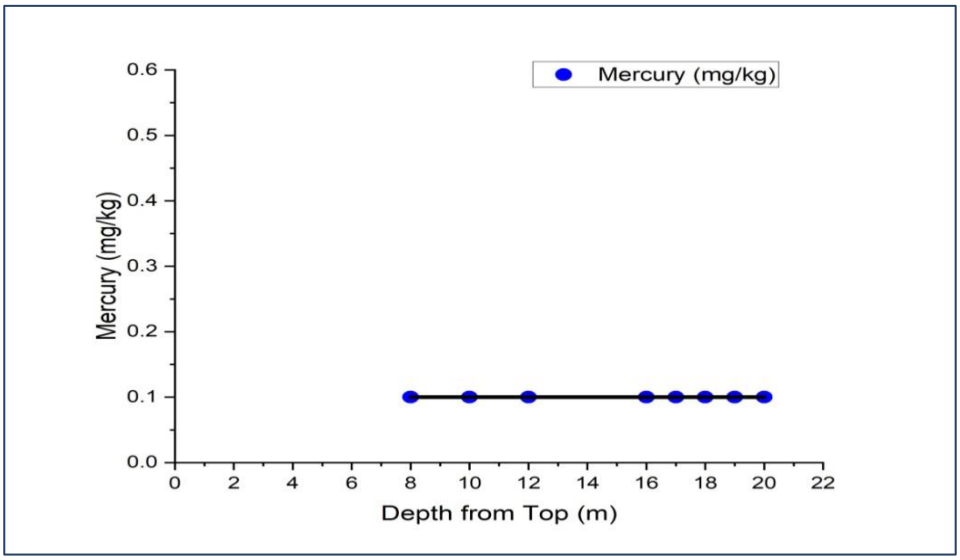

Fig 6.7: Depthwise Variation of Mercury (mg/kg)

6.6.1.8 Parameter: Zinc (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) and Depth from Top (m)** is **+0.100** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Iron (mg/kg)** is **+0.109** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Lead (mg/kg)** is **+0.370** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Nickel (mg/kg)** is **+0.680** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation

between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Cadmium (mg/kg)** is **+0.321** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Total Chromium (mg/kg)** is **+0.498** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Copper (mg/kg)** is **+0.308** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) and Mercury (mg/kg)** is **+0.181** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

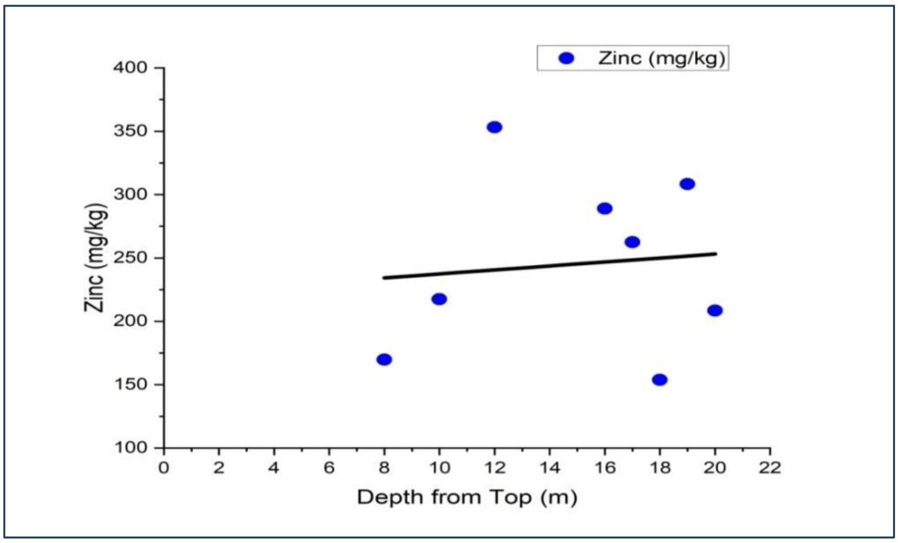

Fig 6.8: Depthwise Variation of Zinc (mg/kg)

6.6.1.9 Parameter: Manganese (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Depth from Top (m)** is **-0.263** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Iron (mg/kg)** is **-0.607** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Lead (mg/kg)** is **+0.866** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Nickel (mg/kg)** is **-0.140** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Cadmium (mg/kg)** is **+0.810** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Total Chromium (mg/kg)** is **-0.184** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Mercury (mg/kg)** is **+0.258** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Zinc (mg/kg)** is **+0.564** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

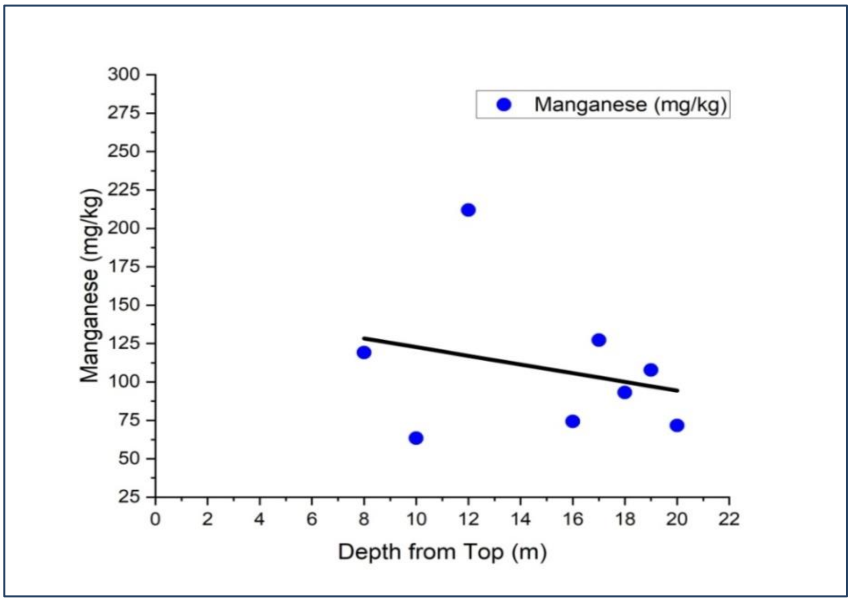

Fig 6.9: Depthwise Variation of Manganese

6.6.2 Statistical Inference from Correlation Matrix Analysis on Seasonal Variation of Total Heavy Metal Characteristics of Soil-like Materials

Based on the available data from KMC (2022), shown in Table 6.3, statistical analysis of the Seasonal variation of the Total Heavy Metal characteristics of coarser fraction of soil-like materials have been studied using the Correlation Matrix method shown in Table 6.7 respectively. The data was checked thoroughly before performing the desired statistical analysis.

Table 6.6: Seasonwise Variation of Total Heavy Metal Characteristics

THM [Seasonwise Variation]										
Seasons	**Winter**			**Summer**				**Monsoon**		
Month	**S -1**	**S - 2**	**S - 3**	**S - 4**	**S – 5**	**S – 6**	**S - 7**	**S - 8**	**S – 9**	**S – 10**
Iron (mg/kg)	366.2	304.1	381.6	561	463	252.3	230.4	1035	926	843
Lead (mg/kg)	89.7	76.1	33.9	50.4	34.7	66	35.8	42.2	33.4	27.8
Arsenic (mg/kg)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Nickel (mg/kg)	14	24.4	28.4	22.5	27.3	10.2	7.53	28.7	20.2	24.2
Cadmium (mg/kg)	2.1	1.2	0.53	0.2	0.2	1.2	0.52	0.5	0.26	0.3
Total Chromium (mg/kg)	69.3	54.7	61.1	84.6	68.6	53.2	46.2	89.1	71.3	59.7
Copper (mg/kg)	52.1	39.3	44.7	45	31.9	47.8	39.7	57.1	46.9	38.3
Mercury (mg/kg)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Zinc (mg/kg)	378.9	327.4	308.3	285.5	239.3	169.7	153.8	289	217.4	208.4
Manganese (mg/kg)	240	183.7	107.8	165	89.4	119.2	93.1	74.3	63.4	71.6

Table 6.7: Total Heavy Metal Correlation Matrix (Seasonwise Variation)

THM Correlation Matrix (Seasonwise Variation)										
	Iron mg/kg	Lead mg/kg	Arsenic mg/kg	Nickel mg/kg	Cadmium mg/kg	Tot. Chromium mg/kg	Copper mg/kg	Mercury mg/kg	Zinc mg/kg	Manganese mg/kg
Iron (mg/kg)	1									
Lead (mg/kg)	-0.47	1								
Arsenic (mg/kg)	#DIV/0!	#DIV/0!	1							
Nickel (mg/kg)	0.520	-0.348	#DIV/0!	1						
Cadmium (mg/kg)	-0.480	0.913	#DIV/0!	-0.442	1					
Total Chromium (mg/kg)	0.676	-0.066	#DIV/0!	0.538	-0.239	1				
Copper (mg/kg)	0.344	0.341	#DIV/0!	-0.088	0.382	0.507	1			
Mercury (mg/kg)	8.1E-17	-2E-17	#DIV/0!	6E-16	-1.2E-16	-1.64847E-16	-2E-16	1		
Zinc (mg/kg)	-0.005	0.561	#DIV/0!	0.435	0.493	0.434	0.343	2E-16	1	
Manganese (mg/kg)	-0.531	0.898	#DIV/0!	-0.234	0.790	-0.002	0.185	1E-17	0.702	1

6.6.2.1 Parameter: Lead (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Lead (mg/kg) and Iron (mg/kg)** is **-0.473** which indicates that these parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

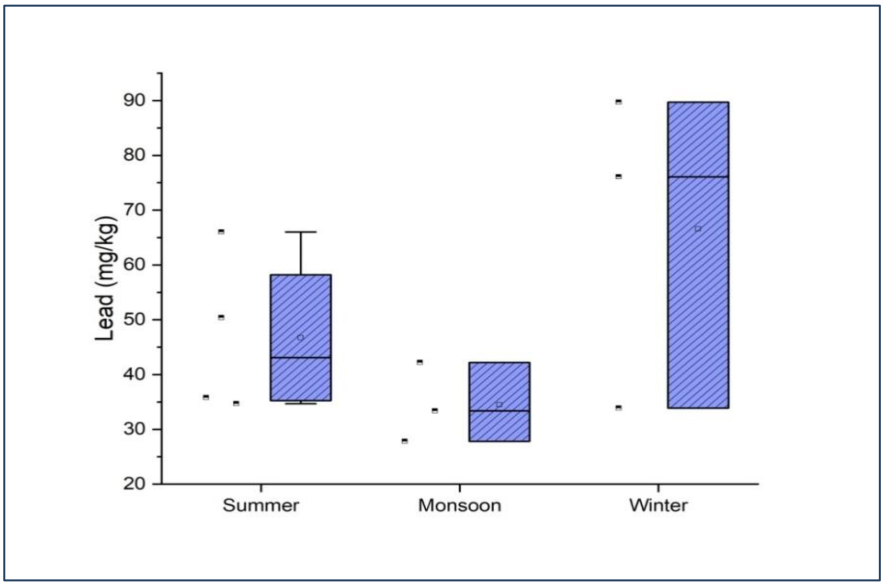

Fig 6.10: Seasonwise variation of Lead (mg/kg)

6.6.2.2 Parameter: Nickel (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Nickel (mg/kg) & Iron (mg/kg)** is **+0.519** which indicates that these two parameters are **moderately positively correlated**. Moreover the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Nickel (mg/kg) & Lead (mg/kg)** is **-0.348** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

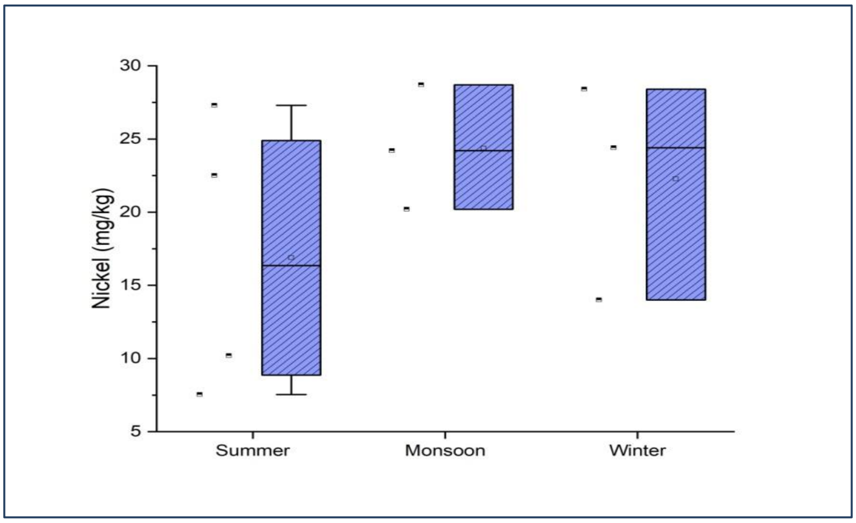

Fig 6.11: Seasonwise Variation of Nickel (mg/kg)

6.6.2.3 Parameter: Cadmium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/kg) & Iron (mg/kg)** is **-0.480** which indicates that these parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5- to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/kg) & Lead (mg/kg)** is **+0.913** which indicates that these two parameters are **strongly positively correlated**. Moreover the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/kg) & Nickel (mg/kg)** is **-0.442** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

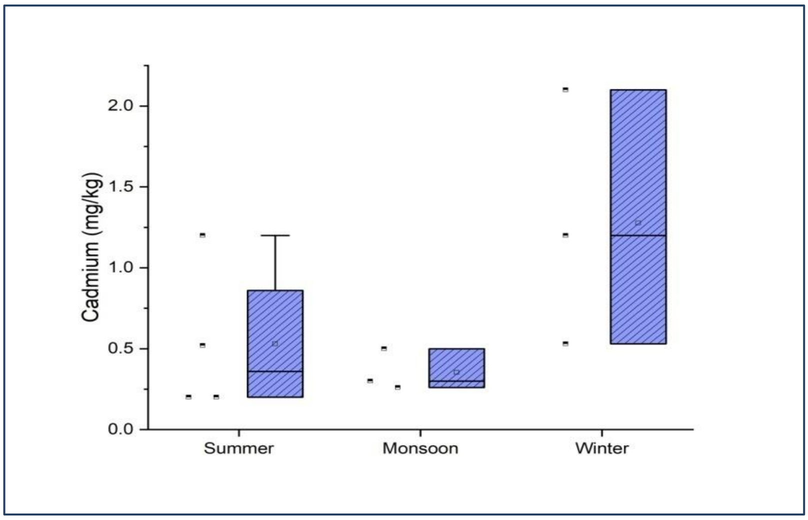

Fig 6.12: Seasonwise Variation of Cadmium (mg/kg)

6.6.2.4 Parameter: Total Chromium (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/kg) & Iron (mg/kg)** is **+0.675** which indicates that these two parameters are **strongly positively correlated**. Moreover the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/kg) & Nickel (mg/kg)** is **+0.538** which indicates that these two parameters are **moderately positively correlated**. Moreover the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/kg) & Cadmium (mg/kg)** is **-0.239** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

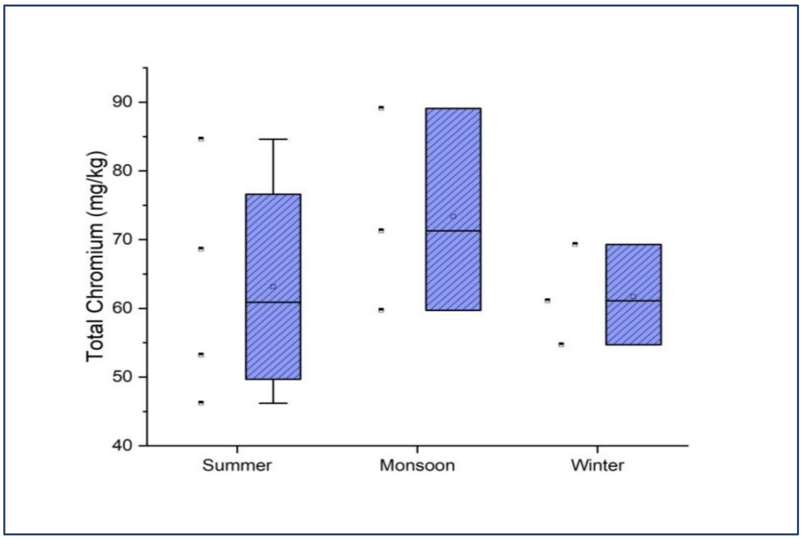

Fig 6.13: Seasonwise Variation of Total Chromium (mg/kg)

6.6.2.5 Parameter: Copper (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Iron (mg/kg)** is **+0.344** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Lead (mg/kg)** is **+0.340** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) and Cadmium (mg/kg)** is **+0.382**which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/kg) & Lead (mg/kg)** is **+0.502** which indicates that these two parameters are **moderately positively correlated**. Moreover the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

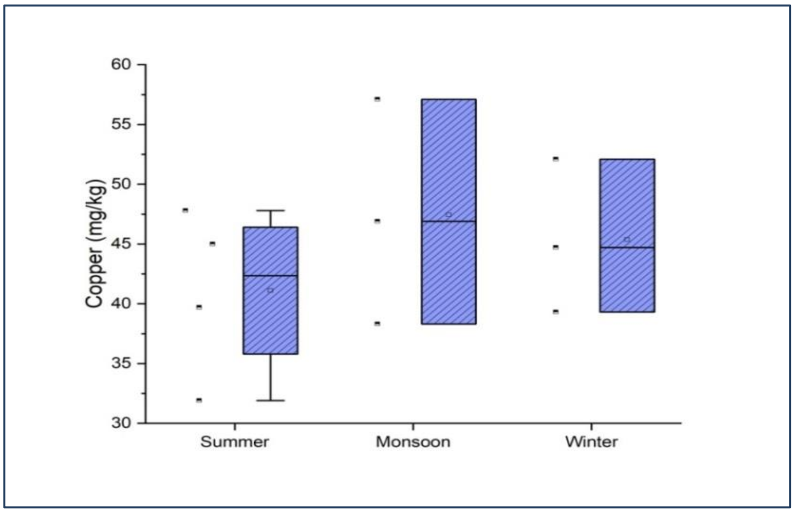

Fig 6.14: Seasonwise Variation of Copper (mg/kg)

6.6.2.6 Parameter: Zinc (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Lead (mg/kg)** is **+0.561** which indicates that these two parameters are **moderately positively correlated**. Moreover the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Nickel (mg/kg)** is **+0.435** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Cadmium (mg/kg)** is **+0.493** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Total Chromium (mg/kg)** is **+0.434** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/kg) & Copper (mg/kg)** is **+0.343** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

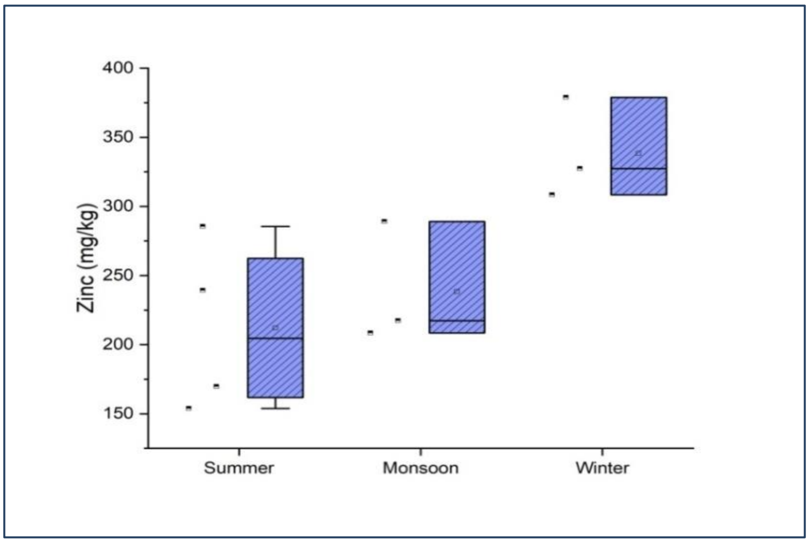

Fig 6.15: Seasonwise Variation of Zinc (mg/kg)

6.6.2.7 Parameter: Manganese (mg/kg)

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Iron (mg/kg)** is **-0.531** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Lead (mg/kg)** is **+0.897** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Nickel (mg/kg)** is **-0.234** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Cadmium (mg/kg)** is **+0.790** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Copper (mg/kg)** is **+0.185** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/kg) & Zinc (mg/kg)** is **+0.702** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

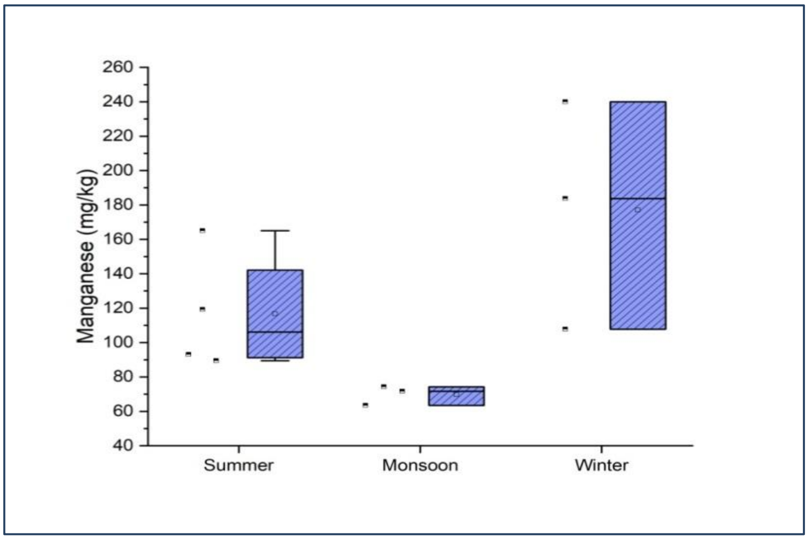

Fig 6.16: Seasonwise Variation of Manganese (mg/kg)

6.6.3 Statistical Inference from 1-way ANOVA Analysis on Seasonal Variation of Total Heavy Metal Characteristics of Soil-like Materials

Based on the available data from KMC (2022) shown in Table 6.3, statistical analysis of the Seasonal variation of the Total Heavy Metal characteristics of coarser fraction of the soil-like materials have been studied further using the 1-way ANOVA model which is shown in Table 6.8 respectively. The dataset was checked thoroughly before performing the statistical analysis.

Table 6.8: Seasonwise 1-way Anova Analysis of Total Heavy Metals Characteristics

THM 1-way Anova Analysis [Seasonwise]						
Seasons	**Summer**	**Monsoon**	**Winter**	**F[Stat]**	**P-value**	**F [Crit.]**
Iron (as Fe) in mg/kg	150.7 ± 26097.7	2804 ± 9272.3	1052 ± 1683.3	23.801	0.001	4.737
Lead (as Pb) in mg/kg	186.9 ± 216.3	103.4 ± 52.69	199.7 ± 846.57	2.260	0.175	4.737
Arsenic (as As) in mg/kg	1 ± 0	0.75 ± 0	0.75 ± 0	65535.000	#DIV/0!	4.737
Nickel (as Ni) in in mg/kg	67.53 ± 90.73	73.1 ± 18.08	66.8 ± 55.25	0.885	0.454	4.737
Cadmium (as Cd) in mg/kg	2.12 ± 0.222	1.06 ± 0.017	3.83 ± 0.621	2.657	0.138	4.737
Total Chromium (as Cr) in mg/kg	252.6 ± 292.03	220.1 ± 2019.3	185.1 ± 53.56	0.616	0.567	4.737
Copper (as Cu) in mg/kg	164.4 ± 48.9	142.3 ± 88.57	136.1 ± 41.29	0.636	0.558	4.737
Mercury (as Hg) in mg/kg	0.4 ± 0	0.3 ± 0.0002	0.3 ± 0.0002	2.333	0.167	4.737
Zinc (as Zn) in mg/kg	848.3 ± 3774.68	714.8 ± 1950.65	1014.6 ± 1333	5.653	0.035	4.737
Manganese (as Mn) in mg/kg	466.7 ± 1213.8	209.3 ± 32.22	531.5 ± 4401.2	4.872	0.047	4.737

Based the results shown in Table 6.8, the statistical inferences from the Seasonwise 1-way ANOVA Analysis of Total Heavy Metal characteristics of coarser fraction of the soil-like materials have been described below:

6.6.3.1 Parameter: Iron (as Fe) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Iron (mg/kg)**. The average concentrations of Iron (mg/kg) is (150.7 ± 26097.7) in summer, (2804 ± 9272.3) in monsoon, (1052 ± 1683.3) in winter respectively. It has been found that average iron concentration in monsoon is maximum and minimum in summer respectively. After performing the analysis, we find the F[statistic] is greater than F[critical], so the test is a significant one. As $p<0.05$, alternative hypothesis considered which implies that the result has found significant difference in Iron (mg/kg) according to the seasonal variation.

6.6.3.2 Parameter: Lead (as Pb) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Lead (mg/kg)**. The average concentrations of Lead (mg/kg) is (186.9 ± 216.3) in summer, (103.4 ± 52.69) in monsoon, and (199.7 ± 846.57) in winter respectively. It has been found that the average lead concentration in winter is maximum and minimum in monsoon. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in Lead (mg/kg) according to seasonal variations.

6.6.3.3 Parameter: Nickel (as Ni) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Nickel (mg/kg).** The average nickel concentrations are (67.53 ± 90.73) in summer, (73.1 ± 18.08) in monsoon and (66.8 ± 55.25) in winter respectively. It has been found that the average nickel concentration is maximum in monsoon and minimum in summer. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p> 0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in nickel (mg/kg) according to seasonal variation.

6.6.3.4 Parameter: Cadmium (as Cd) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Cadmium (mg/kg)**. The average cadmium concentrations are (2.12 ± 0.22) in summer, (1.06 ± 0.017) in monsoon and (3.83 ± 0.62) in winter respectively. It has been found that average nickel concentration is maximum in winter and minimum in monsoon. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not a significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in cadmium (mg/kg) according to seasonal variation.

6.6.3.5 Parameter VI: Total Chromium (as Cr) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Total Chromium (mg/kg)**. The average total chromium concentrations are (252.6 ± 292.03) in summer, (220.1 ± 2019.3) in monsoon and (185.1 ± 53.16) in winter respectively. It has been found that the average concentration of total chromium is maximum in summer and minimum in winter. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$ null hypothesis is considered which implies that the result does not found any statistically significant difference in total chromium (mg/kg) according to seasonal variation.

6.6.3.6 Parameter VII: Copper (as Cu) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of Copper (mg/kg). The average concentrations of copper is (164.4 ± 48.9) in summer, (142.3 ± 88.57) in monsoon, and (136.1 ± 41.29) in winter respectively. It has been found that the average copper concentration in summer is maximum whereas in winter it is minimum. After performing the analysis, we find the F[statistic] is lesser than the F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in copper (mg/kg) according to seasonal variation.

6.6.3.7 Parameter IX: Zinc (as Zn) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the mean of the **Zinc (mg/kg)**. The average zinc concentrations are (848.3 ± 3774.68) in summer, (714.80 ± 1950.65) in monsoon, and (1014.6 ± 1333) in winter respectively. It can be said that average zinc concentration is maximum in winter season and minimum in monsoon season. After performing the analysis, we find the F[statistic] is greater than the F[critical] so the test is a significant one. As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in zinc (mg/kg) according to the seasonal variations.

6.6.3.8 Parameter: Manganese (as Mn) in mg/kg

Analysis of Variance is performed for checking the effect of the three seasons on the means of the **Manganese (mg/kg).** The average manganese concentrations are (466.7 ± 1213.8) in summer, (209.3 ± 32.22) in monsoon, and (531.5 ± 4401.2) in winter respectively. It can be said that average magnesium concentration in winter is maximum whereas in monsoon it is minimum. After performing the analysis, we find the F[statistic] is greater than the F[critical], so the test is a significant one. As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in manganese (mg/kg) according to the seasonal variation.

6.7.1 Statistical Inference from Correlation Matrix Analysis on Depthwise Variation of Leachate Characteristics (Leachability) of Soil-like Materials

Based on the available data from KMC (2022), shown in Table 6.10, statistical analysis of the Depthwise variation of the Leachate characteristics of coarser fraction of soil-like materials have been studied using the Correlation Matrix method which is shown in Table 6.11 respectively. The data was checked thoroughly before the analysis. We used the Pearson correlation coefficient and linear regression to study the relationship between different physicochemical characteristics. Pearson correlation coefficient was employed to detect the pattern in different parameters.

The correlation coefficient varies between -1 and +1 which indicates the positive and negative correlation between the two analysed parameters respectively. When the correlation coefficient value is negative then the considered parameters tend to move in the opposite direction and vice-versa respectively. More closer is the correlation coefficient value to ±1 which means more the parameters are positively or negatively correlated with each other. Sometimes to further deduce the relationship between the different physicochemical characteristics, analysed parameters were selected for linear regression analysis respectively.

Table 6.9: Leachate Characteristics of Coarser Soil-like materials

TCLP test for Leachability of Coarser Fraction	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23
Depth from top (m)	15	12	12	19	17	17	8	18	16	10	20
Lead (as Pb), in mg/l	0.96	1.04	1.33	1.54	1.79	1.17	1.92	0.74	0.39	0.33	0.24
Nickel (as Ni), in mg/l	1.68	0.67	0.91	0.87	0.61	0.69	0.34	0.21	0.27	0.19	0.21
Copper (as Cu), in mg/l	0.03	0.05	0.12	0.38	0.46	0.52	0.69	0.58	0.93	0.64	0.53
Total Chromium (as Cr), in mg/l	0.03	0.24	0.38	0.52	1.23	1.19	0.83	0.9	1.34	0.92	0.71
Mercury (as Hg), in mg/l	0.004	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (as As), in mg/l	0.015	0.011	0.014	0.014	0.011	0.018	0.012	0.017	0.012	0.01	0.02
Cadmium (as Cd), in mg/l	0.044	0.075	0.02	0.008	<0.002	<0.002	0.04	0.012	0.006	0.004	0.002
Zinc (as Zn), in mg/l	3.61	5.2	6.58	11.7	9.92	7.83	3.96	2.49	3.14	3.82	3.11
Iron (as Fe) in mg/l	5.33	8.81	7.21	3.89	12.4	10.1	8.04	5.83	18.3	16.8	14.7
Manganese (as Mn), in mg/l	0.08	5	3.09	1.74	2.18	1.77	1.85	1.51	1.86	1.24	0.98

TCLP (Depthwise Variation)									
Depth from Top (m)	**8**	**10**	**12**	**15**	**16**	**17**	**18**	**19**	**20**
Lead (mg/l)	1.92	0.33	1.185	0.96	0.39	1.48	0.74	1.54	0.24
Nickel (mg/l)	0.34	0.19	0.79	1.68	0.27	0.65	0.21	0.87	0.21
Copper (mg/l)	0.69	0.64	0.085	0.03	0.93	0.49	0.58	0.38	0.53
Total Chromium(mg/l)	0.83	0.92	0.31	0.03	1.34	1.21	0.9	0.52	0.71
Mercury (mg/l)	0.001	0.001	0.001	0.004	0.001	0.002	0.001	0.001	0.001
Arsenic (mg/l)	0.012	0.01	0.0125	0.015	0.012	0.0145	0.017	0.014	0.02
Cadmium (mg/l)	0.04	0.004	0.0475	0.044	0.006	0.002	0.012	0.008	0.002
Zinc (mg/l)	3.96	3.82	5.89	3.61	3.14	8.875	2.49	11.7	3.11
Iron (mg/l)	8.04	16.8	8.01	5.33	18.3	11.25	5.83	3.89	14.7
Manganese (mg/l)	1.85	1.24	4.045	0.08	1.86	1.975	1.51	1.74	0.98

Table 6.10: Depthwise Variation of Leachate Characteristics of Soil-like material

Table 6.11: Correlation Matrix of Leachate Characteristics (Depthwise Variation)

TCLP Correlation Matrix (Depthwise Variation)											
	Depth from Top (m)	Lead mg/l	Nickel mg/l	Copper mg/l	Tot. Chromium mg/l	Mercury mg/l	Arsenic mg/l	Cadmium mg/l	Zinc mg/l	Iron mg/l	Manganese mg/l
Depth from Top (m)	1										
Lead (mg/l)	-0.287	1									
Nickel (mg/l)	0.063	0.337	1								
Copper (mg/l)	-0.049	-0.260	-0.816	1							
Total Chromium(mg/l)	0.054	-0.183	-0.753	0.892	1						
Mercury (mg/l)	0.059	0.094	0.849	-0.585	-0.507	1					
Arsenic (mg/l)	0.765	-0.231	0.013	-0.177	-0.164	0.125	1				
Cadmium (mg/l)	-0.549	0.453	0.562	-0.607	-0.692	0.384	-0.224	1			
Zinc (mg/l)	0.252	0.588	0.309	-0.273	-0.080	-0.040	-0.124	-0.1611	1		
Iron (mg/l)	-0.097	-0.663	-0.589	0.641	0.644	-0.321	-0.201	-0.5222	-0.39	1	
Manganese (mg/l)	-0.258	0.314	-0.199	-0.092	0.079	-0.532	-0.339	0.2592	0.286	-0.038	1

The Statistical inferences from Correlation Matrix Analysis performed on Depthwise Variation of Leachate Characteristics show in Table 6.11 of Soil-like Materials are as follows:

6.7.1.1 Parameter: Lead (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Lead (mg/l) & Depth from Top (m)** is **-0.287** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

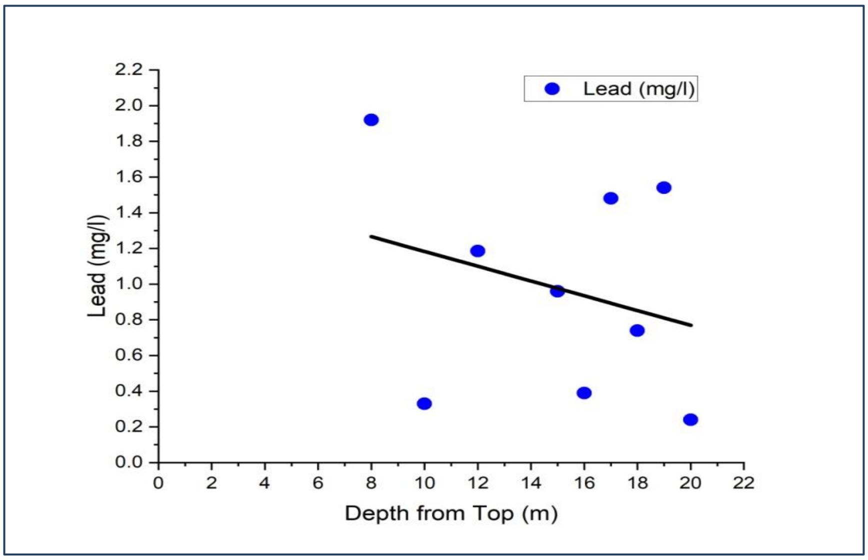

Fig 6.17: Depthwise Variation of Lead (mg/l)

6.7.1.2 Parameter: Nickel (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Nickel (mg/l) & Lead (mg/l)** is **+0.337** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

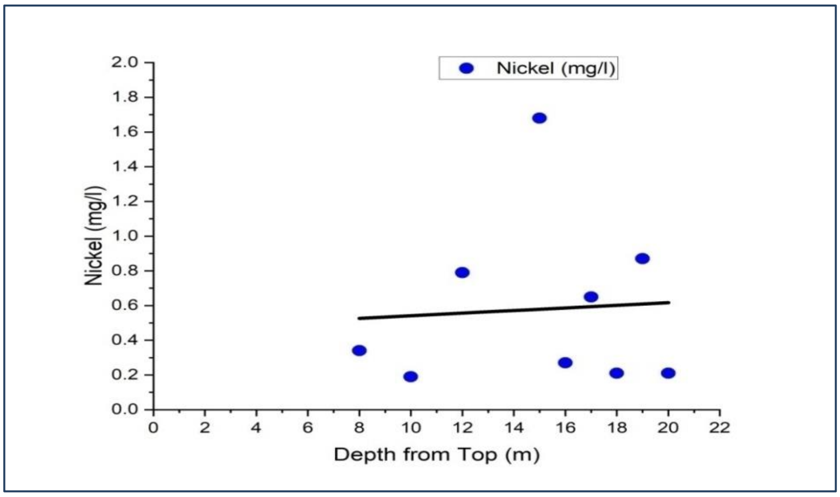

Fig 6.18: Depthwise Variation of Nickel (mg/l)

6.7.1.3 Parameter: Copper (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/l) & Lead (mg/l)** is **-0.260** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/l) & Nickel (mg/l)** is **-0.815** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

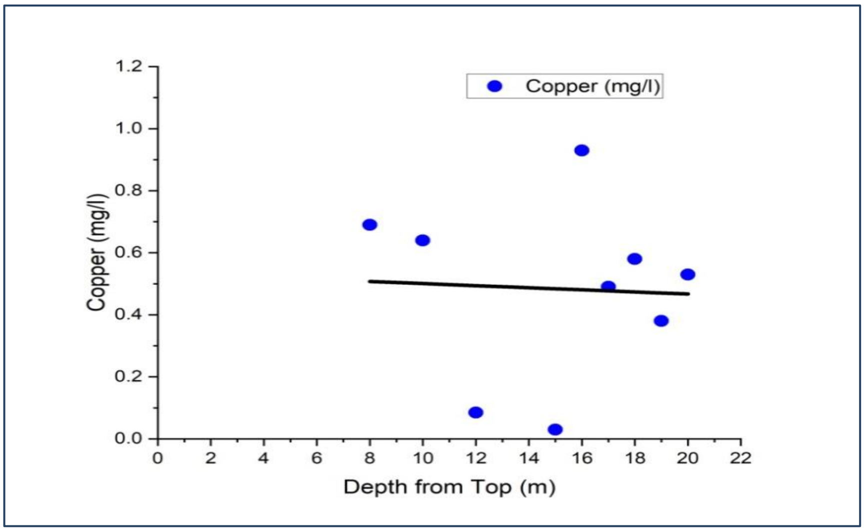

Fig 6.19: Depthwise Variation of Copper (mg/l)

6.7.1.4 Parameter: Total Chromium (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/l) & Lead (mg/l)** is **-0.183** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/l) & Nickel (mg/l)** is **-0.753** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/l) & Copper (mg/l)** is **+0.892** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

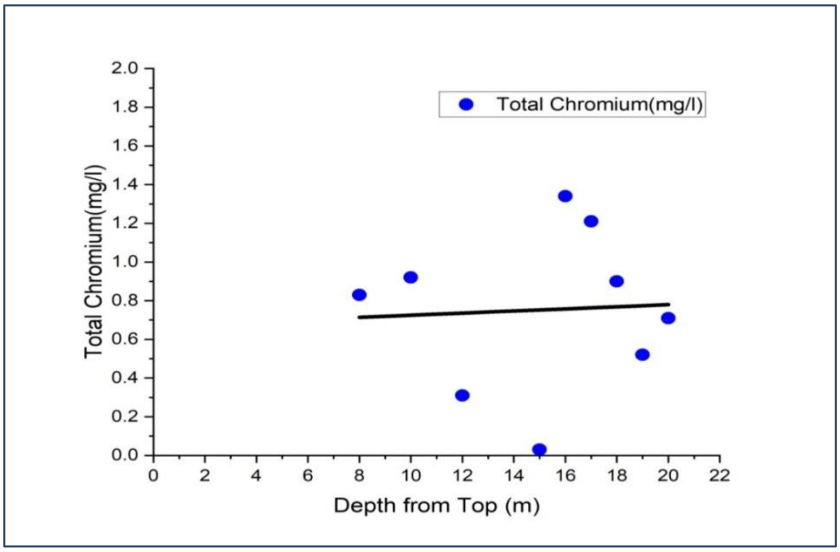

Fig 6.20: Depthwise Variation of Total Chromium (mg/l)

6.7.1.5 Parameter: Mercury (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/l) & Nickel (mg/l)** is **+0.848** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation

between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/l) & Copper (mg/l)** is **-0.584** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/l) & Total Chromium (mg/l)** is **-0.507** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is a moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

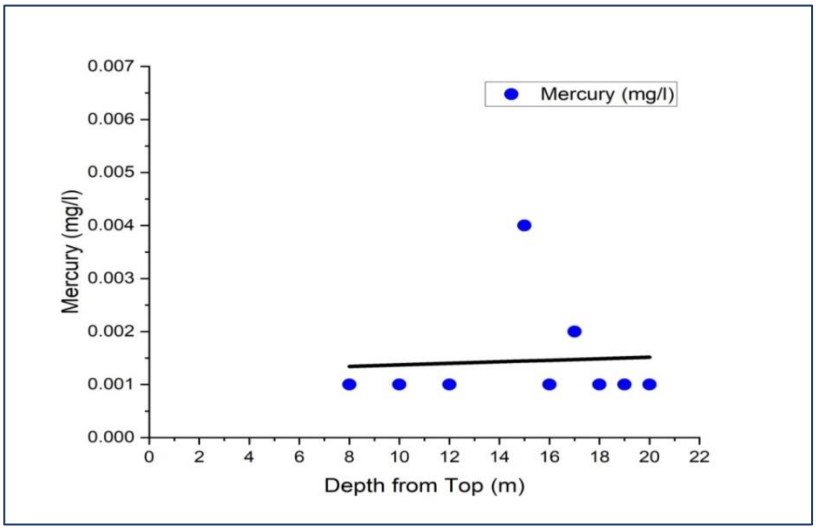

Fig 6.21: Depthwise Variation of Mercury (mg/l)

6.7.1.6 Parameter: Arsenic (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Arsenic (mg/l) & Depth from Top (m)** is **+0.765** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Arsenic (mg/l) & Lead (mg/l)** is **-0.231** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The

negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Arsenic (mg/l) & Copper (mg/l)** is **-0.177** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Arsenic (mg/l) & Total Chromium (mg/l)** is **-0.164** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Arsenic (mg/l) & Mercury (mg/l)** is **+0.125** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

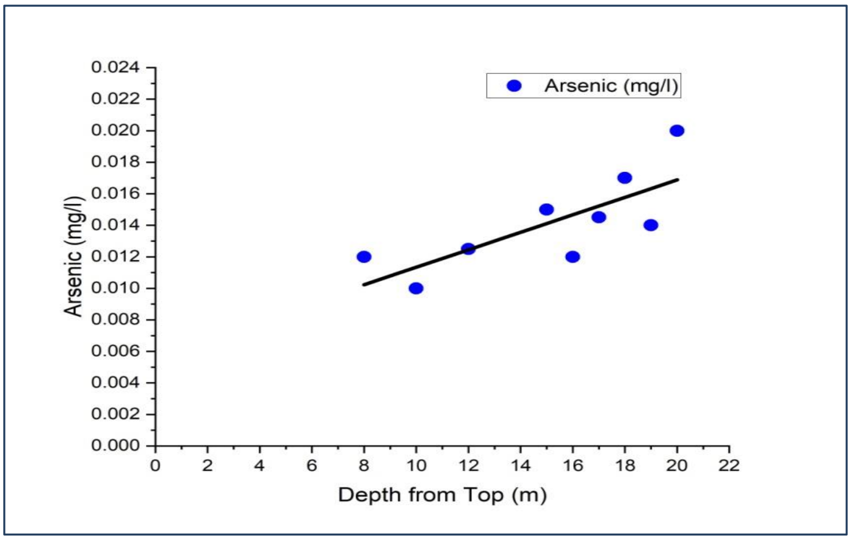

Fig 6.22: Depthwise Variation of Arsenic (mg/l)

6.7.1.7 Parameter: Cadmium (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Depth from Top (m)** is **-0.549** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The

negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Lead (mg/l)** is **+0.453** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Nickel (mg/l)** is **+0.562** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Copper (mg/l)** is **-0.607** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Total Chromium (mg/l)** is **-0.692** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Mercury (mg/l)** is **+0.384** which indicates that these two parameters are **weakly positively correlated**. Moreover the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Arsenic (mg/l)** is **-0.224** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

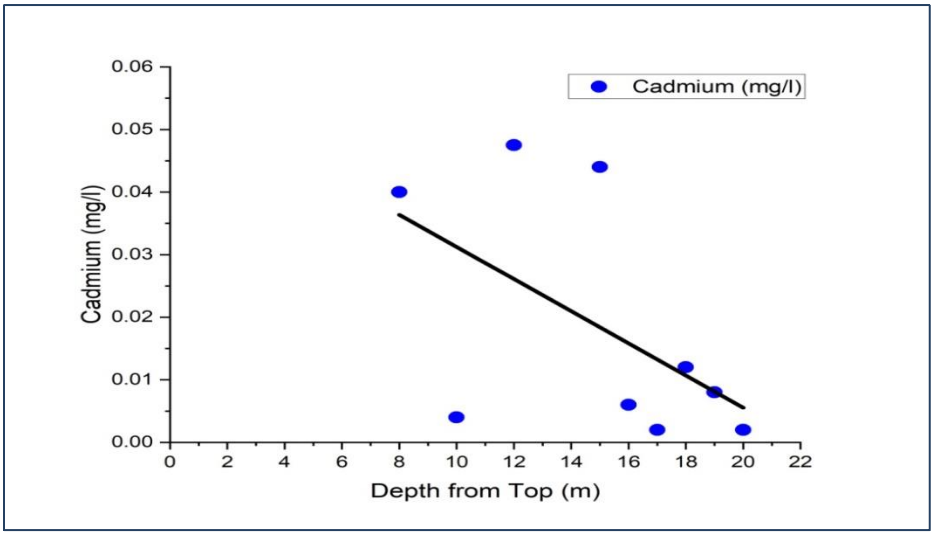

Fig 6.23: Depthwise Variation of Cadmium (mg/l)

6.7.1.8 Parameter: Zinc (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Depth from Top (m)** is **+0.252** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Lead (mg/l)** is **+0.588** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Nickel (mg/l)** is **+0.309** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Copper (mg/l)** is **-0.273** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Arsenic (mg/l)** is **-0.124** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Cadmium (mg/l)** is **-0.161** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

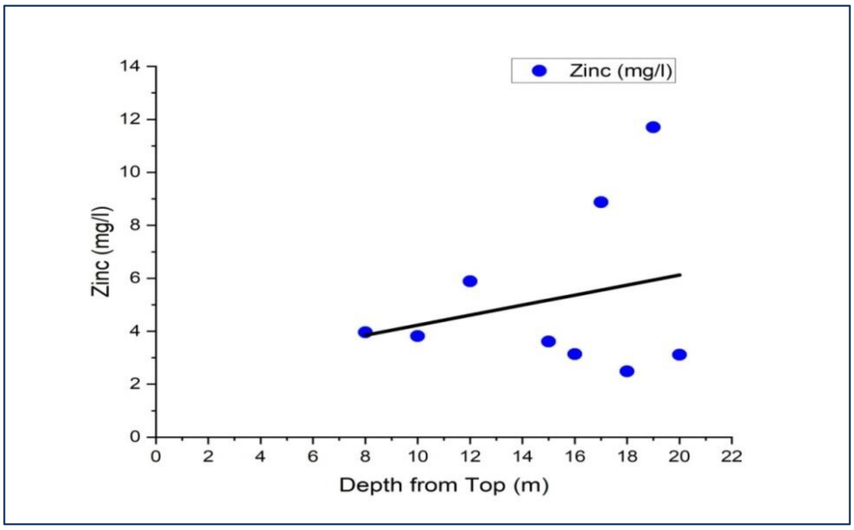

Fig 6.24: Depthwise Variation of Zinc (mg/l)

6.7.1.9 Parameter: Iron (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Lead (mg/l)** is **-0.663** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Nickel (mg/l)** is **-0.589** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Copper (mg/l)** is **+0.641** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Total Chromium (mg/l)** is **+0.643** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Mercury (mg/l)** is **-0.321** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Arsenic (mg/l)** is **-0.201** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Cadmium (mg/l)** is **-0.522** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Zinc (mg/l)** is **-0.391** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

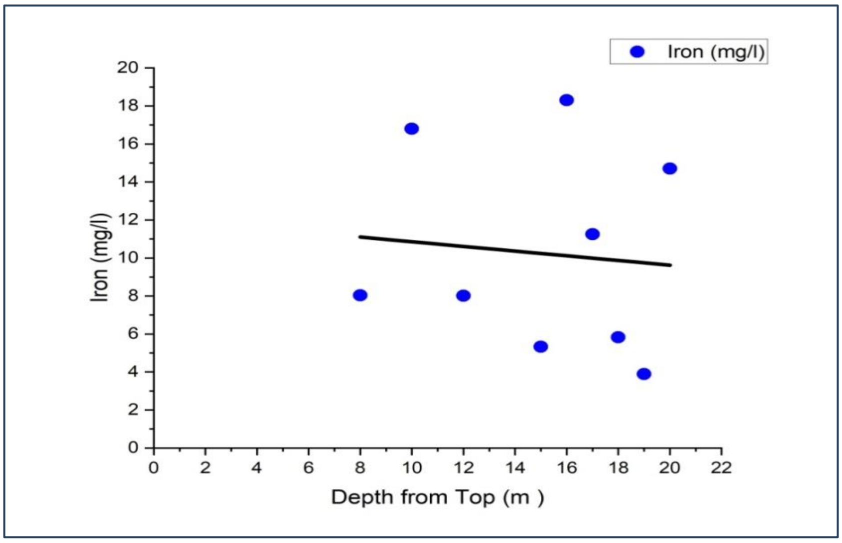

Fig 6.25: Depthwise Variation of Iron (mg/l)

6.7.1.10 Parameter: Manganese (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Depth from Top (m)** is **-0.257** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Lead (mg/l)** is **+0.314** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Nickel (mg/l)** is **-0.198** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Mercury (mg/l)** is **-0.532** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not so close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Arsenic (mg/l)** is **-0.339** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Cadmium (mg/l)** is **+0.259** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Zinc (mg/l)** is **+0.286** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

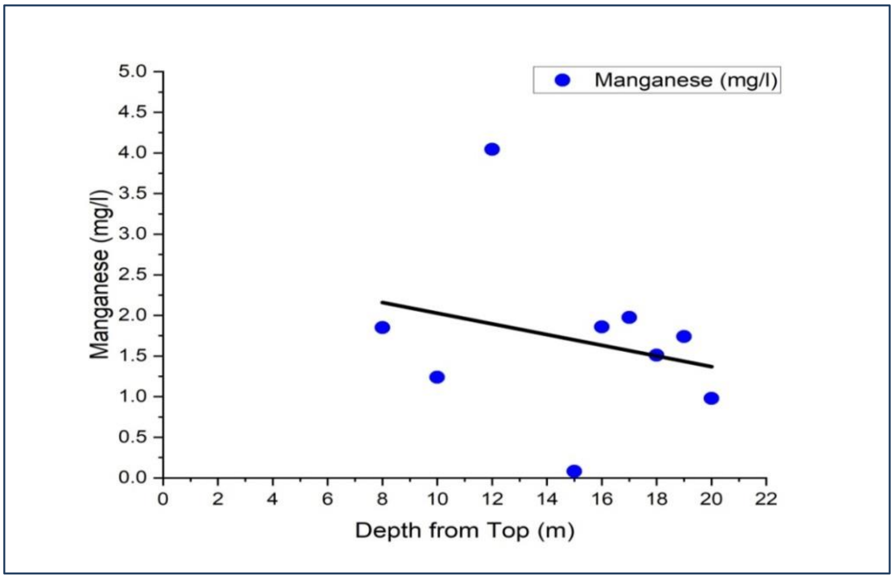

Fig 6.26: Depthwise Variation of Manganese (mg/l)

6.7.2 Statistical Inference from Correlation Matrix Analysis on Seasonal Variation of Leachate Characteristics (Leachability) of Soil-like Materials

Based on the available data from KMC (2022) shown in Table 6.12, statistical analysis of the Seasonal variation of Leachate characteristics (Leachability) of the coarser fraction of the soil-like materials have been studied using the Correlation Matrix method which is shown in Table 6.13 respectively.

Table 6.12: Seasonal Variation of Leachate Characteristics

TCLP (Seasonwise Variation)											
Seasons	**Winter**				**Summer**				**Winter**		
Months	**Nov-22**	**Dec-22**	**Jan-23**	**Feb-23**	**Mar-23**	**Apr-23**	**May-23**	**Jun-23**	**Jul-23**	**Aug-23**	**Sep-23**
Lead (mg/l)	0.96	1.04	1.33	1.54	1.79	1.17	1.92	0.74	0.39	0.33	0.24
Nickel (mg/l)	1.68	0.67	0.91	0.87	0.61	0.69	0.34	0.21	0.27	0.19	0.21
Copper (mg/l)	0.03	0.05	0.12	0.38	0.46	0.52	0.69	0.58	0.93	0.64	0.53
Total Chromium (mg/l)	0.03	0.24	0.38	0.52	1.23	1.19	0.83	0.9	1.34	0.92	0.71
Mercury (mg/l)	0.004	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.001	0.001	0.001
Arsenic (mg/l)	0.015	0.011	0.014	0.014	0.011	0.018	0.012	0.017	0.012	0.01	0.02
Cadmium (mg/l)	0.044	0.075	0.02	0.008	0.002	0.002	0.04	0.012	0.006	0.004	0.002
Zinc (mg/l)	3.61	5.2	6.58	11.7	9.92	7.83	3.96	2.49	3.14	3.82	3.11
Iron (mg/l)	5.33	8.81	7.21	3.89	12.4	10.1	8.04	5.83	18.3	16.8	14.7
Manganese (mg/l)	0.08	5	3.09	1.74	2.18	1.77	1.85	1.51	1.86	1.24	0.98

Table 6.13: Correlation Matrix of Leachate Characteristics (Seasonal Variation)

TCLP Correlation Matrix (Seasonal Variation)										
	Lead mg/l	Nickel mg/l	Copper mg/l	Tot. Chromium mg/l	Mercury mg/l	Arsenic mg/l	Cadmium mg/l	Zinc mg/l	Iron mg/l	Manganese mg/l
Lead (mg/l)	1									
Nickel (mg/l)	0.334	1								
Copper (mg/l)	-0.256	-0.772	1							
Total Chromium (mg/l)	-0.079	-0.672	0.858	1						
Mercury (mg/l)	0.003	0.734	-0.379	-0.295	1					
Arsenic (mg/l)	-0.275	0.035	-0.033	-0.050	0.329	1				
Cadmium (mg/l)	0.226	0.385	-0.597	-0.685	0.156	-0.312	1			
Zinc (mg/l)	0.642	0.305	-0.239	0.052	-0.044	-0.140	-0.222	1		
Iron (mg/l)	-0.578	-0.596	0.619	0.620	-0.289	-0.206	-0.406	-0.323	1	
Manganese (mg/l)	0.261	-0.111	-0.320	-0.142	-0.452	-0.402	0.522	0.217	-0.072	1

6.7.2.1 Parameter: Nickel (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Nickel (mg/l) & Lead (mg/l)** is **+0.334** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

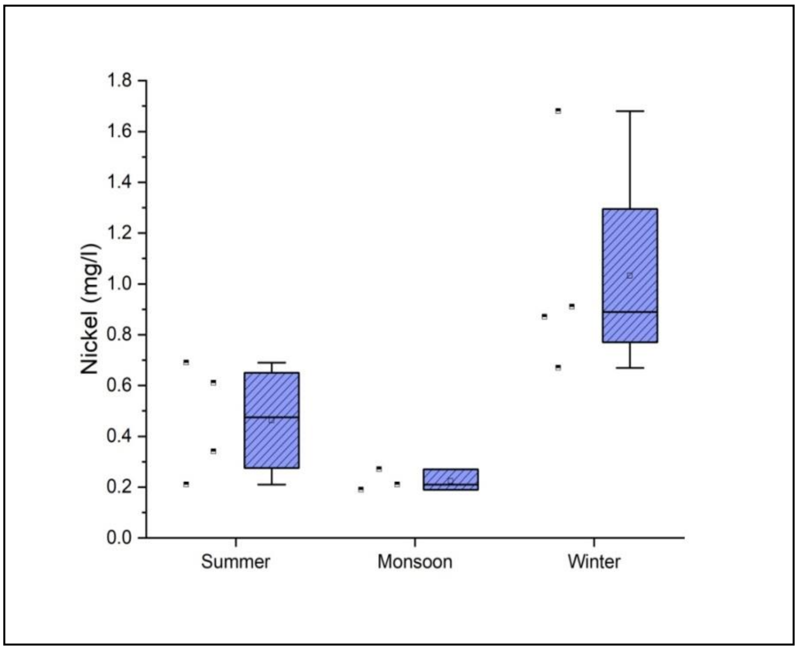

Fig 6.27: Seasonwise Variation of Nickel (mg/kg)

6.7.2.2 Parameter: Copper (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/l) & Lead (mg/l)** is **-0.256** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Copper (mg/l) & Nickel (mg/l)** is **-0.772** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

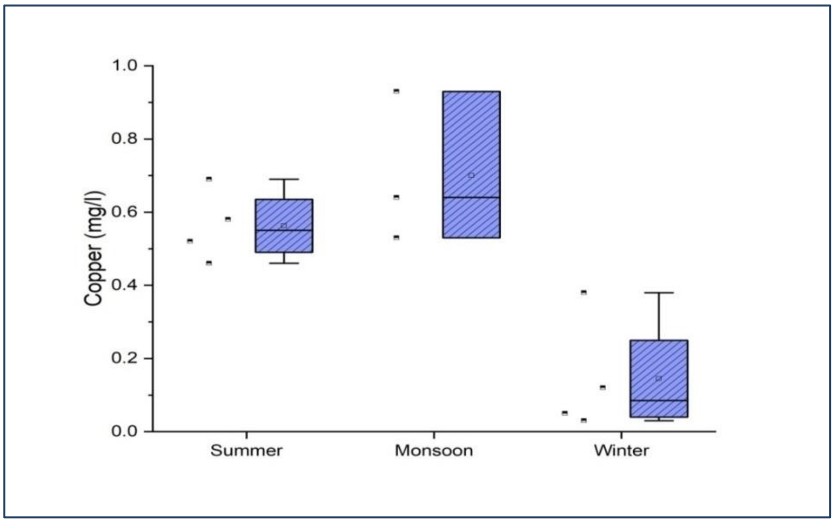

Fig 6.28: Seasonwise Variation of Copper (mg/l)

6.7.2.3 Parameter: Total Chromium (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/l) & Nickel (mg/l)** is **-0.672** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Total Chromium (mg/l) & Copper (mg/l)** is **+0.858** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

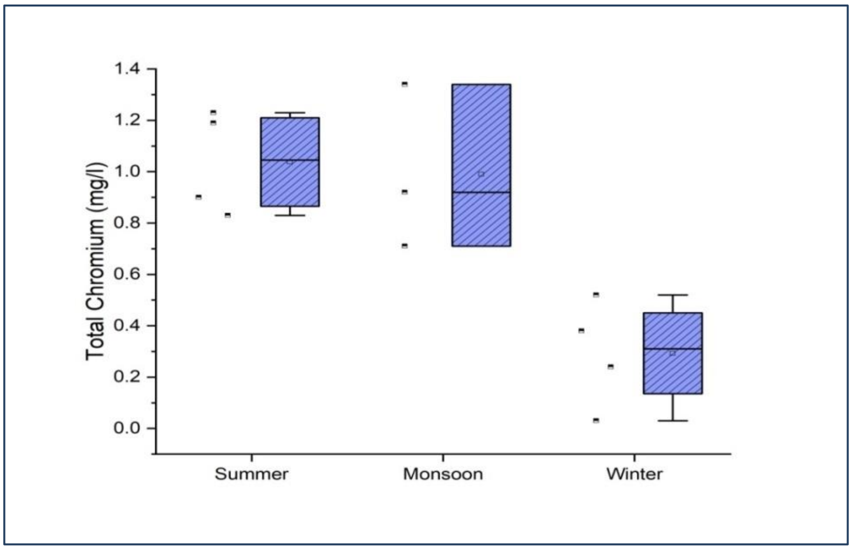

Fig 6.29: Seasonwise Variation of Total Chromium (mg/l)

6.7.2.4 Parameter: Mercury (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/l) & Nickel (mg/l)** is **+0.734** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/l) & Copper (mg/l)** is **-0.379** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Mercury (mg/l) & Total Chromium (mg/l)** is **-0.295** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

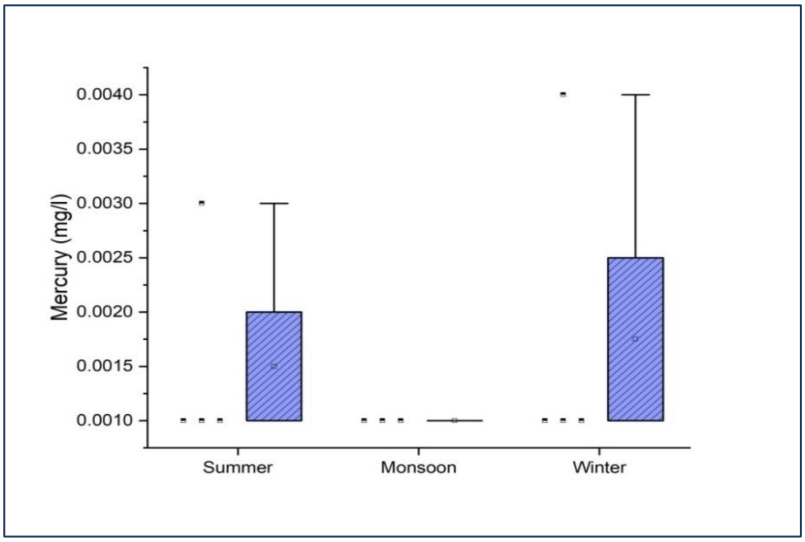

Fig 6.30: Seasonwise Variation of Mercury (mg/l)

6.7.2.5 Parameter: Arsenic (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Arsenic (mg/l) & Lead (mg/l)** is **-0.275** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The

negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Arsenic (mg/l) & Mercury (mg/l)** is **+0.329** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

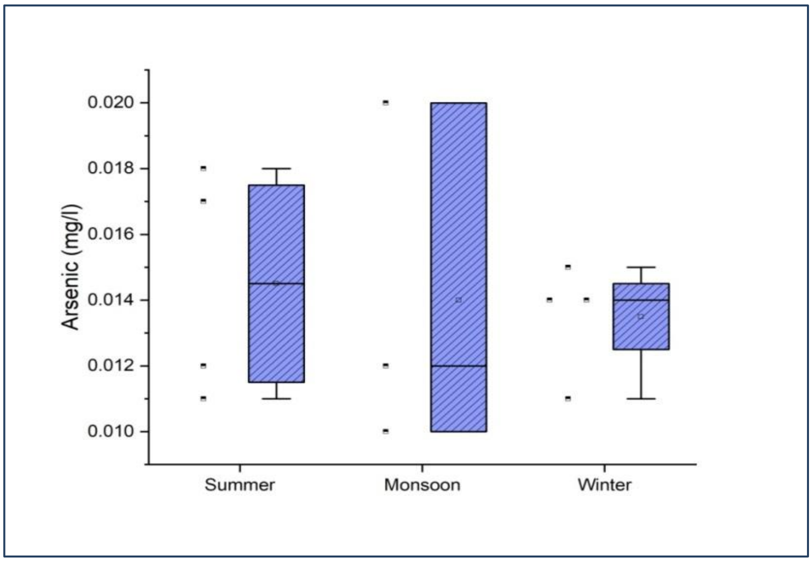

Fig 6.31: Seasonwise Variation of Arsenic (mg/l)

6.7.2.6 Parameter: Cadmium (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Lead (mg/l)** is **+0.226** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Nickel (mg/l)** is **+0.385** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Copper (mg/l)** is **-0.597** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Total Chromium (mg/l)** is **-0.685** which indicates that these two parameters are **strongly negatively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is a strong relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Mercury (mg/l)** is **+0.156** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Cadmium (mg/l) & Arsenic (mg/l)** is **-0.312** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

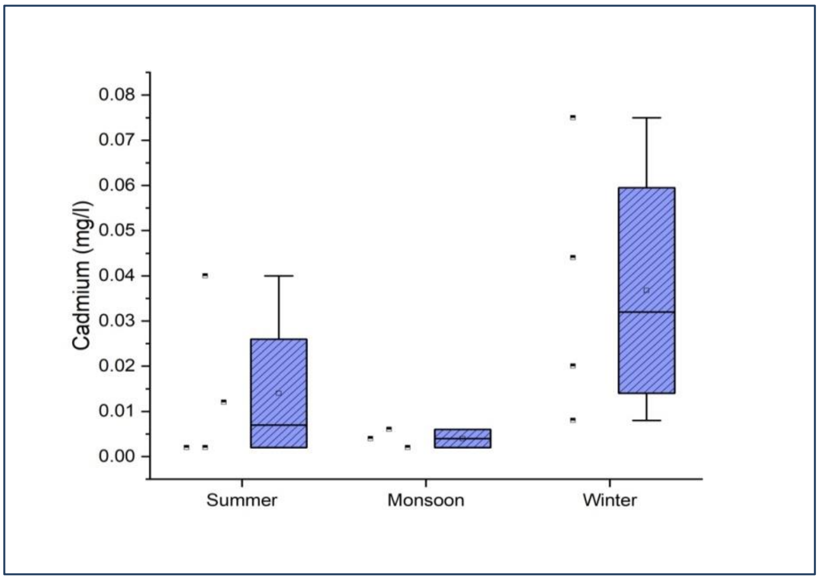

Fig 6.32: Seasonwise Variation of Cadmium (mg/l)

6.7.2.7 Parameter: Zinc (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Lead (mg/l)** is **+0.642** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Nickel (mg/l)** is **+0.305** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Copper (mg/l)** is **-0.239** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Arsenic (mg/l)** is **-0.139** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Zinc (mg/l) & Cadmium (mg/l)** is **-0.222** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

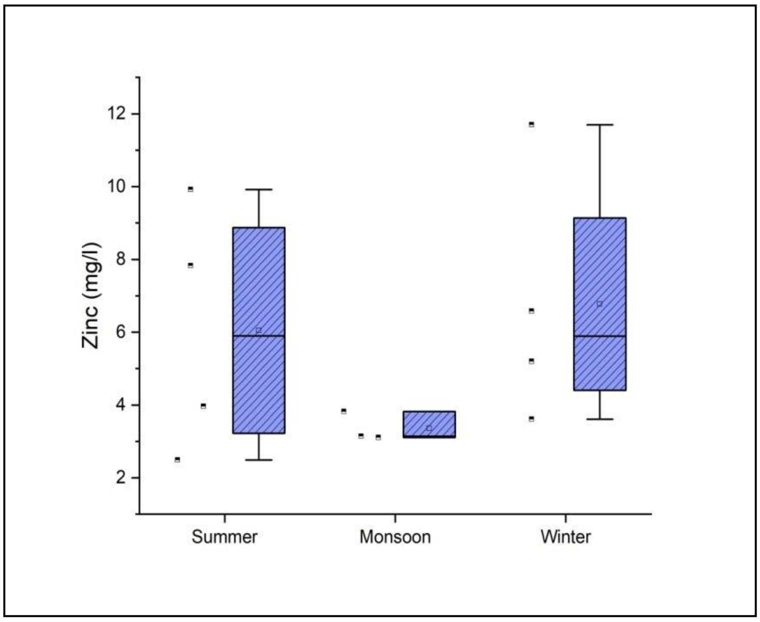

Fig 6.33: Seasonwise Variation of Zinc (mg/l)

6.7.2.8 Parameter: Iron (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Depth from Top (m)** is **-0.578** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient value is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Nickel (mg/l)** is **-0.596** which indicates that these two parameters are **moderately negatively correlated**. Moreover, the correlation coefficient is not close to -1 so it can be said that there is moderate relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Copper (mg/l) is +0.619** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to -1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Total Chromium (mg/l)** is **+0.620** which indicates that these two parameters are **strongly positively correlated**. Moreover, the correlation coefficient value is closer to +1 so it can be said that there is strong relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Mercury (mg/l)** is **-0.289** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Arsenic (mg/l)** is **-0.206** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Cadmium (mg/l)** is **-0.406** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Iron (mg/l) & Zinc (mg/l)** is **-0.323** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

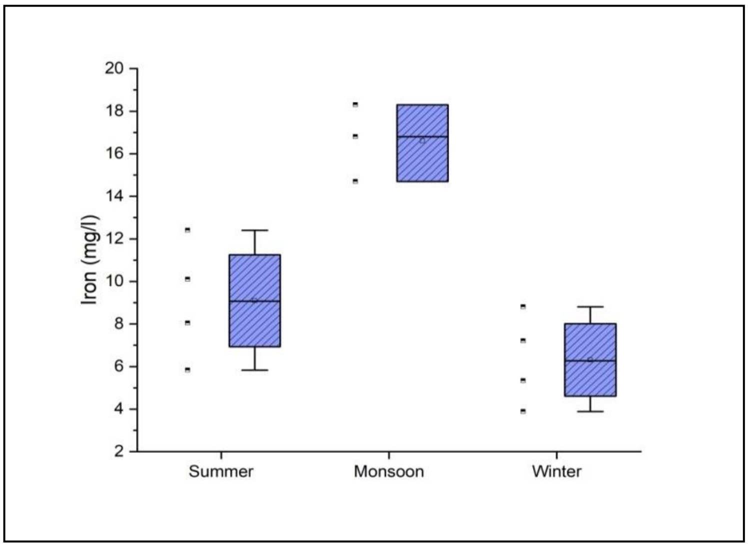

Fig 6.34: Seasonwise Variation of Iron (mg/l)

6.7.2.9 Parameter: Manganese (mg/l)

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Lead (mg/l)** is **+0.261** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Nickel (mg/l)** is **-0.111** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Copper (mg/l)** is **-0.320** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Total Chromium (mg/l)** is **-0.142** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Mercury (mg/l)** is **-0.452** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Arsenic (mg/l)** is **-0.402** which indicates that these two parameters are **weakly negatively correlated**. Moreover, the correlation coefficient value is not in the range of [-0.5 to -1] so it can be said that there is weak relationship between these two parameters. The negative correlation between these two parameters indicates that these two variables tend to move in the opposite direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Cadmium (mg/l)** is **+0.522** which indicates that these two parameters are **moderately positively correlated**. Moreover, the correlation coefficient value is not close to +1 so it can be said that there is moderate relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

From the correlation matrix, it has been found that correlation coefficient between **Manganese (mg/l) & Zinc (mg/l)** is **+0.227** which indicates that these two parameters are **weakly positively correlated**. Moreover, the correlation coefficient value is not in the range of [+0.5 to +1] so it can be said that there is a weak relationship between these two parameters. The positive correlation between these two parameters indicates that these two variables tend to move in the same direction.

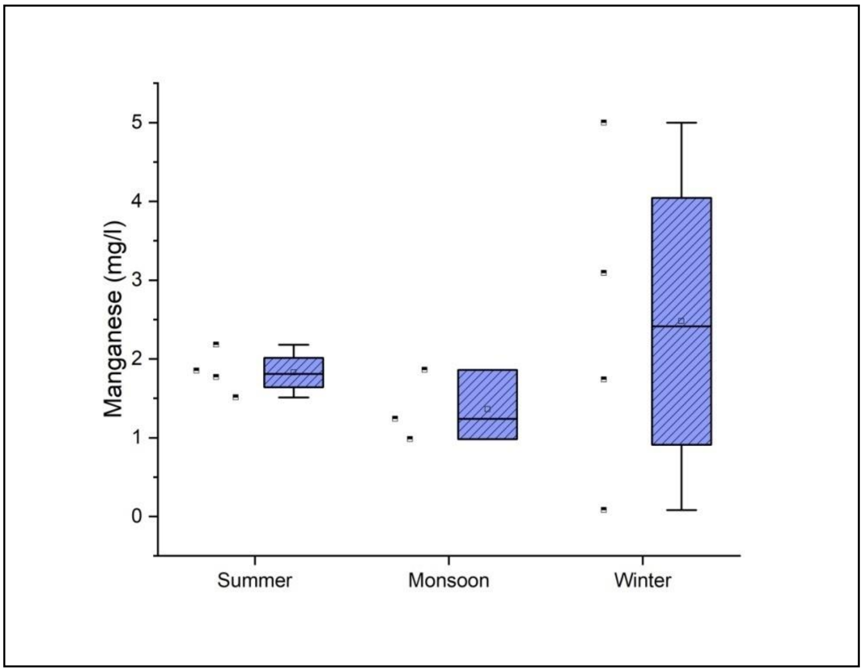

Fig 6.35: Seasonwise Variation of Manganese (mg/l)

6.7.3 Statistical Inference from 1-way ANOVA Analysis on Seasonal Variation of Leachate Characteristics of Coarser Soil-like Materials

Based on the available data from KMC (2022), shown in Table 6.12 statistical analysis of the Seasonal variation of the Leachate Characteristics of the coarser fraction of soil-like materials have been studied further using the 1-way ANOVA analysis which is shown in Table 6.14 respectively. The purpose of using descriptive statistical method like 1-way ANOVA is to study the relationship between the physicochemical characteristics and to observe the differences in the mean values. Before performing the statistical analysis, the data set was checked thoroughly.

Table 6.14: 1-way Anova Analysis of Leachate Characteristics (Seasonwise)

TCLP 1-way Anova Analysis [Seasonwise]						
Seasons	**Summer**	**Monsoon**	**Winter**	**F[Stat]**	**P-value**	**F [Crit.]**
Lead (as Pb), in mg/l	5.62 ± 0.304	0.96 ± 0.01	4.87 ± 0.07	7.791	0.013	4.459
Nickel (as Ni), in mg/l	1.85 ± 0.051	0.67 ± 0.001	4.13 ± 0.19	6.682	0.020	4.459
Copper (as Cu), in mg/l	2.25 ± 0.01	2.1 ± 0.04	0.58 ± 0.03	12.687	0.003	4.459
Total Chromium (as Cr), in mg/l	4.15 ± 0.04	2.97 ± 0.103	1.17 ± 0.04	11.678	0.004	4.459
Mercury (as Hg), in mg/l	0.006 ± 0.0001	0.003 ± 0	0.007 ± 0.0002	0.401	0.682	4.459
Arsenic (as As), in mg/l	0.058 ± 0.001	0.042 ± 0.003	0.054 ± 0.0003	0.078	0.925	4.459
Cadmium (as Cd), in mg/l	0.056 ± 0.0003	0.012 ± 0.00004	0.147 ± 0.0009	2.259	0.167	4.459
Zinc (as Zn), in mg/l	24.20 ± 11.73	10.07 ± 0.16	27.09 ± 12.26	1.184	0.354	4.459
Iron (as Fe) in mg/l	36.37 ± 7.9	49.8 ± 3.27	25.24 ± 4.63	17.067	0.001	4.459
Manganese (as Mn), in mg/l	7.31 ± 0.076	4.08 ± 0.204	9.91 ± 4.34	0.648	0.548	4.459

6.7.3.1 Parameter: Lead (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Lead (mg/l)**. The average lead concentrations is (5.62 ± 0.304) in summer, (0.96 ± 0.01) in monsoon, (4.87 ± 0.07) in winter respectively. It has been found that the average concentrations of lead (mg/l) is maximum in summer whereas is minimum in monsoon season. After performing the analysis, we find the F[statistic] is greater than F[critical], so the test is a significant one. As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in Lead (mg/l) according to the seasonal variations.

6.7.3.2 Parameter: Nickel (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of the **Nickel (mg/l)**. The average nickel concentrations are (1.85 ± 0.051) in summer, (0.67 ± 0.001) in monsoon, (4.13 ± 0.19) in winter respectively. It has been found that the average concentration of nickel is maximum in winter and is minimum in monsoon season. After performing the analysis, we find the F[statistic] is greater than the F[critical] so the test is a significant one. As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in Nickel (mg/l) according to the seasonal variations.

6.7.3.3 Parameter: Copper (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of the **Copper (mg/l)**. The average concentration of copper is (2.25 ± 0.01) in summer, (2.1 ± 0.04) in monsoon, and (0.58 ± 0.03) in winter respectively. It has been found that the average copper concentration is maximum in summer and minimum in winter. After performing the analysis, we find the F[statistic] is greater than F[critical] so the test is a significant one. As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in Copper (mg/l) according to the seasonal variation.

6.7.3.4 Parameter: Total Chromium (mg/l)

Analysis of variance is performed for checking the effect of the three seasons on the mean of the **Total Chromium (mg/l)**. The average concentration of total chromium is (4.15 ± 0.04) in summer, (2.97 ± 0.103) in monsoon, and (1.17 ± 0.04) in winter respectively. It has been found that the average concentration of total chromium is maximum in summer and minimum in winter. After performing the analysis, we find the F[statistic] is greater than the F[critical] so the test is a significant one. As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in total chromium (mg/l) according to the seasonal variation.

6.7.3.5 Parameter: Mercury (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Mercury (mg/l)**. The average mercury concentration is (0.006 ± 0.0001) in summer, (0.003 ± 0) in monsoon, (0.007 ± 0.0002) in winter respectively. It has been found that average concentrations of mercury are almost similar irrespective of seasonal variation. After performing the analysis, we find the F[statistic] is lesser than the F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in mercury (mg/l) according to seasonal variation.

6.7.3.6: Parameter: Arsenic (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Arsenic (mg/l)**. The average arsenic concentrations are (0.058 ± 0.001) in summer, (0.042 ± 0.003) in monsoon, (0.054 ± 0.0003) in winter respectively. It has been found that the average arsenic concentration is more or less similar irrespective of seasonal variation. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in arsenic (mg/l) according to seasonal variation.

6.7.3.7 Parameter: Cadmium (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Cadmium (mg/l)**. The average cadmium concentrations are (0.056 ± 0.0003) in summer, (0.012 ± 0.00004) in monsoon, (0.147 ± 0.0009) in winter respectively. It has been found that the average cadmium concentration is maximum in winter and minimum in monsoon season. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in cadmium (mg/l) according to the seasonal variation.

6.7.3.8 Parameter: Zinc (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Zinc (mg/l)**. The average zinc concentration is (24.20 ± 11.73) in summer, (10.07 ± 0.16) in monsoon, and (27.09 ± 12.26) in winter. It has been found that the average zinc concentration in winter is maximum but minimum in monsoon season. After performing the analysis, we find the F[statistic] is lesser than the F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in zinc (mg/l) according to the seasonal variation.

6.7.3.9 Parameter: Iron (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of the Iron (mg/l). The average iron concentration is (36.37 ± 7.9) in summer, (49.8 ± 3.27) in monsoon, and (25.24 ± 4.63) in winter respectively. It has been found that the average iron concentration is maximum in monsoon and minimum in winter season. After performing the analysis, we find the F[statistic] is greater than the F[critical], so the test is a significant one.

As $p<0.05$, alternative hypothesis is considered which implies that the result has found statistically significant difference in iron (mg/l) according to the seasonal variation.

6.7.3.10 Parameter: Manganese (mg/l)

Analysis of Variance is performed for checking the effect of the three seasons on the mean of **Manganese (mg/l)**. The average manganese amounts are (7.31 ± 0.076) in summer, (4.08 ± 0.204) in monsoon and (9.91 ± 4.34) in winter respectively. It has been that the average manganese concentration is highest in winter and lowest in monsoon season. After performing the analysis, we find the F[statistic] is lesser than F[critical], so the test is not significant one. As $p>0.05$, null hypothesis is considered which implies that the result does not found any statistically significant difference in manganese (mg/l) according to seasonal variation.

6.8 INFERENCE REGARDING ENVIRONMENTAL FEASIBILITY OF CHEMICAL CHARACTERISTICS OF SOIL-LIKE MATERIALS

Assessment of the Total Heavy Metals & Leachate Characteristics tests has been done in order to trace out the variation of the concentration of the above mentioned parameters with respect to soil depths. In order to study the nature of variations of the concentrations of the mentioned parameters all over the closed dumpsite, locations for collecting the samples have been changed as well.

Table 6.15: Environmental Feasibility of Total Heavy Metal Characteristics

THM ANALYSIS			
Parameters (mg/kg)	**Mean ± SD**	**Range (mg/kg)**	**Remarks**
Iron (mg/kg)	536.26 ± 294.70	-	
Lead (mg/kg)	49 ± 21.15	100	Within limit
Arsenic (mg/kg)	0.25 ± 0.00	100	Within limit
Nickel (mg/kg)	20.74 ± 7.64	150	Within limit
Cadmium (mg/kg)	0.701 ± 0.62	20	Within limit
Total Chromium (mg/kg)	65.78 ± 13.63	100	Within limit
Copper (mg/kg)	44.28 ± 7.30	135	Within limit
Mercury (mg/kg)	0.1 ± 0.00	4	Within limit
Zinc (mg/kg)	257.77 ± 72.11	300	Within limit
Manganese (mg/kg)	120.75 ± 57.66	-	

Table 6.16: Environmental Feasibility of Leachate Characteristics

TCLP ANALYSIS			
Parameters (mg/l)	**Mean ± SD**	**Threshold Limit (mg/l)**	**Remarks**
Lead (mg/l)	1.04 ± 0.58	5 mg/l	Within limit
Nickel (mg/l)	0.60 ± 0.45	20 mg/l	Within limit
Copper (mg/l)	0.45 ± 0.28	25 mg/l	Within limit
Total Chromium (mg/l)	0.75 ± 0.42	5 mg/l	Within limit
Mercury (mg/l)	0.00 ± 0.00	0.2 mg/l	Within limit
Arsenic (mg/l)	0.01 ± 0.00	5 mg/l	Within limit
Cadmium (mg/l)	0.02 ± 0.02	1 mg/l	Within limit
Zinc (mg/l)	5.58 ± 3.06	250 mg/l	Within limit
Iron (mg/l)	10.13 ± 4.82	-	Within limit
Manganese (mg/l)	1.94 ± 1.26	10 mg/l	Within limit

After performing elaborate data analysis of the samples collected for THM tests, it can be said that the concentrations (mg/kg) of the heavy metals like Lead, Nickel, Cadmium, Copper, and Zinc are very much below the threshold limit so the desired soil-like materials is considered compatible for onsite & offsite applications. For TCLP tests, it can be said that concentration (mg/l) of the maximum parameters (like lead, nickel, copper, total chromium, arsenic, cadmium, zinc, iron and manganese) are much below the threshold limit so the desired soil-like material is safe to be used for both offsite & onsite application.

Upon observing the nature of variations, irregular dumping in an unscientific manner can be considered as the only cause. For the old and closed dumpsites like Dhapa, this type of dumping is common one. Besides this, it is also a known fact that the major sources of heavy metals in landfills are the co-disposed industrial wastes, biomedical waste and household hazardous substances such as batteries, paints, dyes, inks etc. During the operative years of the Dhapa dumpsite, wastes generated from the tannery industry which at that time is located in the heart of city of Kolkata, are transported and are dumped in Dhapa. The tannery wastes can be considered as the principal source of the Total Chromium in the samples so collected. The main reason responsible for continuous change of soil depth and sample location during the collection of samples is the temporary construction of roads in order to provide easy access for transporting the waste via municipal vehicles. Besides this, the heterogeneous composition of the waste dumped in the Dhapa dumpsite which had started to operate since mid-80s also acts as a primary source of the Total Heavy metals present in the coarser fraction of the soil-like materials. Upon assessing regarding the source of iron, it has been observed that the ferrous concentration in the leachate sample indicates that Fe and Steel scrap are also dumped in the landfill. The dark brown colour of the leachate is mainly attributed to the oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with humic substances.

CHAPTER – VII: COST ANALYSIS & COMPARISON OF LANDFILL REMEDIATION MEASURES

7.1 FEASIBILITY OF LANDFILL REMEDIATION MEASURES FROM ENGINEERING ASPECT

Generally, dumpsite reclamation can be done in two possible methods. One method is Biocapping of dumpsites which is mainly adopted only at the situations when the reclamation of waste by isolating them from the dumpsite is very costly owing to its huge quantity along with high contamination range and unpredictability of the material obtained from the legacy dumpsite. Biocapping is the process of transforming a dumpsite from a wasteland to a natural environment by successfully turning the garbage into resilient landscapes. It involves laying an erosion resistant soil cover over legacy waste materials with the sole purpose for isolating the dumpsite waste and contaminants to restrict contact with natural environment. The other method consists of Biomining of Legacy waste which is the process by which previously dumped waste is dug up after loosening by drying the waste under sun and then processing it to recover valuable recyclable scrap while also recovering the landfill space with prime focus upon soil recovery including the recyclable materials.

It has been observed from the SWM Rules, 2016 and the NGT Directives that Capping might appear to be a convenient and time-effective method for dumpsite remediation, but it does not reclaim the land or ensure the scientific treatment of legacy waste instead it isolates the contaminants in place to avoid the spread of contamination. Biocapping of dumpsites requires at least 15 years of post-closure maintenance to monitor pollution limits in groundwater and surface water sources and landfill gas emissions. Monitoring of the Biocapped landfills has to be done periodically in order to observe the physico-chemical and biological transformation, leachate generation, etc. On the other hand, dumpsite remediation through biomining guarantees long-term sustainability and soil recovery including different revenue generating fractions. Besides, through Biomining process, recovery of the entire base area of the dumpsite upto its ground level is possible whereas in case of Biocapping, only 25 percent of the entire base area can be used which might be located at an inconvenient height. For all the above reasons, engineers have always preferred Biomining over Biocapping.

7.2 FEASIBILITY OF THE LANDFILL REMEDIATION MEASURES FROM ECONOMIC ASPECT

Excavation, material sorting, transport, recovery/treatment plants and plant operations and maintenance account for the majority of the costs associated with landfill mining (LFM) projects. Van Der Zee et al. (2004) evaluated the advantages and expenses of landfill reclamation. The expenses are primarily broken down into capital costs (site preparation, equipment rental or purchase, material handling facility) and operational costs (labour, maintenance, safety, hauling and final disposal). The advantages are primarily attributable to revenue from recyclables, combustibles, recovered landfill space, and reduced expenses.

The cost and benefit will also depend on closure and aftercare requirements, remediation necessity, waste characteristics, waste decomposition status and local economics (cost of recyclables, land value, labour costs among others). In most of the cases, the capital and operational cost exceed the revenue generated from extracted materials (Van Passel et al., 2012; Frändegård et al., 2015; Maheshi et al., 2015; Wolfsberger et al., 2016). However, no literature is available on assessment of economic feasibility of landfill or dumpsite in Indian context. Considering waste characterization under Indian context, major revenue sources would be landfill space recovery and combustible fraction (Dubey et al., 2016; Mandpe et al., 2019). One of the major revenue sources reported in most of the literatures was metal fraction, which is very low in case of Indian dumpsites (Singh & Chandel, 2019). So far, only a very few studies have focused on the economic feasibility of LFM from a private point of view and even less studies have been attempted to economically justify the need for LFM projects from a social point of view (Debsarkar et al., 2022).

In terms of product design and waste separation, both the public and commercial sectors must assume greater responsibility for waste generation and disposal. Formalizing these responsibilities through well-structured public-private-partnerships (PPPs) can result in significant improvements in the efficiency and quality of solid waste management. As public-private partnerships (PPPs) grow more widespread, investments in the trash business have risen as government seek private capital and technical expertise to build, operate and manage waste projects. The most prevalent types of programs include waste incineration, waste treatment, recycling, and electricity from waste initiatives. With programs ranging from waste collection and transportation to waste disposal and treatment, the private sector has been encouraged to participate in solid waste management. In India, a cost-benefit analysis was carried out for two potential scenarios (a) mining for recovery and (b) transferring MSW from the dump to a new sanitary landfill where in case of dumpsite mining for resource recovery, the additional cost of setting up a new dumpsite was saved, as the existing site could be used five times in a period of 50 years assuming dumpsite mining to be carried out once in 10 years.

7.3 COST ANALYSIS OF BIOCAPPING OF DUMPSITES

In the case of Biocapping of Dumpsites, the dumpsite is initially levelled, covered with soil by providing the surface drainage system, leachate management and gas collection systems and then capped. By doing these, the landfill site is converted into a green space having an environmental monitoring system as well. This is used in absence of viable reclaimation options where bioremediation becomes highly expensive, high levels of contamination or unpredictable material that would come out of the legacy dumpsite.

Capping a landfill involves three layers: an upper vegetative (top soil) layer, a drainage layer, and a low permeability layer comprised of a synthetic material overlaying 2 ft. of compacted clay. Capping has 50-100 years of lifetime, although the cap's performance depends on the site's environmental conditions. Caps can crack and erode as result of changes in air temperatures and precipitation, as well as if the region is prone to subsidence and earthquakes. To prevent erosion, the op soil layer must be thick enough to accommodate vegetation and burrowing animals.

The first step in the landfill repair procedure is to assess the contamination. Environmental Site Assessment is frequently the first step in the process. The evaluation technique and type of sample and chemical analysis to be performed will be guides by the site's use and the materials placed there. Even though the current land use appears to be harmless, surrounding sites held by the same ULBs or nearby sites that have been reclaimed, leveled, or filled are frequently contaminated. Off-site pollution of surrounding locations frequently caused by decades of emission to soil, groundwater, and air, is also vital to address. The final criterion is that the environmental impact, social acceptance, and transportation and remediation costs are to be considered.

Fig 7.1: Outline Map of the Dhapa Dumpsite

Fig 7.2: Location of the Boreholes dug for Sample Collection

7.3.1 Sample Collection and Experiments followed for Waste Characterization

A waste characterization programme was conducted as a part of site investigations for determining the containment and closure options for the Dhapa Closed landfill site. The primary objective consisted of collecting samples at different locations and carrying out sieve tests of waste samples. The physical characterization of waste samples was carried out by SKM Geo Survey, Kolkata and the chemical analysis of the waste samples was carried out by SGS Laboratories (Kolkata). The sieve tests (physical characterization of waste) have been carried out in two ways covering the entire closed dumpsite; one way is sample collection from borehole drilling operations of top 3m depth while the other way is sample collection from trial pits of size 1x1 m upto 2-3m depth. The locations are handpicked so that they would give a representative overview of the wastes present in the dumpsite.

Sampling Test-I: The Sieve Testing procedure followed for collection of borehole waste samples at locations marked as [BH 6 (WC - 1); 7 (WC – 2); 8 (WC – 3)] respectively. To determine the composition of the wastes at the above locations, the wastes were analyzed by sieving where the excavated wastes was first segregated in three fractions which are plastics, organic fraction (including paper, cardboard, wood etc.), and inert fraction. The inert fraction from the above was further put on a 2cm mesh sieve and manually sieved until only larger particles remained. The inert fraction was thus further bifurcated into two fractions with sizes smaller than 2cm and bigger than 2cm. All these waste fractions were then weighed and weight percentages are calculated. From each sieving test, a sample of inert fraction (<2 cm size) was further taken and a mixture of all three borehole samples was prepared and was sent to laboratory for further chemical analysis.

Sampling Test-II: The Sieve Testing procedure followed for collection of borehole waste samples at locations marked as [(WC – 4); (WC – 5); (WC – 6)] respectively. To determine the waste composition from trial pits, three trial pits were excavated on the dumpsite at the three mentioned locations. Waste material of minimum 50kg was collected from trial pits from depth of 2-3m below ground level. Then the excavated material was further segregated into three fractions like plastics, organics (including bones, wood, etc.), and inert fraction of two different sizes (<2cm &>2cm) respectively. The different fractions were further weighed and weight percentages of each component were then calculated. After completion of waste characterization, the excavated material was filled back in the same trial pit.

7.3.2 Observation and Results from the Experiments of Waste Characterization

The dumpsite is characterized by an uncovered surface with waste exposed in areas in particular at the slopes. The top of the dumpsite is dominated by inert sand and soil materials. It is anticipated that the exposed waste at the surface which mainly consisting of plastic and paper are escaping from the dumpsite either as windblown litter or transcend by surface water leaving the heavier inert materials behind at the site. It is anticipated that the waste in the dumpsite consist of plastic, an organic fraction exclusive plastic (mainly paper and cardboard) and inert (sand, silt, construction & demolition (C&D) waste respectively. Results of the onsite sieve test conducted on the mixed sample of the waste from boreholes at location BH-6, BH-7 and BH-8 at the dumpsite are as follows:

Table 7.1: BH-06 (WC-1): Results of Sieve Test (KMC, 2017)

BH-06 (WC – 1): Results of Sieve Test		
Description	**Weight (in kg)**	**% by Weight**
Plastic	0.904	10.62%
Organic fraction	0.914	10.74%
Inert particles > 2cm	1.520	17.86%
Inert particles < 2cm	5.170	60.76%
Total	8.508	99.98%

Table 7.2: BH-07 (WC - 2): Results of Sieve Test (KMC, 2017)

BH-07 (WC - 2): Results of Sieve Test		
Description	**Weight (in kg)**	**% by Weight**
Plastic	1.078	7.68%
Organic fraction	0.804	5.73%
Inert particles > 2cm	3.352	23.89%
Inert particles < 2cm	8.796	62.69%
Total	14.03	99.99%

Table 7.3: BH-08 (WC – 3): Result of Sieve Test (KMC, 2017)

BH-08 (WC – 3): Result of Sieve Test		
Description	**Weight (in kg)**	**% by Weight**
Plastic	0.783	9.55%
Organic fraction	0.927	11.31%
Inert particles > 2cm	1.876	22.88%
Inert particles < 2cm	4.610	56.24%
Total	8.196	99.98%

Table 7.4: Trial Pit - 1 (WC – 4) (KMC, 2017)

Trial Pit - 1 (WC – 4)			
Parameter	**Weight (kg)**	**Weight (%)**	**Remarks**
Metals	Nil	Nil	Only one or two small pieces observed on surface
Plastics and Rubbers	13	26	-
Organic Matters	3	6	-
Inert < 2cm	15	30	-

Inert > 2cm	19	38	-

Table 7.5: Trial Pit – 2 (WC – 5) (KMC, 2017)

Trial Pit – 2 (WC – 5)			
Parameter	**Weight (kg)**	**Weight (%)**	**Remarks**
Metals	Nil	Nil	No metal pieces found
Plastics and Rubbers	9	18	-
Organic Matters	2	4	-
Inert < 2cm	21	42	-
Inert > 2cm	18	36	-

Table 7.6: Trial Pit – 3 (WC – 6) (KMC, 2017)

Trial Pit – 3 (WC – 6)			
Parameter	**Weight (kg)**	**Weight (%)**	**Remarks**
Metals	Nil	Nil	No metal pieces found
Plastics and Rubbers	10	20	-
Organic Matters	1	2	-
Inert < 2cm	24	48	-
Inert > 2cm	15	30	-

The samples are only representative for the specific location and it is upto desired agency to make the proper interpretation of the composition and characteristics of the disposed waste at Dhapa dumpsite. The desired agency was offered the authority to carry out additional sampling tests and investigations as per requirement with its own cost prior or during the project implementation.

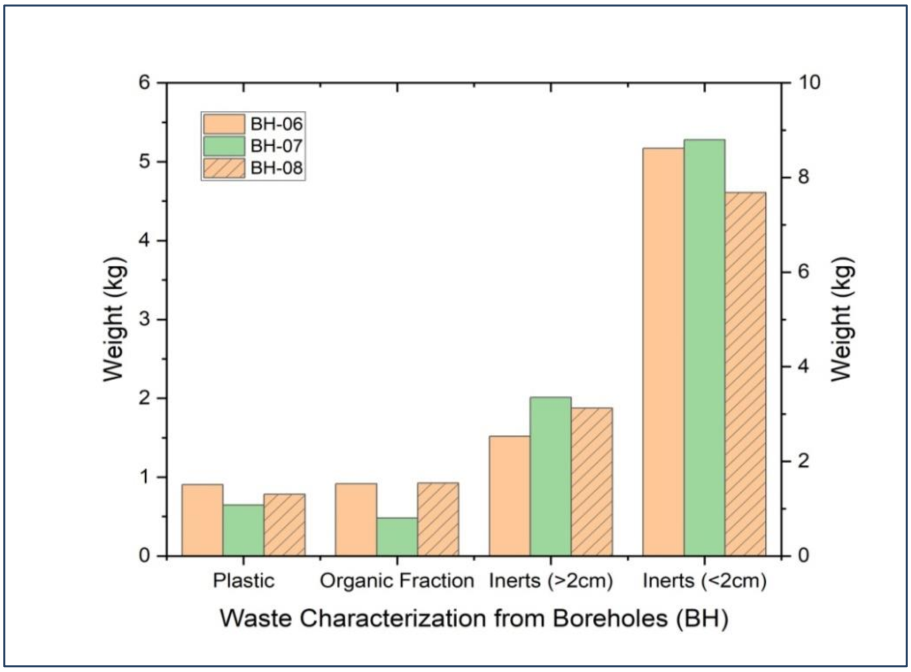

Fig 7.3: Characterization of Wastes collected from Boreholes

7.3.3 Main Activities & Specifications of Construction Works for Containment and Closure Project

From the technical perspective, the containment and closure project of the dumpsite is defined as an engineered way of utilizing Impermeable Cover, Leachate Collection & Treatment, along with the Passive Gas Control concept with the objective of encapsulating the closed dumpsite. The idea of this option is to avoid generation of leachate in future and achieving a scenario of zero pollution from leachate generated from the closed dumpsite within a few years. Leachate collected at the site will be treated in an on-site leachate treatment plant which was planned to be located south-east of the closed Dhapa dumpsite.

Gas will still be generated but due to lack of infiltration of rainwater, the gas generation will decrease faster and can be controlled by venting (via a compost filter) to the atmosphere without further treatment. Surface water will be collected in lined ditches on and around the closed dumpsite and was discharged to the adjacent existing surface water drains as uncontaminated surface water. The main activities and specifications of construction works for containment and closure project are described as follows:

- Introduction of general items and site preparation works like construction of temporary fence, site clearing and grading, along with other works which were deemed suitable for closure requirements of dumpsite.
- The boundary line (fence) and centreline for perimeter surface drain (at toe of slope) was to be laid out as per the coordinates mentioned in plan drawing and levels according to longitude section.

- Profiling of waste surface to achieve final closure levels as per closure plan. The profiling of the wastes in slopes are to done according to cross sections like 1:2.5/1:3 upto first berms in level +14.00 m (waste level approx. 1.0m below final level) followed by 3m wide berm. After the profiling of the waste, storm water drainage, gas drainage system and cost filter for passive gas venting system were constructed.
- Installation of Gas Drainage Layer, 1.5mm HDPE liner, Drainage mat made of geo composite materials, soil layer and vegetative layer including grass and other vegetation.
- Construction of concrete lined surface water ditches on and around the closed dumpsite and with connection to existing open surface drains or canals.
- Collection and transfer of Leachate to Leachate Treatment Plant and providing pumping facilities upto the leachate treatment plant from leachate collection sumps. Leachate collection drain pipe (for on-going collection and pumping of Leachate and also permanent rising of mains to the Leachate Treatment Facility.) are to be laid out.
- Landfill gas collection and passive gas venting system through compost filter.
- Construction of internal service and access roads along with recreational areas or view point. Final Cover layer followed by Grass & vegetation cover layer with landscaping were to be constructed and laid out.
- Installation of Steel wire fence around the dumpsite for the closure of construction compound areas.

7.3.4 Selection of Containment & Closure Options & their Environmental Effects

Containment & closure options of a dumpsite are to be selected properly by thoroughly analyzing the environmental effects on the neighbouring regions. One of the most common problems is subsidence which is the setting of the ground when garbage begins to compact and shift. Sometimes, it can be very severe causing significant damages to any built environment like foundations, irrigation etc. The percentage of subsidence needs is considered to be a key factor in determining the technology which was to be implemented. Another common problem is the surface and groundwater contamination due to the percolation of leachate through the layers of closed dumpsite. In order to prevent the infiltration, it is essential to have the sites capped with the compacted clay layers topped with erosion cover layer that is capable of sustaining vegetation. Considering these problems, the studies have been carried out to derive a thorough idea about the variation and intensity of the environmental effects with respect to the selection of the options.

7.3.5 Effect on Air of Surrounding Regions due to Biocapping

Landfill gas (LFG) is a natural by-product of the decomposition of organic material in landfills. Landfill gas is composed of roughly 50 percent methane (the primary component of natural gas), 50 percent carbon dioxide (CO_2) and a small amount of non-methanogenic organic compounds. Air emissions are mainly landfill gases like methane, carbon dioxide etc. Other parameters such as dust, odour etc. is assumed insignificant during the aftercare period.

The analysis from the Ambient Air Quality monitoring, even recorded for the pre-remediation situation, demonstrates that ambient air monitoring during the aftercare period is of less or no importance.

During the construction phases, all the 5 considered options are assumed equal related to emission of gases, dust, noises etc. The main impact will occur during excavation, transport, sorting and re-disposal of waste and as the amount of waste to be excavated is the same for all 5 options, so this is not qualified. Rationale for estimation of methane emissions is described under each option in the Containment & Closure options.

Table 7.7: CO_2 Emission Reduction for "Option 5" & for "Do Nothing" (KMC, 2017)

CO_2 Emission Reduction for "Option 5" & for "Do Nothing"		
Options	**Installations related to reduction of methane emissions**	**Methane Emission as ton CO_2 equivalents (30 years)**
Option 1: Do Nothing	None (Baseline)	429,723
Option 2: Simplified closure concept	Cover with soil & top soil. Some oxidation in top soil	388,664
Option 3.1: Reduced infiltration & passive gas venting	Low permeable cover and oxidation 'windows'	220,692
Option 3.2: Reduced infiltration & active gas treatment	Low permeable cover & with active landfill gas collection & flaring	134,747
Option 4: Reduced infiltration & leachate treatment	Same as Option 3.1	220,845
Option 5: Impermeable top cover	Impermeable cover & oxidation "filters"	75,660

7.3.6 Effect on Soil of Surrounding Regions due to Bio-capping

Waterlogging as well as release of toxic gases like methane, carbon dioxide etc. produced by degrading waste is problematic because it causes conditions in the soil that could be devastating for surrounding region. Improvement or impact of surface soils in the surrounding of the Dhapa Dumpsite after remediation will be the same for all options. Pollution of soil from leachate flowing horizontally from the upper reservoir towards the surroundings will continue but at reduced rates for remedial options 2 & 3, whilst it will be eliminated for remedial options 4 and 5.

Soil below the dumpsite will continue to be contaminated by leachate for all remediation options. But the impact will be reduced because of a decrease in the downward gradient after lowering of water (leachate) table inside the water body. The downwards gradient will be lowest for remediation option 5 and highest for option 2. The leachate is generally assumed to be generated only by the lowest and saturated part of the dumpsite and is expected to less pollute after a relatively short time.

Table 7.8: Impact on soils due to leachate from remediated dumpsite (KMC 2017)

Impact on soils due to leachate from remediated dumpsite		
Option	**Contamination of soil in surroundings Leachate (m^3/year)**	**Contamination of soils below dumpsite Leachate (m^3/year)**
Option 1: Do Nothing	62,000	3,100
Option 2: Simplified Closure Concept	43,000	3,010
Option 3.1: Reduced infiltration and passive gas venting	33,000	2,310
Option 3.2: Reduced infiltration & active gas treatment	33,000	2,310
Option 4: Reduced infiltration & leachate treatment	0	2,310
Option 5: Impermeable Top Cover	10,000	< 2000

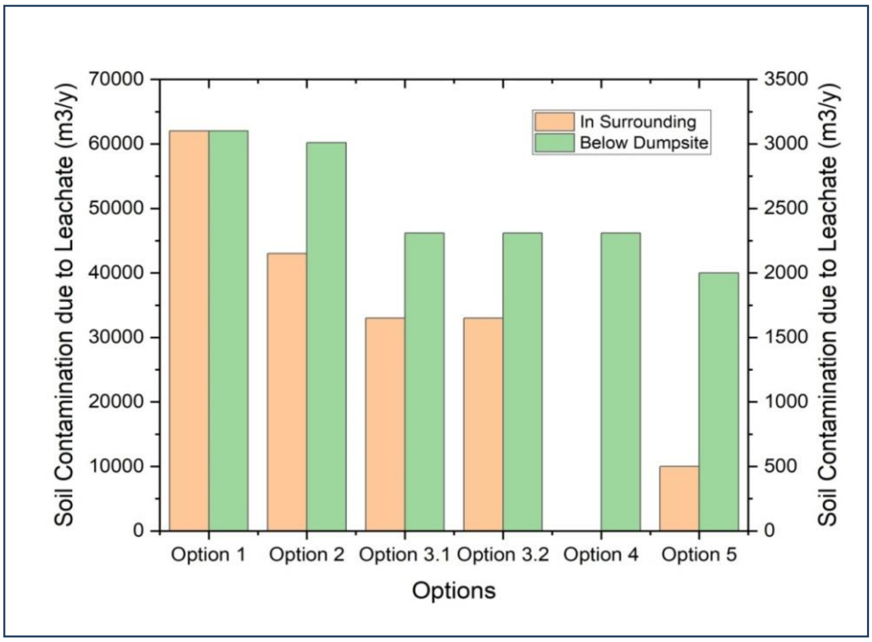

Fig 7.4: Impact on Soils due to Leachate from Remediated Dumpsite

7.3.7 Effect on Surface water of Surrounding Regions due to Bio-capping

At present, there were approximately 95,000 m^3/year of leachate and waste contaminated surface water pollutes the surrounding surface water bodies the situation will be improved dramatically by any of the defined options. After closure with a top cover, all surface water will be non-contaminated as the surface water and the leachate will be 100% separated. The control and protection of receiving surface water bodies around Dhapa dumpsite are identical for all remediation options. However, there is a risk for seepage of leachate out from slope for remediation option 2 and 3 however assumed low and not included in comparison of the options. After remediation, the amount of surface water running out of the site is estimated as shown in below table:

Table 7.9: Estimated surface water run-off for 5 options and 'Do Nothing" (KMC, 2017)

Estimated surface water run-off for 5 options and 'Do Nothing"	
Option	**Non Contaminated Surface water run-off (m³/year)**
Option 2: Simplified closure concept	98,855
Option 3.1: Reduced infiltration and passive gas venting	100,201
Option 3.2: Reduced infiltration and active gas treatment	100,201
Option 4: Reduced infiltration and leachate treatment	100,201
Option 5: Impermeable top cover	148256

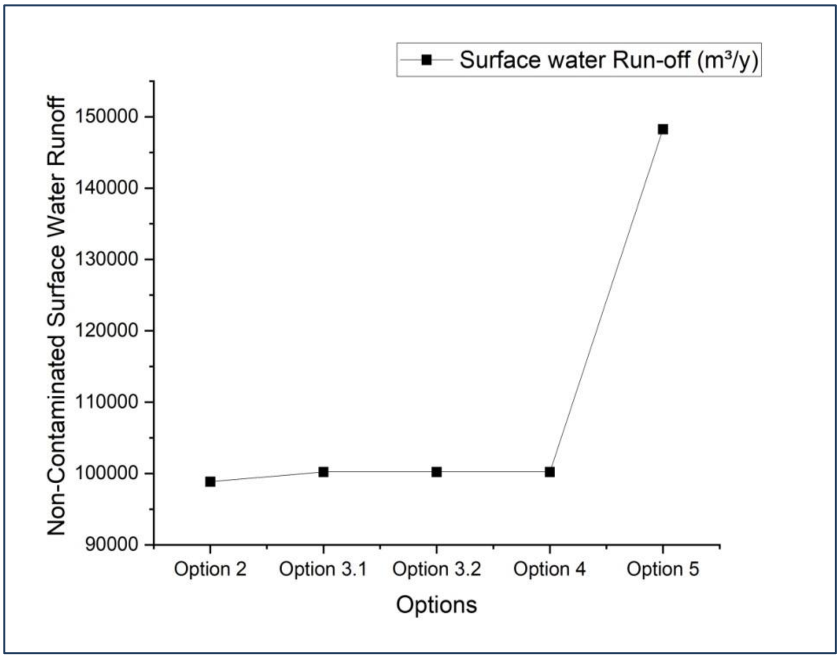

Fig 7.5: Estimated Surface Water Runoff for "5 Options" & "Do Nothing"

7.3.8 Effect on Groundwater (subdivided in upper ground reservoir & primary aquifer) of Surrounding Regions due to Bio-capping

Groundwater protection for remediation of Dhapa dumpsite is divided up in upper groundwater and the primary aquifer. For the upper aquifer a continuing amount of leachate will flow from the dumpsite in the upper fill and silt layers for remediation option 2 and 3 but will be prevented for remediation option 4 and 5.The downwards flow of leachate will continue however reduced for all remediation options. The downwards gradient defines the flow. For the existing situation (option1) the downwards gradient is estimated to 5% resulting in a downwards flow of 3,100 m^3/year.

As downward gradient to the primary aquifer is assumed more critical than contamination of the upper groundwater reservoir only 10% of the flow to upper groundwater reservoir is included in the "Total" flow. It is to be noted that 300,000 m^3 of leachate are captured in the waste body below the dump site. A part of this leachate will be collected during construction phase and in the initial years after closure. The amount is however uncertain but total contamination of the groundwater is assumed to be similar as for option 4. The leachate is generally assumed to be generated only by the lowest and saturated part of the dumpsite and is expected to less pollute after a relatively short time.

Table 7.10: Leachate Emissions from Dhapa Dumpsite (KMC, 2017)

Leachate Emissions from Dhapa dumpsite			
Option	**Flow to upper groundwater reservoir (m^3/year)**	**Flow to primary aquifer (m^3/year)**	**"Total" Flow**
Option 1: Do nothing	62,000	3,100	9,300
Option 2: Simplified closure concept	43,000	3,010	7,310
Option 3.1: Reduced infiltration and passive gas venting	33,000	2,310	5,610
Option 3.2: Reduced infiltration and active gas treatment	33,000	2,310	5,610
Option 4: Reduced infiltration & leachate treatment	0	2,310	2,310
Option 5: Impermeable top cover	0	< 2,000	2,310

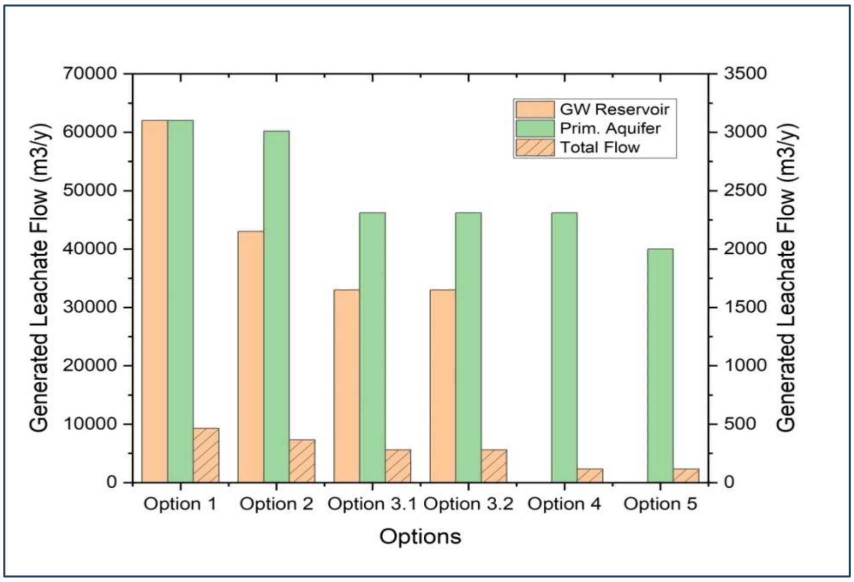

Fig 7.6: Categories of Leachate Emissions from Remediated Dumpsite

7.3.9 Monitoring, Aftercare and Maintenance of Bio-capped Dumpsite & its Economic Feasibility

High degree of maintenance, aftercare and monitoring will create jobs which basically are positive however it will for remediation of Dhapa dumpsite mainly be skilled staff for gas and leachate treatment. The local society will not benefit from that. Also it will add additional responsibilities and costs on the beneficiary (KMC). The remediation option with minimum requirements of maintenance, aftercare and monitoring is assumed better than an option with high requirements of maintenance, aftercare and monitoring. Besides this, Risks for failures for each option is described in Containment and Closure options report. Use of closed landfill sites after fifteen years of post-closure monitoring can be considered for human settlement or otherwise only after ensuring that gaseous emission and leachate quality analysis complies with the specified standards along with the assurance of soil standard. Monitoring, aftercare and maintenance for a remediated dumpsite will include the following tasks:

- Maintenance of vegetation such as cutting of grass, repair of erosion ditches, replanting of dead plants etc. (similar for all remediation options).
- Maintenance and clean-up of surface water ditches and canals (similar for all remediation options).
- Monitoring of groundwater reservoirs, surface water bodies, air, settlements of dumpsite, landfill gas monitoring (option 3.1,4, & 5), monitoring of leachate and leachate treatment (option 4).
- Operation and maintenance of pumps, pipes, wells, flare and other equipment for active gas collection (Option 3.2).
- Operation and maintenance of pumps, pipes, ponds and wells for leachate treatment system (Option 5).
- Maintenance of cover system. In particular for option 5 where the artificial sealing liner will require maintenance indefinite years ahead.

- Option 5 is not a sustainable solution as the entire concept relay on that the liner is impermeable.
- Complexity in technologies implemented.
- Risk of failures of constructions implemented in remediation of the dumpsite.

Table 7.11: Maintenance, Aftercare and Monitoring Costs and required Staff (KMC)

Maintenance, Aftercare and Monitoring Costs and required Staff					
Option	**Require Staff (Man-years)**	**Required Rate for O&M**	**Complexity in Technologies**	**Risk for failures**	**Total score [5-Best; 0-Worst]**
Option 1: Do nothings	0				0 (Due to continuous impact on surroundings)
Option 2: Simplified closure concept	Unskilled: 4; Skilled: 0; Professionals: 0,25	Low	Low	Medium	3
Option 3.1: Reduced infiltration & passive gas venting	Unskilled: 5; Skilled: 0; Professionals: 0,25	Low	Low	Low	5
Option 3.2: Reduced infiltration & active gas treatment	Unskilled: 10; Skilled: 1-2; Professionals: 0,25	Medium	Medium	Medium	2
Option 4: Reduced infiltration & leachate treatment	Unskilled: 15; Skilled: 1-2; Professionals: 0,5	Medium	Medium	Medium	2
Option 5: Impermeable top cover	Unskilled: 5; Skilled: 0; Professionals: 0,25	High (Replacement of membrane)	Medium	Low	1

7.3.10 Selection of Best Option

By allocating a percentage score for each of the three weighted aspects, a quantitative distinction can be made between the 6 options. For this distinction, all three weighed aspects are treated equally. If required, a different weight can be given for the three aspects depending on the preferences and priorities of the project. Based on the scoring system option 4 and 5 has got the highest score. Option 5 with an impermeable liner is more expensive to construct but less expensive to operated and have a higher score on environmental parameters. However, the score for option 5 for maintenance, aftercare and monitoring looking at a 30 years aftercare period are critical. Option 5 has a low score in maintenance, aftercare and monitoring as a solution with an artificial sealing liner is not a sustainable solution as the liner shall be kept intact for ever. Eventually the liner will require replacement maybe after 50 years or 100 years. These very long term expenses are not included in the cost estimate for option 5. Based on the scoring system presented, option 4 with a low permeable top cover and leachate collection and treatment system turns out to have lesser same score as option 5. A scoring system is always a subjective assessment of importance and impact on different parameters.

The basic difference between option 4 and 5 is whether the contaminant and closure system shall rely on an impermeable top cover which shall be kept intact (replaced every > 50th year) or a system where waste will stabilise in time (>50 years) but continuous collection and treatment of leachate is required until then. The comparison model is very complex and as weighing of parameters and factors to some extent involve a subjective assessment; a simplified model is introduced in below table. The result of the simplified scoring model is more or less identical with scoring presented in complex model. On the basis of the similarity between the arguments mentioned, option 4 and option 5 are assumed to be the most favourable options.

Table 7.12: Simplified Matrix for comparison of the 6 options (KMC, 2017)

Simplified Matrix for comparison of the 6 options						
Factors evaluated [5-Best/0-Worst]	**Option 1: Do nothing**	**Option 2: Simplified closure concept**	**Option 3.1: Reduced infiltrations & passive gas venting**	**Option 3.2: Reduced infiltration & active gas treatment**	**Option 4: Reduced infiltration & leachate treatment**	**Option 5: Impermeable top layer**
Construction cost	5	3	1	1	1	0
Operational cost	5	3	3	1	0	2
Leachate generation	0	1	3	4	5	5
Methane emission	0	0	3	4	5	5
Risk for failures	0	3	4	3	3	3
Complexity in technologies	5	5	4	3	3	2

O&M needs	0	5	4	3	3	4
Pollutions of soil	0	1	2	2	5	5
Pollution of surface water	0	1	3	3	5	4
Pollution of ground water	0	3	4	4	4	5
Total CO2 eq. emission	0	1	2	2	2	4
Total CO2 eq. emission	15	26	33	30	36	39

7.3.11 Landfill Gas Generation

Landfill gas a natural by-product which can be caught, processed and used as a renewable energy resource instead of escaping into the atmosphere. Landfill gas is used to eliminate odour and other risks associated with Landfill Gas emissions, as well as to prevent methane from escaping into the atmosphere and contributing to local smog and global climate change. Landfill Gas energy projects are primary source of various revenue generating opportunities. The First Order Decay Model (FOD Model) from IPCC Guideline 2006, IPCC Guidelines for National Greenhouse Gas Inventories is used to estimate the total landfill gas generation at the closed Dhapa dumpsite.

The input to the model is based on assumed waste amounts (2.0 million, m^3) and age (disposed in period 1987-2009), observation from the site, analyzed waste samples and the landfill gas monitoring carried out on site. The maximum annual LFG generation at Dhapa dumpsite was in 2009 and estimated to approximately 5.1 million Nm^3/year. The generation is decreased to approximately 4.3 million Nm^3/year in 2013 (equivalent to 1,520 ton CH4/year or 32,000 CO2 equivalents). In fig given below the estimated development of landfill gas from Dhapa dumpsite is presented including conversation into CO2 equivalents and expected reduction rate by active extraction of gas from the dumpsite.

Table 7.13: Estimated landfill gas generation at Dhapa dumpsite (2013-2022)

Estimated landfill gas generation at Dhapa dumpsite (2013-2022)										
Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Landfill Gas Generation, 1000 m^3/year	4,284	4,034	3,800	3,578	3,370	3,174	2,989	2,815	2,651	2,496

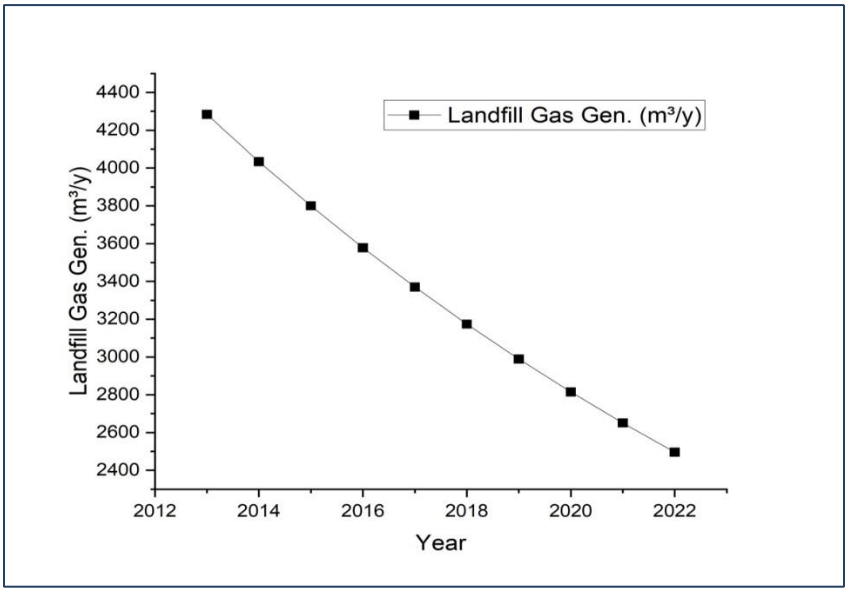

Fig 7.7: Estimated Landfill Gas Generation at Remediated Dumpsite

7.3.12 Brief Description of Uncontrolled and Controlled Passive Oxidation in Top Cover Layer and in Compost Windrows

In option 2, the top cover proposed include of vegetative layer. The vegetative layer will act as a methane oxidation zone. The oxidation potential in top soils containing humus is assumed to be approximately 0-20g/m^2/day. With an area of 11.8 ha the total potential amount of methane that can be oxidized is between 0 and 861 tons of methane per year or maximum between 57% (2013) and 96% (2022) for the first 10 years period. However for this option only 10% of the landfill gas is assumed to be oxidized. The oxidation rate is reduced to 10% because most of the landfill gas will emit through fissures and fractures in the top cover and because of the flow pattern of landfill gas is not controlled.

In Option 3.1 and Option 5, a controlled passive methane oxidation system is proposed. The methane oxidation will take place in oxidation window which consist of a compost layer above a gas distribution system of coarse gravel/stones. In this case where reduction of leachate generation is desirable the clay layers is intact (however slightly reduced in thickness) and ventilation pipes are install instead. The gas distribution layer below the clay layer is connected to the venting pipes and landfill gases are moved via the pipes into the gas distribution layer below the compost layer and then via the compost to the atmosphere. The compost has a high potential for oxidation of methane into CO2 and water.

7.3.13 Cost Analysis of Containment and Closure of a Closed Dumpsite

For the rough estimate it has been found that the Total Cost for Closure and Containment for 30 Acre land is nearly Rs. 50 Crores. Therefore, it can be said that the Total Cost for Closure and Containment for 60 Acre land is about Rs. 100 Crores. Now considering the operation & maintenance cost for the closure and containment of the 60 Acre land including 300 KLD capacity of 60 Acre land is given as follows:

Table 7.14: Remediation & Containment of Existing Dumpsite (KMC, 2017)

Remediation/Closure & Containment of Existing Dumpsite (Land - 30 Acre)		
Sr. No.	**Description**	**Amount (in INR)**
1	Part 1: Construction of Peripheral Leachate Collection System	11948803
2	Part 2: Profiling & Reshaping of Dumpsite	97398655
3	Part 3: Installation of Erosion Protection Layer & Waste Cover Layers over the reshaped Dumpsite	289022473
4	Part 4: Construction of Surface Water Drainage System, Passive Gas Collection System & Leachate Collection Wells	33587461
5	Part 5: Construction of Service Road, Footpath, Access Road & Steel fence over landfill site	19011460
6	Part 6: Providing Vegetative Cover with Horticulture over the cover layers along with irrigation system	32079172
7	Part 7: Construction of Monitoring Well, Site clearance & Handling over including submission of As. Built Drawings	2038706
A	Construction Costs for Closure & Capping of Landfill Site	485086730
B	Total Capital Costs of Containment & Closure	485086730
	Project Contingencies – 3%	14552602
C	Total Cost for Closure & Containment of 30 Acre of Dumpsite	499639332
Net Amount (Say)(In INR)		50 Cr.
Therefore, Total Capital Cost for 60 acre of Dumpsite (Say) is		999278663.8
	Net Amount (Say) (in INR)	100 Cr.

Table 7.15: O & M Cost of Leachate Treatment Plant at Closed Dumpsite (KMC, 2017)

Operation & Maintenance Cost of Leachate Treatment Plant at Closed Dumpsite			
Serial No.	**Item Description**	**Rate (Rs.)**	**Yearly Expense (Rs.)**
1	Chemicals – Aluminum, Chloride, Sodium Hypochlorite, Molasses, Enzyme etc.	167481	2009774
2	Chemist – Testing, Chemical Dosing etc.	15000	180000
3	Monthly Testing – 4 times in Bidder own lab; 1 time in outside lab	16000	193000
4	Laboratory Expenses – all expenses regarding laboratory	25000	300000
5	Monthly Maintenance – all machineries of LTP	75000	900000
6	Consultancy Charges – Monthly visit at Dhapa LTP site along advice and guideline	20000	240000
7	Office Expenses – printing & stationary expenses, local conveyance, staff welfare expenses, etc.	4900	58800
8	Operator – 6 persons	12000	864000
9	Electrician – 1 person	12000	144000
10	Security – 2 person	12000	288000

11	Labour & Transportation – sludge cleaning, time to time garbage collection & dumping etc. required work	18000	216000
12	Miscellaneous Expenses – monthly purchase of broom, detergent powder, old clothing etc.	1918	23018
	Total Project Value		5415592
13	Agency Profit – 10% of Profit Value	45130	541559
	Total Expenses	496429	5957151

Table 7.16: O&M Cost of Bioremediation project at Dhapa Dumpsite (KMC, 2017)

Serial No.	Item Name	Cost per Acre per Year (Rs.)	Cost for 30 Acres per year (Rs.)
01	Inspection and Certification	38000	1140000
02	Final Cover repair	11552	346560
03	Vegetation repair and maintenance	46892	1406760
04	Grass mowing	6080	182400
05	Gas management	13680	410400
06	Leachate management	15580	467400
07	Groundwater monitoring	77824	2334720
08	Well maintenance	17024	510720
09	Sub Total		6798960
10	Contingency @ 15%		1019844
11	Net Amount		7818804

As per Report, the closure and containment of the closed dumpsite have to be under thorough monitoring and control for at least 5 years. The purpose of this monitoring is solely to observe the environmental effect of the biocapped landfill and to provide the time to the biocapped land to settle and stabilize. The 300 KLD Leachate Treatment Plant has also been provided for the treatment of the leachate generating from the closed dumpsite. For this reason, an increment in the operation and maintenance cost of the Biocapping project will be observed over the 5 years. During this period, no projects shall be carried out upon the remediated dumpsite area. The table illustrating this increment (considering 5% increment for each year) in the Operational & Maintenance of Closure of 60 acre land including 300 KLD capacity of Leachate Treatment Plant is given below:

Table 7.17: O&M Cost for Closure & Containment of Biocapped Dumpsite (for 5 years)

O&M Cost for Closure & Containment of Biocapped Dumpsite (for 5 years)			
Years	**O&M Cost (Bioremediation)**	**O&M Cost (300 KLD LTP)**	**Amount (in INR)**
Year I	7818804.00	5957151.00	27551910.00
Year II	8209744.20	6255008.55	28929505.50
Year III	8620231.41	6567758.98	30375980.78
Year IV	9051242.98	6896146.93	31894779.81

Year V	9503805.13	7240954.27	33489518.80
Net Amount	43203827.72	32917019.73	152241694.89

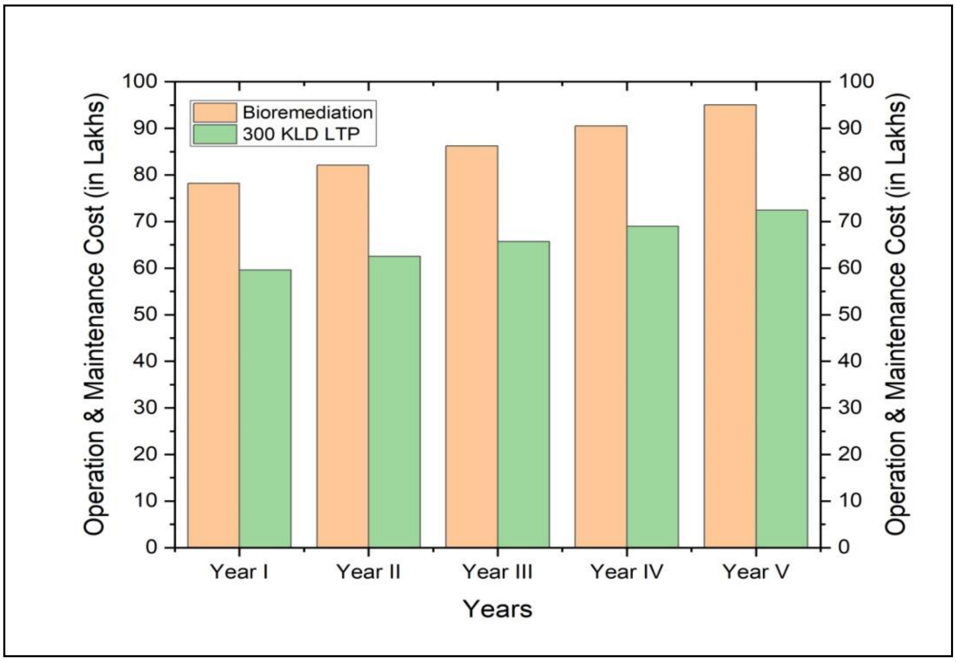

Fig 7.8: O&M Cost for Closure & Containment of Biocapped Dumpsite

7.3.14 Outline regarding the estimated Revenue Generation from the Biocapped Landfill

The plantation of the re-cultivation layer with the aim of energy recovery from green biomass can take place with the help of grass mowing. The mowing of grass or plantation of the re-cultivation layer is considered to the main source of biomass. The silage from the grasses can be used as the co-substrate along with organic waste and sewage sludge in a biogas plant, where it is converted together with the basic substrate into biogas through fermentation by bacteria. The resulting biogas can be used for energy needs (co-generation). Grass silage provides a biogas yield from 170 to 200m^3/ton of fresh mass. The calorific value of biogas is given as 21.6 mJ/m^3. Therefore, from 1 ton of Fresh Mass, approximately (3.7-4.2) GJ of energy can be obtained. Residual materials with high water content are particularly suitable for biochemical conversion. In the process, biomass is degraded with participation of microorganisms. Degradation can occur anaerobically and aerobically, sometimes alcoholic fermentation can also be observed. Thus, the Biogas generated can be converted either to energy, using for heat generation or used for the operation of gas-powered vehicles.

Estimated Yearly Earnings from a Bio-gas Plant:

- Inserted amount of substrate = 130m^3/day;
- Land required = 1,000 sq.m;
- Amount of energy can be produced = 7000 kWh/day;
- Assuming an input fund = Rs. 2.5/kWh;

- Estimated daily earning for electricity input = Rs. (7000*2.5)/day = Rs. 17,500/day
- Energy can be produced yearly = (7000*365) kWh/yr. = 2555000 kWh/yr.
- Est. Yearly Earning for electricity input = Rs. (17,500*365)/yr. = Rs. 6387500/yr.
- Est. Total earning from electricity input = Rs. (6387500*5) = Rs. 31937500

7.4 COST ANALYSIS OF BIOMINING OF LEGACY WASTE

Reports has said that Biomining is an expensive process and the Government ends up paying a fee for processing every ton of legacy waste mined, stabilized and processed. The company appointed for landfill mining projects is short-listed after verification of technical and financial bids and ensuring land recovery at the maximum possible extent, aimed at getting a relatively flat land after biomining (Datta et al., 2022). The projects are mainly based on Design and Build basis. The agency is selected after reviewing their submitted management plans for dumpsite land reclaimation, excavation, screening and resource recovery, biomining of unprocessed municipal solid waste and development of facility for scientific disposal of residual waste. Government registered private organizations are involved in the process of biomining and remediation of solid waste.

Based on the characteristics of the individual fractions separated from the legacy waste, the valorisation options were assessed. The benefits of the landfill mining activities are associated with the recovered materials and landfill air space. The process of recyclables are influenced by the fluctuations in the market prices, the structure of the local market, as well as other parameters like the like the quantity of materials sold and the distance between the landfill and the recycling industry (Datta et al., 2023). The possibility of using the fine fraction of waste in the building and construction industry, road repairing, and soil nutrient, however, requires further study. Legislative gaps, dubious viability, leaching risks, and challenging geotechnical properties are issue that will be required to be resolved in the future.

With respect to India, the valorisation study of legacy waste is not so important since in India, legacy waste is mostly composed of soil-like materials and the percentage is around (40-70)%. Thus it is difficult to calculate the direct cost of legacy waste rather than the indirect cost. To study the application of Biomining remediation method for legacy waste reclaimation, Nagpur model was adopted by the West Bengal government for a period of time (Datta et al., 2023). Bir et al., (2022) suggested some revenue generation options for the Kolkata landfill that include compost products, anaerobic digester, power generation, and recycling products which will enhance the economy to meet the sustainable circularity solution. At Dhapa dumpsite of Kolkata, total amount of legacy waste is around 40 lakh MT (Banerjee et al., 2022).

7.4.1 Collection of Samples & Experiments followed for Waste Characterization

Waste samples are collected from different locations at different heights of the legacy dumpsite in order to identify the preliminary characteristics of the legacy waste for further processing and thermo-chemical processes (Kieckhäfer et al., 2017). Waste samples are given for testing after separation by screening them through different screen sized trommels.

Different characterization tests done for solid waste collected from open dumpsite are Calorific value, C/N ratio, Density, Moisture content, Total organic carbon etc. Calorific value is the amount of energy in a fuel or food that can be measured by measuring the amount of heat that is created once a specific amount of it is completely burned. It is often represented in Joules per kg. The content of the legacy wastes affects the calorific value of the waste. Waste that contains more PVC does have a greater calorific value than waste that contain more paper and less PVC. The C/N ratio refers to the mass proportion of Carbon to Nitrogen components in organic remnants is another important factor since for Bioremediation of mined legacy wastes, a proper mix of Carbon and Nitrogen is essential to activate the Bacteria. Besides, as moisture content will directly affect the density as well as the treatment processes, it is important to find out the moisture content of the legacy waste.

7.4.2 Processing of Dry Stabilized Legacy Waste

The responsible agency is expected to install plant and machinery of required capacity for bio-mining of the existing legacy solid waste and subsequently reclaim the land. Broadly, the Project involves the reduction or removal of the unprocessed legacy mixed waste and land reclaimation through biomining as per guidelines for disposal of legacy waste by CPCB, advisory on landfill reclaimation by CPHEEO and SWM Rules, 2016 but it is not limited to excavating compacted mixed solid waste which underwent biological degradation, by using bio-culture and suitable mechanical sieving machine or any other equipment and taking all the materials excavated in the assigned land area and retrieving recoverable materials and segregating, sorting, selling, storing, and diverting for recycling the excavated materials and final disposal of inert and or hazardous material if any.

The operator shall survey thoroughly to determine the area of dumpsite, quantity of legacy waste, characterization of legacy waste to finalize the process flow chart and shall be approved by the EIC prior to start of execution. The operator shall submit detailed process design of processing units to be installed at site. Number of units (Trommel/Vibrating Screen etc.) shall be designed based on quantity of waste to be processed, capacity of each unit and completion period. Rainy season (4 months) shall be deducted from completion period while determining number of processing units to be installed at site (Datta et al., 2022). Removal of legacy waste through biomining process within the completion period and disposing the materials retrieved from the legacy waste to the end users or vendors has to be done without stocking them at site for not more than 60 days, including the cost of electrical consumption, manpower, machineries etc.

7.4.3 Observation and Result from Waste Characterization Experiments

Upon analyzing the samples collected from different sampling location through both physical and chemical waste characterization experiments, a rough estimate of different fraction of components are found which are as follows:

Table 7.18: Expected Fraction Range of Different Biomining Components

Expected Fraction Range of Different Biomining Components	
Name of the Waste Fraction generated	**Expected Fraction (in %)**
Non-combustible (C&D & inorg. Coarser fraction)	(25-30)%
Recyclables	(1-2)%
Compostable (Bio-earth & Org. Coarser fraction)	(15-20)%
Combustible (Refused Derived Fuel)	(10-15)%
Inert (Process Reject)	(5-10)%
Moisture content (15%)	(15-25)%

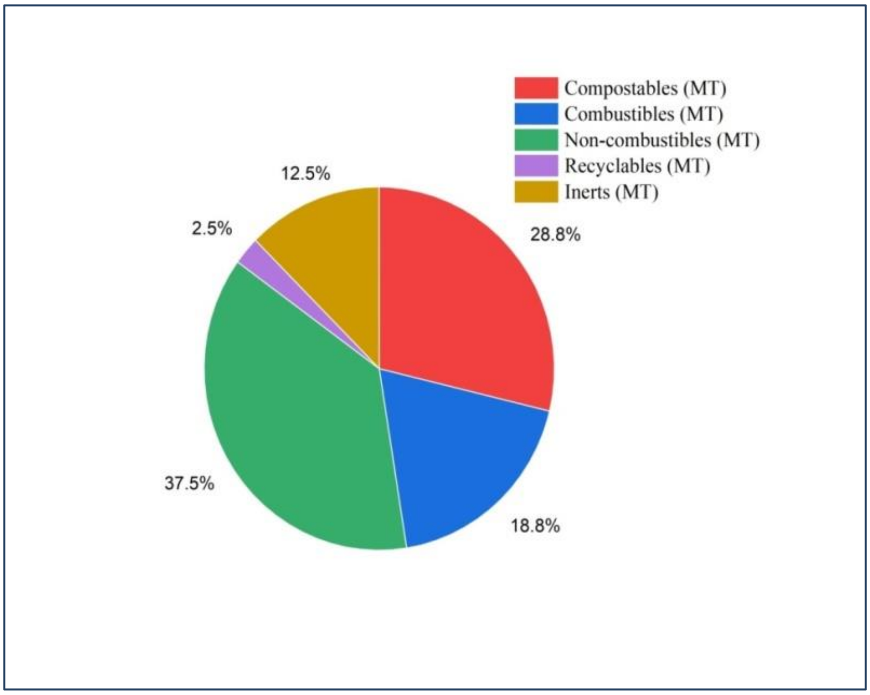

Fig 7.9: Fractions of Biomining Components per MT

From the preliminary characterization of waste samples collected, it has been observed that the calorific value of the samples collected is in the range of (700-750) Kcal/kg. The C/N ratio & Density (kg/m³) is in the desired range. According to SWM rules 2016, it is not recommended to send non-recyclable solid waste with a calorific value of 1500 Kcal/kg or more, but it can be used for waste-to-energy facilities. However, it has been found that the calorific value of the collected samples is less than that and thus safe. For optimum digestion, the C/N ratio should be in the range of (30-50). As the moisture content is high, it is difficult to process waste immediately, thus it is required to adopt the techniques for drying like sun-drying. As the biomining project of the total study area i.e. Dhapa Dumpsite consists mainly of net quantity of 40 lakh MT of legacy waste and the total tenure of the project has been decided to be around 3 years. So, the entire budget of the Biomining project of 200 Crores has also been divided proportionately within the 3 years (Datta et al., 2022).

The Kolkata Municipal Corporations has decided to break the total waste consecutively into 3 proportions which will act as the target to be met for the respective year. As suggested by Banerjee et al. (2023), Revenue Rate or the Economic Potential of the mentioned Biomining components and the market prices of the total area, Bio-mining fee and the project cost for the entire biomining project have been adopted.

7.4.4 Cost Analysis of Biomining Project of Legacy Dumpsite

Table 7.19: Target Waste Amount to be processed & Yearly Recoverable Land area

Year	Zone Name	Yearly Target Quantity (MT)	Yearly Excavated Waste (MT)
Year I	Mount A	900,000	354501.60
Year II	Mount B	1300,000	502758.09
Year III	Mount C	1800,000	3142740.31
	Total	4000,000	4000000

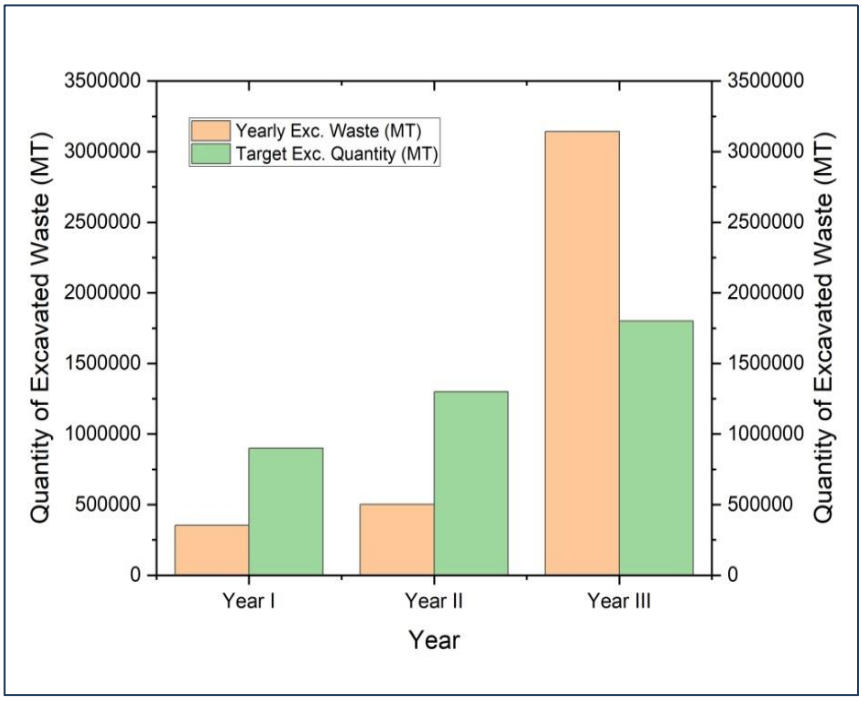

Fig 7.10: Quantities of Legacy Waste excavated vs. Target per year (MT)

Table 7.20: Expected Amount of Different Wastes generated per year

Expected Amount of Different Wastes generated per year			
Item Name	**Year-I (MT)**	**Year-II (MT)**	**Year-III (MT)**
Yearly Exc. Waste (MT)	354501.60	502758.09	3142740.31
Compostable (MT)	70900.32	100551.62	628548.06

Combustible (MT)	53175.24	75413.71	471411.05
Non-combustible (MT)	106350.48	150827.43	942822.09
Recyclable (MT)	7090.03	10055.16	62854.81
Process Reject (MT)	35450.16	50275.81	314274.03
Moisture Content (MT)	81535.37	115634.36	722830.27

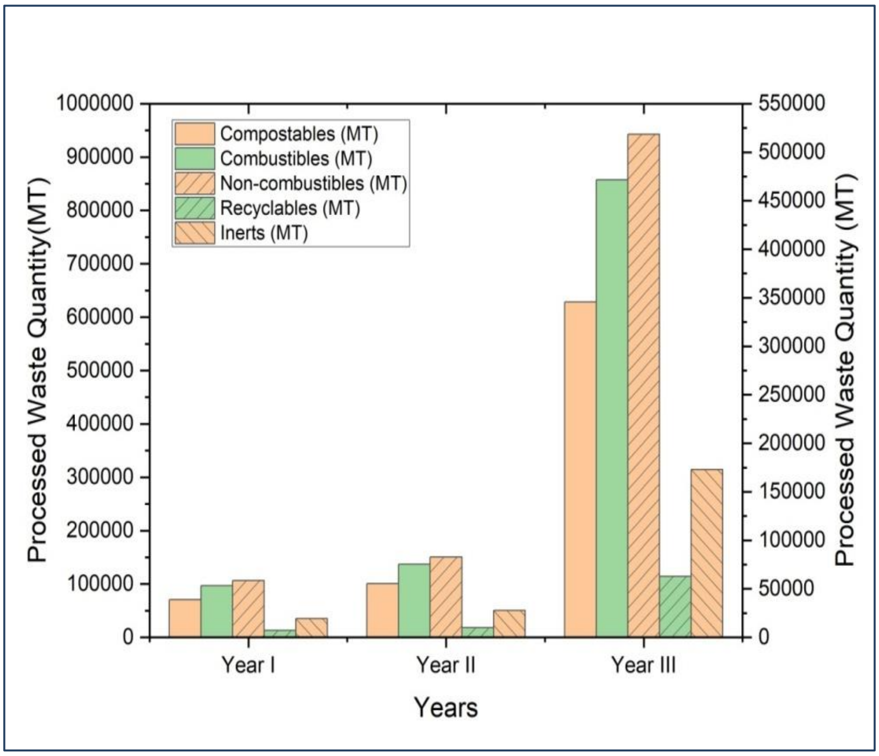

Fig 7.11: Quantities of Biomining Components retrieved per year (MT)

Table 7.21: Expected Number of Working Machineries and Vehicles per day

Amount of Machineries	**Project Year - I**	**Project Year – II**	**Project Year - III**
Yearly Excavated Quantity (MT)	354501.60	502758.09	3142740.31
Daily Excavated Quantity (MT)	1418.00	2011.03	12570.96
Number of Working Machineries and Vehicles per day			
Trommels (500 MT/)	3	4	10
Ballistics (1000 MT)	2	3	8
Excavators	2	3	21
Dumpers	102	144	898

[**Note**: Considering total numbers of working days per project year (say) = 250 days since considering the Indian seasons, 3 months of the year has been considered to be monsoon season and at that time working in the dumpsite is problematic one. Beside the considering the monsoon season, the government holidays and holidays have been considered]

Table 7.22: Total Capital Cost of Biomining Project for 3 years

Total Capital Cost of Biomining Project (Land - 60 Acre)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Cost of excavation, loading, unloading, weighing, storage	180.00	4000000	720000000
2	Processing cost by mechanical means	320.00	4000000	1280000000
3	Processing cost by manual means & other manpower	100.00	4000000	400000000
4	Statutory clearance cost	1.00	4000000	4000000
5	Leachate treatment cost	9.02	4000000	36080000
6	Environmental monitoring system cost	2.00	4000000	8000000
7	Fire-fighting system cost	2.00	4000000	8000000
8	Miscellaneous cost including contingency	54.00	4000000	216000000
Net Capital Cost (in Rs.)				2672080000

Table 7.23: Total Operational Cost for Biomining & Processing (Project Year – I)

Total Operational Cost for Biomining & Processing (Project Year - I)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Non-combustible material operational cost	49.45	106350.48	5259031.24
2	Recyclable material operational cost	0.21	7090.03	1488.91
3	RDF & Combustible material operational cost	23.54	53175.24	1251745.15
4	Inert operational cost	12.96	35450.16	459434.07
5	Compostable material operational cost	103.67	81535.37	8452771.81
Net Operational Cost for Processing Waste Fractions (in Rs.)				15424471.17

Table 7.24: Net Revenue generated (Project Year – I)

Net Revenue generated from Recovered Materials (Project Year - I)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Revenue from compost product	156.25	81535.37	12739901.56
2	Revenue from combustible materials	349.00	53175.24	18558158.76
3	Revenue from Non-combustible materials	1000.00	106350.48	106350480.00
4	Revenue from recyclable materials	5.24	7090.03	37151.76
Net Revenue generated from Recovered Materials				137685692.08

Table 7.25: Total Operational Cost for Biomining & Processing (Project Year – II)

Total Operational Cost for Biomining & Processing (Project Year - II)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Non-combustible material operational cost	49.45	150827.43	7458416.41
2	Recyclable material operational cost	0.21	10055.16	2111.58
3	RDF & Combustible material operational cost	23.54	75413.71	1775238.73
4	Inert operational cost	12.96	50275.81	651574.50
5	Compostable material operational cost	103.67	115634.36	11987814.10
Net Operational Cost for Processing Waste Fractions (in Rs.)				21875155.33

[**Notes**: In the Project Years I, II, & III, Operation hours for machineries and equipments are considered to be 8 hours per day. However, owing to meet the deadline of the completion of the desired biomining project the operation hours or the working period can vary.]

Table 7.26: Net Revenue generated (Project Year - II)

Net Revenue generated from Recovered Materials (Project Year - II)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Revenue from compost product	156.25	115364.36	18025681.25
2	Revenue from combustible materials	349.00	75413.71	26319384.79
3	Revenue from Non-combustible materials	1000.00	150827.43	150827430.00
4	Revenue from recyclable materials	5.24	10055.16	52689.04
Net Revenue generated from Recovered Materials				195225185.08

Table 7.27: Total Operational Cost for Biomining & Processing (Project Year – III)

Total Operational Cost for Biomining & Processing (Project Year - III)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Non-combustible material operational cost	49.45	942822.09	46622552.35
2	Recyclable material operational cost	0.21	62854.81	13199.51
3	RDF & Combustible material operational cost	23.54	471411.05	11097016.12
4	Inert operational cost	12.96	314274.03	4072991.43
5	Compostable material operational cost	103.67	628548.06	65161577.38
Net Operational Cost for Processing Waste Fractions (in Rs.)				126967336.8

Table 7.28: Net Revenue generated (Project Year III)

Net Revenue Collected from Recovered Materials (Project Year - III)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Revenue from compost product	156.25	628548.06	98210634.38
2	Revenue from combustible materials	349.00	471411.05	164522456.45
3	Revenue from Non-combustible materials	1000.00	942822.09	942822090.00
4	Revenue from recyclable materials	5.24	62854.81	329359.20
Net Revenue generated from Recovered Materials				1205884540.03

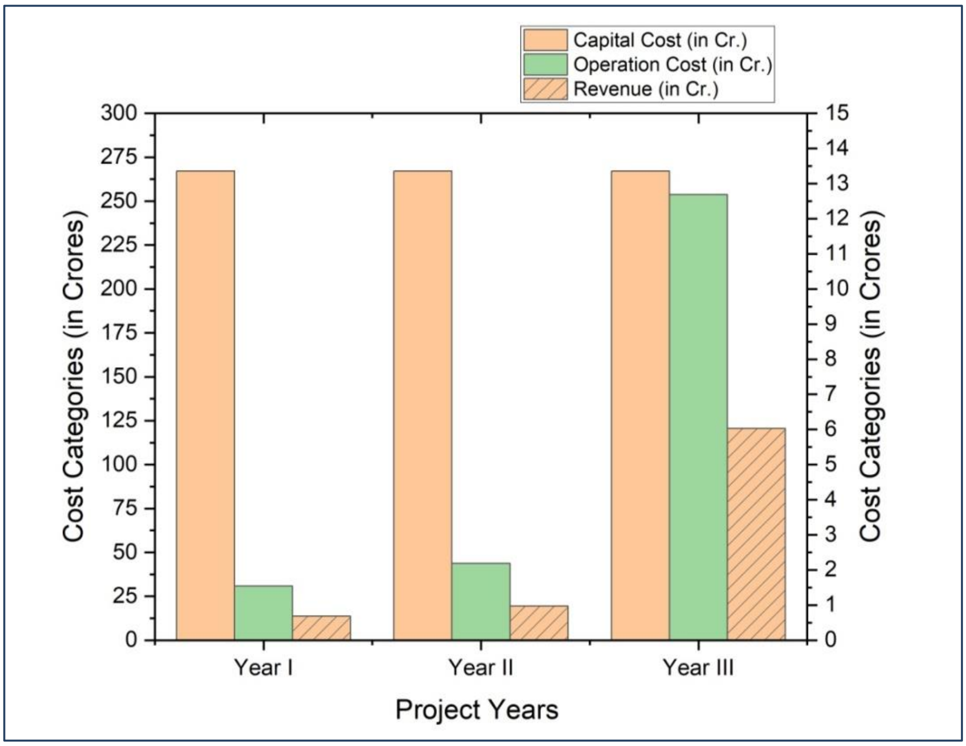

Fig 7.12: Different Cost Categories for Biomining Project (3 years)

Table 7.29: Net Excavated Waste Quantity & Land Recovered (per year)

Year	Desired Land to be recovered (Acre)	Recovered Land (Acre)
Year I	13.5 acre	5.32
Year II	19.5 acre	7.54
Year III	27.0 acre	47.14
Net Amount	60.0 acre	60.00

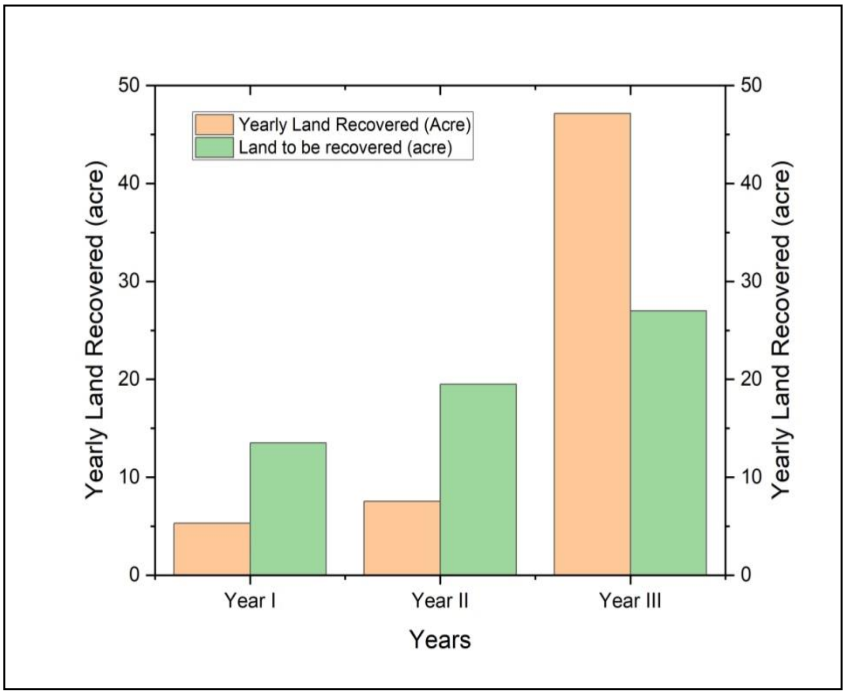

Fig 7.13: Acres of Land recovered vs. Land to be recovered (per year)

7.5 OBSERVATION & INFERENCES FROM THE COST ANALYSIS OF BIOMINING AND BIOCAPPING OF THE LEGACY DUMPSITE

Upon analysing the Environmental Impact Assessment data due to the Biocapping project, it has been observed that during the construction phases, all the 5 considered options are assumed equal related to emission of gases, dust, noises etc. The main impact on air of surrounding regions will occur during excavation, transport, sorting, and re-disposal of waste and as the amount of waste to be excavated is the same for all 5 considered options, so this is not qualified. In case of soil, the pollution of soil from leachate flowing horizontally from the upper reservoir towards the surroundings will continue but at a reduced rates for options 2 & 3, while it will be eliminated for remedial options 4 and 5. Soil below the dumpsite will continue to be contaminated by leachate for all remediation options. The downward gradient will be lowest for remediation option 5 and highest for remediation option 2. In case of surface water run-off, the control and protection of receiving surface water bodies around Dhapa dumpsite are identical for all remediation options. However, there is a risk for seepage of leachate out from slope for remediation option 2 and remediation option 3 are assumed low and not included in comparison of the options.

In case of groundwater, for the upper aquifer, a continuing amount of leachate will flow from the dumpsite in the upper fill and silt layers for remediation option 2 and option 3 but will be prevented for remediation option 4 and option 5. As downward gradient to the primary aquifer is assumed more critical than contamination of the upper groundwater reservoir, only 10% of the flow to upper groundwater reservoir is included in the "Total Flow". The amount is however uncertain but total contamination of the groundwater is assumed to be similar as for option 4. During monitoring, aftercare and maintenance, operation and maintenance of pumps, pipes ponds and wells for active gas collection (Option 3.2) and for leachate treatment plant (Option 5) has to be considered. In option 3.1 and in option 5, a controlled passive methane oxidation system is proposed.

In case of Biocapping, from the rough estimate, it has been found that the total cost for the closure and containment for 30 acre land is nearly Rs. 50 crores. Therefore, it can be said that the total cost for closure and containment for 60 acres of land is about Rs. 100 crores. The operation and maintenance cost for the bioremediation project is Rs. 78 lakhs per year whereas the operation and maintenance cost for 300 KLD leachate treatment plant is Rs. 59.57 lakhs per annum. So, a rough estimate illustrating the increment in the operational and maintenance cost of the closure of 60 acres land including 300 KLD capacity of leachate treatment plant for over 5 years has been shown in Table 7.6 respectively. To cope up with the operation and maintenance cost for 5 years including the project cost, the biogas generated from the remediation project can either be used for heat generation or can be converted to electrical energy. The estimated yearly earning from a biogas plant with substrate input rate of $130m^3$/day has been around Rs. 3.5 crores (7.3.13). Besides this, the land recovered from the biocapping cannot be used immediately after the remediation has been done and the quantity of the recovered land is nearly 25% of the total estimated consumed area. The revenue which can be generated from the recovered land is possible only when the desired land will be announced to be suitable for using in other purposes.

In case of Biomining, a detailed survey has been performed and the entire volume of 40 lakh metric tons of legacy waste has been divided into 3 consecutive legacy waste mounts (Mount A; Mount B; & Mount C) and the respective area consumed by each mount, shown in Table 7.19. On the basis of the report collected from Kolkata Municipal Corporation till now, an estimate regarding the daily use of the vehicles and instruments has been done which has been shown in Table 7.21. In Table 7.22, the capital cost of the entire biomining project of 3 years has been estimated. The operational cost and revenue generated from the selling of raw materials for the project year I have been shown in Table 7.24. On the basis of collected data from Kolkata Municipal Corporation, a study of the amount of the disposed legacy waste along with the recovered land for over 3 years has been calculated and is shown in Table 7.19 and 7.22 respectively. In case of biomining, the total area of the waste consumed land can be reclaimed and the recovered land can be reused for the preferred purposes immediately after the remediation. Thus, the revenue which can be generated from the recovered land is considerably much more than revenue from Biocapping.

However, certain factors or parameters have been pointed on the basis of which engineering and economic feasibility of these two most preferred landfill remediation measures can be evaluated which are as follows:

- ❖ **Cost Effectiveness**: Biocapping is more cost-effective than Biomining process. Reports has said that Biomining is an expensive process and the Government ends up paying a fee for processing every ton of legacy waste mined, stabilized and processed.
- ❖ **Environmental Impact**: Biocapping has a lower environmental impact than Biomining since the main purpose of biocapping is to isolate the contaminants in the

place to avoid the spread of contamination by restricting them from coming in contact with the natural environment whereas in Biomining process the dumped waste is dug up after loosening by drying the waste under sun resulting in high level of contamination owing to the presence of unpredictable material that would come out of the legacy dumpsite so the environmental impact is also high.

- **Timeframe**: Biocapping takes less time to complete than Biomining since in Biomining process, excavation, material sorting, transport, recovery/treatment plants and plant operations and maintenance will consumes a huge amount of time whereas on the other hand in Biocapping, no such processes are involved.
- **Effectiveness**: Biomining is more effective in managing legacy waste than Biocapping since in Biomining process; the legacy waste is dug up and then is loosened by drying under the sun and then processing the wastes to recover valuable recyclable scrap while also recovering the landfill space with prime objective upon soil recovery including the recyclable materials.
- **Scalability**: Biomining is more scalable for larger areas or projects than Biocapping since through Biomining process, recovery of the entire base area of the dumpsite upto its ground level is possible whereas in Biocapping, only 25 percent of the entire base area can be used which might be located at an inconvenient height.
- **Maintenance Requirements**: Biocapping requires less maintenance than Biomining.
- **Technological Requirements**: Biomining requires more advanced technology than Biocapping.
- **Waste Reduction**: Biomining leads to greater waste reduction than Biocapping.
- **Long-term Sustainability**: Biomining offers more long-term sustainability benefits than Biocapping since considering the Indian pretext, through Biomining process the additional cost of setting up a new dumpsite was saved, as the existing site could be used five times in a period of 50 years assuming dumpsite mining to be carried out once in every 10 years.

CHAPTER VIII: CONCLUSION

Population expansion and rapid urbanization in India have led to larger cities and increased municipal solid waste generation. Moreover, improper waste management due to financial, technological, social and other constraints has landed most of these wastes in open dumpsites (Greedy, 2016). Around 79% of collected waste ends up in dumpsites, and there are more than 1000 reported dumpsites in India (CSO, 2018). The old dumpsites have various problems like leachate percolation to groundwater and release of harmful gases, which can lead to health issues in the nearby inhabitants and, moreover, can be harmful to the nearby ecosystem. In addition, landfill fire and slope failure are becoming common issues in dumpsites (Singh and Chandel, 2020). Various alternatives are being studied for the recovery of secondary resources from these sites. One of them is landfill mining or Biomining of legacy dumpsite, which includes the recovery of buried resources from a landfill with upgrading of existing landfill to mitigate the environmental problems (Hogland et al., 2004; Kurian et al., 2003). Researches have shown that biomining will not only reclaim the landfill space but also will provide an opportunity to remediate prevailing human health problems and environmental issues accompanied with the existing or closed landfills otherwise that would cause surface water and groundwater pollution and climate change. In Asian cities like Kolkata, Biomining concepts are becoming the popular MSWM concept adopted to reclaim the old landfills.

From the intensive literature review, it has been observed that soil-like material is the largest product obtained from landfill mining and its reuse is one of the major factors to justify the economic viability of mining projects. Soil-like materials is observed to be usually 40-80% of the total materials mined from the landfills (Somani et al., 2018; Rong et al., 2017). To assess the relationship and difference among the analysed physicochemical, heavy metals and leachate characteristics of the soil-like materials with respect to the variation of waste depth and seasons, descriptive statistical methods like Correlation Matrix and Analysis of Variance have been used. Through the correlation matrix, the pairwise relationships between the analysed parameters like calcium% and organic matter% have been studied. The strength and direction of linear relationships between these two analysed parameters have been depicted on the basis of their correlation coefficient. From the correlation matrix, it has been observed that the correlation value between these two analysed parameters is +0.756 which means they are highly correlated and directly proportional to each other. It means that if one of the considered parameters increases then the other parameters will also increases. On the other hand, 1-way ANOVA have been used in order to examine the main effects of categorical variables like waste depths, seasons etc., on the continuous variable like organic matter%. Through 1-way ANOVA analysis, the differences in the mean values of the organic matters% have been evaluated (3.24 ± 1.47) and then will be compared with standard range (3-6) % to get a proper inference.

The heavy metal characteristics and the leachate characteristics have also been studied in the same manner by using the two above mentioned statistical descriptive methods. Through the correlation matrix, the pairwise relationships between the analysed parameters like manganese (mg/kg) and lead (mg/kg) have been studied. The strength and direction of linear relationships between these two analysed parameters have been depicted on the basis of their correlation coefficient. In case of heavy metals characteristics, from the correlation matrix, it has been observed that the correlation value between these two analysed parameters is +0.898 which means they are highly correlated and directly proportional to each other. It means that if one of the considered parameters increases then the other parameters will also increases. On the other hand, in case of leachate characteristics, 1-way ANOVA have been used in order to examine the main effects of categorical variables like waste depths, seasons etc., on the continuous variable like manganese (mg/kg). Through 1-way ANOVA analysis, the differences in the mean values of the nickel (mg/l) have been evaluated (0.60 ± 0.45) and then will be compared with standard range (0.23-0.77) to get a proper inference.

Economic feasibility and social justification are crucial aspects of making decisions regarding the landfill remediation projects over conversion of open landfill considering the cost associated with the closure and post closure management. There has been a fundamental dilemma that the economic incentive will not be adequate for private landfill mining operators, despite the social or public benefits of landfill mining being extraordinarily high. Therefore, proper economic feasibility analysis is essential for checking the sustainability of the project. Biomining and Biocapping are the two options of bioremediation techniques. By conducting a cost comparison, stakeholders can make informed decisions, optimize resources and ensure this sustainability of legacy waste management project.

Cost comparison is required (i) to determine the cost effective approach for legacy waste management, ensuring optimal use of resources, (ii) to establish a realistic budget for the project considering the cost of different approaches, (iii) to inform decision makers about the financial implications of different options, enabling him to make informed choices, (iv) to prioritise projects or activities based on their cost effectiveness and potential impact, (v) to evaluate the financial performance of different approaches and identify areas for improvement, (vi) to compare costs with industry standards, benchmarks, or other similar projects (vii) to identify opportunities for cost reduction or optimization without compromising environmental or social benefits, (viii) to communicate costs and benefits to stakeholders, ensuring transparency and accountability, (ix) to identify and mitigate potential costs related risks associated with different approaches, (x) to ensure that the chosen approach is sustainable in the long term considering both environmental and financial aspects.

From the environmental aspects as well, the Biomining measures is considered to be much more superior to Biocapping measure. The analysis of the physical characteristics, chemical analysis, and leachate characteristics can be related to biocapping in the following ways:

- Physicochemical characteristics: The particle size distribution, specific gravity, bulk density, and porosity of the coarser fraction of soil-like material can affect the biocapping process. For example, a higher bulk density may reduce the permeability of the biocap, while a higher porosity may increase the risk of leachate migration. The pH, electrical conductivity, organic matter content, and nutrient content can influence the biocapping process. For example , a high organic matter, content may support, microbial growth, while a high EC may indicate the presence of contaminants that can affect biocap performance.

- Heavy Metal and Leachate Characteristics: The concentration of heavy metals (Cd, Cr, Cu, Pb, Zn) can impact the biocapping process whereas the leachate characteristics can indicate the potential for contaminant migration and effect the biocap performance. For example, high concentrations of heavy metals may inhibit microbial growth or affect the stability of the biocap.

Biocapping is a remediation technology that involves covering contaminated soil or waste with a biologically active cap to contain and degrade contaminants. The analysis of physical, chemical, and heavy metal characteristics can inform the design and implementation of biocapping systems, for legacy waste biomining. For example:

- Selecting appropriate biocap materials, based on physical and chemical characteristics.
- Designing biocap systems, to manage heavy metal contamination.
- Monitoring leachate characteristics to assess biocap performances.

The correlation matrices and ANOVA model can help identify relationships, between these characteristics and inform strategies for optimizing biocapping systems.

In case of Biocapping, from the rough estimate, it has been found that the total cost for the closure and containment for 30 acre land is nearly Rs. 50 crores. Therefore, it can be said that the total cost for closure and containment for 60 acres of land is about Rs. 100 crores. The operation and maintenance cost for the bioremediation project is Rs. 78 lakhs per year whereas the operation and maintenance cost for 300 KLD leachate treatment plant is Rs. 59.57 lakhs per annum. So, a rough estimate illustrating the increment in the operational and maintenance cost of the closure of 60 acres land including 300 KLD capacity of leachate treatment plant for over 5 years has been shown in Table 7.6 respectively. To cope up with the operation and maintenance cost for 5 years including the project cost, the biogas generated from the remediation project can either be used for heat generation or can be converted to electrical energy. The estimated yearly earning from a biogas plant with substrate input rate of $130m^3$/day has been around Rs. 3.5 crores (7.3.13). Besides this, the land recovered from the biocapping cannot be used immediately after the remediation has been done and the quantity of the recovered land is nearly 25% of the total estimated consumed area. The revenue which can be generated from the recovered land is possible only when the desired land will be announced to be suitable for using in other purposes.

In case of Biomining, a detailed survey has been performed and the entire volume of 40 lakh metric tons of legacy waste has been divided into 3 consecutive legacy waste mounts (Mount A; Mount B; & Mount C) and the respective area consumed by each mount, shown in Table 7.19. On the basis of the report collected from Kolkata Municipal Corporation till now, an estimate regarding the daily use of the vehicles and instruments has been done which has been shown in Table 7.21. In Table 7.22, the capital cost of the entire biomining project of 3 years has been estimated. The operational cost and revenue generated from the selling of raw materials for the project year I have been shown in Table 7.24. On the basis of collected data from Kolkata Municipal Corporation, a study of the amount of the disposed legacy waste along with the recovered land for over 3 years has been calculated and is shown in Table 7.19 and 7.22 respectively. In case of biomining, the total area of the waste consumed land can be reclaimed and the recovered land can be reused for the preferred purposes immediately after the remediation. Thus, the revenue which can be generated from the recovered land is considerably much more than revenue from Biocapping.

The comparative cost analysis of biomining and biocapping for legacy waste management reveals (i) biomining is more cost effective approach with a total cost of Rs. 260 crores compared to biocapping which costs Rs. 115 Crores including the 5 years operation and maintenance cost (ii) Biomining offers significant saving of Rs. 1800 Crores due to the recovery of valuable resources and reduced landfill costs, along with the cost of land recovered after biomining (iii) biocapping, while more expensive, provides a higher level of environmental protection & safety.

FUTURE SCOPE OF WORK

The future scope of work may be as follows:

1. In this project work, only the environmental feasibility of the coarser fraction of soil-like materials have been studied, but the geotechnical feasibility of the coarser soil-like materials can be studied.
2. In this project work, cost Analysis and comparison between the two different landfill remediation measures have been done on the same dumpsite. However, the cost analysis and comparison of the landfill remediation measures with respect to different dumpsites can also be studied.
3. Socio-economic impact of the Biomining operation upon the neighbouring areas of the legacy dumpsites can also studied.
4. Carbon Footprint Analysis of the Biomining Project of a single dumpsite or two different dumpsites can also be studied.
5. Unlike this project work, the variation or comparison between characteristics properties of soil-like materials of two or more dumpsites can be studied.

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ANNEXURE

Annexure I: Detailed Estimation for Biocapping of 100 Acre Land

Remediation/Closure & Containment of Existing Dumpsite (Land - 30 Acre)		
Sr. No.	**Description**	**Amount (in INR)**
1	Part 1: Construction of Peripheral Leachate Collection System	11948803
2	**Part 2: Profiling & Reshaping of Dumpsite**	**97398655**
3	Part 3: Installation of Erosion Protection Layer & Waste Cover Layers over the reshaped Dumpsite	289022473
4	**Part 4: Construction of Surface Water Drainage System, Passive Gas Collection System & Leachate Collection Wells**	**33587461**
5	Part 5: Construction of Service Road, Footpath, Access Road & Steel fence over landfill site	19011460
6	Part 6: Providing Vegetative Cover with Horticulture over the cover layers along with irrigation system	32079172
7	Part 7: Construction of Monitoring Well, Site clearance & Handling over including submission of As. Built Drawings	2038706
A	Construction Costs for Closure & Capping of Landfill Site	485086730
B	Total Capital Costs of Containment & Closure	485086730
	Project Contingencies – 3%	14552602
C	Total Cost for Closure & Containment of 30 Acre of Dumpsite	499639332
Net Amount (Say)(In INR)		50 Cr.
Therefore, Total Capital Cost for 60 acre of Dumpsite (Say) is		999278663.8
	Net Amount (Say) (in INR)	100 Cr.

Table 1A: Remediation/Closure & Containment of Existing Dumpsite

Stage II: For Profiling/Reshaping of Dumpsite

Item Description: Excavation (upto ground level on the north side of landfill site as per future layout) and removal of MSW along the north boundary of the dumpsite and also all along the outside of the boundary wall wherever observed. Transportation & Relocation of MSW on the top/side slopes of the dumpsite wherever necessary within a lead of 1km and lift upto 25m, levelling and compacting the area in layers of 500mm thick by deploying suitable machineries. The rate analysis shall include all labour & manpower, material, plant & machinery.

Calculation of Item Quantity& Estimated Cost:

Redisposal of non-recyclable waste at dumpsite = 6250m^3

Estimated Item Quantity = 7983.74 cu.m

Market Rate of this Item per cu.m (as per Rate Analysis) = Rs. 294.30/cu.m

Estimated Cost for this item is = (7984.74 cu.m * Rs. 294.30/cu.m) = Rs. 2349615

Item Description: Profiling of wastes - Levelling and Reformation of Slopes along the area of landfill site by excavation and relocating the MSW and filling of the low areas by shifting MSW and achieving level as per future layout of landfill, formation of berms, side slopes achieving total height of the dumpsite to around +35m above the ASL. Relocating the MSW from areas adjoin to the footprint on the top of landfill/side slopes to be maintained as 1V to 3H (on the north side) and 1V to 2.5H (on south side). All the activities will be carried out within a lead of 750m along with levelling and compacting in layers of 300mm thick by deploying suitable plant and machineries, dumper trucks, excavators, front end loaders etc. The compaction of the area will be carried out using (spiked/special wheels) steel wheeled mobile landfill compactors (on all side slopes (1:2.5 & 1:3) and flat surfaces) to the satisfaction of engineer-in-charge.

Calculation of Item Quantity& Estimated Cost:

Excavation of waste & re-disposal on site = 200000 m^3

Transport and Storing of Inert (8-50 mm) = 46450 m^3

Re-disposal of non-recyclable waste at dumpsite = 6350 m^3

Total Estimated Quantity of Item = (200000 + 46450 + 6350) = 252800 m^3

Estimated Item Quantity = 252800 m^3

Market Rate of this Item per cu.m (as per Rate Analysis) = Rs. 294.30/cu.m

Estimated Cost for this item is = (252800 m^3 * Rs. 294.30/m^3) = Rs. 74399040

Item Description: Identification & Segregation of Asbestos in the dumpsite to be removed and re-disposed in accordance to Hazardous Waste (Management, Handling and Trans-boundary Movement) Rules, 2008; the item shall include disposal charges to TSDF, all labour, materials, and manpower, equipments & transportation to the TSDF facility for hazardous waste site at Haldia, fuel & incidental charges, operation charges of equipments etc. as directed by engineer-in-charge.

Calculation of Item Quantity& Estimated Cost:

Estimated Item Quantity = 500 ton

Market Rate of this Item per tons (considered based on existing disposal arrangements at existing operating site at Dhapa) is = Rs. 1100/ton

Estimated Cost for this Item is = (500 ton * Rs. 1100/ton) = Rs. 550000

Item Description: Excavation of surplus waste above +35m level from the dumpsite (as per layout of closure contours) loaded, transported, and disposed to the active dumpsite from the closed dumpsites as directed by engineer-in-charge. The item shall include all labour & manpower, materials, equipments & machinery.

Calculation of Item Quantity & Estimated Cost:

Estimated Item Quantity is = 67000 ton

Market Rate of this item per ton (considered based on existing disposal arrangements at existing operating site at Dhapa) is = Rs. 300/ton

Estimated Cost for this Item = (67000 ton * Rs. 300/ton) = Rs. 20100000

Total Estimated Cost for Profiling/Reshaping of the entire Dumpsite is = (Rs. 2349615 + Rs. 74399040 + Rs. 550000 + Rs. 20100000) = Rs. 97398655

Stage-IV: Construction of Leachate Collection Sumps, Passive Gas Collection System, Storm Water Drainage, ancillary Civil, Mechanical & Electrical Works:

Part I: Construction of Leachate Collection Sumps:

Item Description: Providing & Construction of Leachate Collection Sumps of size 1m diameter x average of 2.5 – 3.8m depth (as per Drawing) in PE Construction using 1.2m OD HDPE Pipes (PN 8) with base of 300mm stabilized soil with lime and fly ash; 300mm of brick bat concrete overlaying with 150mm thick PCC 1:2:4 bases. The HDPE pipe will be embedded in the PCC base and inside of the base will be lined with HDPE liner system welded on the HDPE pipes internally as shown in the drawings. The 1.2m OD HDPE pipe will have puddle pipes ends of 200mm dia. At specified intervals as per the location and L section drawing with manhole cover and opening at the top having 750mm x 750mm opening (HDPE) with flap on HDPE pipe for pumping out leachates from the manhole. The leachate collection system comprising of 200mm diameter HDPE perforated pipes laid in slopes will be connected to these puddle pipes discharging the leachates into the leachate collection sumps. The consolidated item shall be executed as per specifications including all materials like cement, sand, steel (Fe 415 CRS Grade), coarse & fine aggregates, HDPE pipe connections etc. labour, supply etc. complete as directed by Engineer.

Calculation of the Item Quantity & Estimated Cost:

Construction of leachate collection wells = 3 nos.

Estimated Item Quantity (in Unit) is = 3 unit

Market Rate of this item per unit (Rate Analysis as per Annexure – 3) is = Rs. 204464/unit

Estimated Cost for this Item is = (3 unit * Rs. 204464/unit) = Rs. 613392

Item Description: Supply, Installation, Testing & Commissioning (SITC) for Submersible type Pumps in SS 304 construction of 3HP capacity each for leachate transfer from the leachate collection sump to LTP including all machinery & allied accessories for operation along with Level Sensor and cabling works. Motor and starter panel with butterfly valve operation etc. complete including all materials, machinery, tools & plants, as directed by Engineer (1W + 1S Pumps for each leachate collection sumps at three locations of leachate collection sumps).

Calculation of Item Quantity& Estimated Cost:

Pumps & other mechanical installations = 1no.

Total number of leachate sumps is = 3 nos. ;

For each leachate sumps, (1W + 1S) pumps are required.

Therefore, for 3 leachate sumps, (3*2) = 6 nos. of pumps are required.

Estimated Item Quantity (in Unit) is = 6 units.

Market Rate of this item per unit (As per Public Health SOR effective from July 2013, Item No. 1 Page No. 35) is = Rs. 675000/unit

Estimated Cost for this item is = (6 unit * Rs. 675000/unit) = Rs. 4050000

Item Description: Supply; Laying & Jointing of HDPE pipes PE 100 & PN6 pressure rating as per IS 4984/14333 for pumping of leachate from individual leachate collection sumps to the LTP area including excavation of trenches, laying of pipes & backfilling in trenches along the route as per drawings etc. completed including materials, labour, tools & plants; HDPE welding equipment etc. as directed by Engineer.

Calculation of Item Quantity & Estimated Cost:

Leachate drain trenches excluding cut-off wall (HDPE liner in trench) = 3000m

Estimated Item Quantity is = 1289 Rmt.

Market Rate of this item per Rmt. (As per Market Rules) is = Rs. 369.90/Rmt.

Estimated Cost for this item is = (1289 Rmt. * Rs. 369.90/Rmt.) = Rs. 476801

Sub Total Cost of Leachate Collection Sumps & Disposal of Leachates = Rs. (613392 + 4050000 + 476801) = Rs. 5140193

Part II: Construction of Passive Gas Collection System:

Item Description: Construction of Passive Gas Collection Wells on top of the profiled waste & cover layers consisting of 500mm dia. Boring through MSW to depths of 10m using suitable boring equipment & machinery with casing pipe of 400mm internal diameter; lowering of 200mm dia. HDPE stand pipe PE 100grade, pressure class 6kg/cm^2 (blind pipe of 3m & rest with perforations) for gas collection, supply of gravel & packing in the annular space of 150mm besides the standpipe for easy gas movement, jointing/welding along with clamping arrangements of 1.5mm HDPE liner with the HDPE standpipe; providing top blind flange over the standpipe, interconnections with the 200mm dia. Lateral transport pipes laid in the top soil layer leading to the compost area provided with RCC Precast Concrete Ring 1m dia. X 1m depth using RCC pipe including all interconnections & flanges provided with PVDF/PP lining for air tightness against gas escape. The item is consolidated including all material, labour, tools & equipments for drilling etc. as directed by engineer.

Calculation of the Item Quantity & Estimated Cost:

Construction of passive Gas Collection wells is = 10 nos.

Estimated Quantity is = 10 unit

Market Rate of this item per unit (Rate Analysis as per Annexure 4) is = Rs. 44388.50/unit

Estimated Cost for this item is = (10 unit * Rs. 44388.50/unit) = Rs. 443885

Item Description: Supply; Laying & Jointing of HDPE pipes of different diameters for gas collection and transport PE 100Grade as per IS 14333 pressure class 6kg/cm^2 including making of slots for gas collection system. The pipes will be laid in the Gas Drainage Layer as well as in the top soil layer in order to collect gas from the waste & further transport to the Passive Gas Outlet via Compost box as shown in the tender drawing along with interconnections with the Gas Well Standpipe making air tight joints with PVDF/PP lining on the same to avoid any gas leakage, inclusive of supply, making of perforations/slots & laying of pipes including all materials, labour & transportations etc. as directed.

110mm HDPE pipes (Lateral laid in the Drainage Layer below the Liner System & connected to the Stand pipe of Passive Gas Wells) with perforations.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 4658m

Market Rate of this item per m (Market Rate considered) is = Rs. 499.50/m

Estimated Cost for this item is = (4658m * Rs. 499.50/m) = Rs. 2326671

200mm HDPE pipes (Transport Pipe header connected to Passive Gas Well stand pipe and laid in the 0.5m Soil Layer) blind pipe.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 100m

Market Rate of this item per m (Market Rate considered) is = Rs. 1256.10/m

Estimated Cost for this item is = (100m * Rs. 1256.10/m) = Rs. 125610

110mm HDPE pipes (Transport Pipe Laterals connected to header pipe laid into the Compost Box in the 0.45mm Vegetative Layer) with perforations and wrapped with 100 GSM Geo Textiles in order to avoid chocking with compost.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 360m

Market Rate of this item per m (Market Rate considered) is = Rs. 499.70/m

Estimated Cost for this item is = (360m * Rs. 499.70)= Rs. 179892

Item Description: Construction of RCC M30 Pre Cast Compost Filter Box of size 7.4m x 4.0m x 1.0m depth with cement slabs interconnected on site during laying operations of RCC M30 grade; 100mm thick precast slabs manufactured & laid on site on top & anchored in the 0.5mm soil layer with all materials, tools & plants, labour etc. as directed by engineer.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 10 units

Market Rate of this item per unit (Market Rate considered for concreting work including formwork cast in in situ) is = Rs. 15569.80/unit

Estimated Cost for this item is = (10 unit * Rs. 15569.80/unit) = Rs. 155698

Item Description: Supply; Providing & Laying over the 0.5m soil layer; a drainage layer within the compost filter area with crushed stones of size 5-20mm in which the 110mm laterals are laid for easy gas escape in the compost layer as per specifications in the tender documents. The item includes supply, transportation to worksites, labours, materials required for placing & spreading, necessary testing as per ISO/ASTM standards. Grain size & Organic content shall be tested & got approved from the engineer before profiling on landfill site.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 44.4 cu.m

Market Rate of this above item per cu.m (Considering the Market Rate of Crushed Stone) is = Rs. 2081.50/cu.m

Estimated Cost for this item is = (44.40 cu.m * Rs. 2081.50/cu.m)= Rs. 92419

Item Description: Supply & Laying of matured compost fertilizer in the Compost box of size 7.4m x 4.0m x 0.7m depth including material, labour, transportation, loading & unloading of material, all operational & incidental charges etc. complete as directed by engineer.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 153328 kg

Market Rate of this above item per cu.m (Considering the Market rate of Matured Compost) is = Rs. 5/kg

Estimated Cost for this item is = (153328kg * Rs. 5/kg)= Rs. 766640

Sub Total Estimated Cost of Passive Gas Collection Well System with Compost Filter = Rs. (443885 + 2326671 + 125610 + 179892 + 155698 + 92419 +766640) = Rs. 4090815

Item Description: Construction of Trapezoidal (surface water) Storm Water Drainage System in RCC M30 grade cast in situ at the periphery of the dumpsite at Ground level (Type 1) and along the access/service roads on top of berms of the closure layers of the dumpsite (Type 2) PreCast per dimensions shown on the drawings including providing stabilised soil layer, rubble soiling base over which laid with RCC Precase/cast in situ slabs including cement, sand, aggregates (6-20mm size) and steel of FE 415 CRS Grade, excavation, surface dressing, preparation of bed by levelling, casting of RCC slabs, centering & shuttering etc. complete as directed by engineer.

i) Storm Water Drain – Type I - Including excavation and dewatering

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 1278m

Market Rate of this item per m (Rate Analysis as per Annexure 5) = Rs. 11596.897/m

Estimated Cost for this item is = (1278m * Rs. 11596.8968/m) = Rs. 14820834

ii) Storm Water Drain – Type II – On top of the berm

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 1223m

Market Rate of this item per m (Rate Analysis as per Annexure 5) = Rs. 6999.34/m

Estimated Cost for this item is = (1223m * Rs. 6999.34/m) = Rs. 8560193

Item Description: Providing and Constructing Surface Water Collection RCC M30 well/sump with internal size of 1m & height as per locations specified in drawings and specifications on the dumpsite/ground levels in surroundings for connection to the storm water outlets/ interconnection of storm water drainage channels/storm water pipes including sub-base of stabilized soil rubble soling PCC M15 and RCC base raft & walls with interconnection puddle/sleeve pipes of required diameters including cement, sand, aggregates (6-20mm size) and steel of FE 415 CRS Grade including excavation, dewatering of trenches wherever required, surface dressing casting of RCC slabs etc. as per standard specification and as directed by engineer.

i) Surface Water Collection Sump for interconnection of drain channels at +25m height Service Road location (Type 2)

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 4 unit

Market Rate of this item (Considering Rate Analysis as per Annexure 6) is = Rs. 12092/unit

Estimated Cost for this item is = (4 unit * Rs. 12092/unit) = Rs. 48368

ii) Surface Water Collection Sump for interconnection of drain channels to outside natural drainage at ground level (Type 1)

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 5 unit

Market Rate of this item (Considering Rate Analysis as per Annexure 6) is = Rs. 24090.5/unit

Estimated Cost for this item is = (5 unit * Rs. 24090.50/unit) = Rs. 120452

Item Description: Supply; Laying & Jointing of HDPE/RCC Pipes of different diameters for connection to the storm water outlets/ interconnection of storm water drainage channels/ storm water pipes etc. including laying & jointing of pipes in the top cover layers with structures laid in levels as required for smooth flow of storm water drainage, with all materials, labour, transportation etc. as directed by Engineer.

200 OD HDPE pipe PE 100. Pressure Class PN6 as per IS 4984 connecting Type 2 Storm Water channels to Type 1 laid along the slopes of 1:2.5 or 1:3

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 380m

Market Rate of this item per m (Market Rates considered) is =Rs. 1256.10/m

Estimated Cost for this item is = (380m * Rs. 1256.10/m) = Rs. 477318

400mm dia. RCC NP3 pipe as per IS standards connecting surface water drainage well/sump of Type 1 Surface Water Channels to outside natural drain at 5 different locations as shown in drawing

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 80m

Market Rate of this item per m (Market Rates considered) is = Rs. 2879.20/m

Estimated Cost for this item is = (80m * Rs. 2879.20/m) = Rs. 230336

300mm dia. RCC NP3 pipe as per IS standards entry (Gate-1) south side of the dumpsite connecting surface water drainage well/sump of Type 2 Surface Water Channels to Drain Type 1 as shown in drawing.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 20m

Market Rate of this item per m (Market Rate considered) is = Rs. 2379.2/m

Estimated Cost for this item is = (20m * Rs. 2379.20/m) = Rs. 47584

Item Description: Excavation & widening of the existing natural drainage in width of 1.5m and depth of 1m on North-west side of the dumpsite in order to cater for increased flow conditions and easy and safe disposal of storm waters avoiding any ponding of water in the areas including all materials, labour & manpower etc. complete as directed by engineer.

Calculation of Item Quantity & Estimated Cost:

Estimated Quantity is = 375 cu.m

Market Rate of this item per cu.m (As per SOR of Building Works & Material effective from 1st August, 2010 – Section 1 Building Works (A – Earth work Item No. 2) Page no.1. Price Escalation Rise of 10%) is = Rs. 137/cu.m

Estimated Cost for this item is = (375 cu.m * Rs. 137/cu.m) = Rs. 51375

Sub Total Cost of Storm Water Drainage = Rs. (14820834 + 8560187 + 48367 + 120452 + 477318 + 230336 + 47584 + 51375) = Rs. 24356453

Total Estimated Cost for Construction of Leachate Collection Sumps, Passive Gas Collection System, Storm Water Drainage, Ancillary Civil/Mechanical/Electrical works is = Rs. (5140193 + 4090815 + 24356453) = Rs. 33587461

From the Table mentioned above, it has been found that the Total Capital Cost for Biocapping project of 30 acre land is = Rs. 50 Crores

Therefore, Total Capital Cost for Biocapping project of 60 acre land is = Rs. (50 Crores * 2) = Rs. 100 Crores.

Annexure-II: Detailed Evaluation of the Operation & Maintenance Cost for the Leachate Treatment Plant & the Bioremediation Project is mentioned below

Operation & Maintenance Cost of Leachate Treatment Plant at Closed Dumpsite			
Serial No.	**Item Description**	**Rate (Rs.)**	**Yearly Expense (Rs.)**
1	Chemicals – Aluminium, Chloride, Sodium Hypochlorite, Molasses, Enzyme etc.	167481	2009774
2	Chemist – Testing, Chemical Dosing etc.	15000	180000
3	Monthly Testing – 4 times in Bidder own lab; 1 time in outside lab	16000	193000
4	Laboratory Expenses – all expenses regarding laboratory	25000	300000
5	Monthly Maintenance – all machineries of LTP	75000	900000
6	Consultancy Charges – Monthly visit at Dhapa LTP	20000	240000

	site along advice and guideline		
7	Office Expenses – printing & stationary expenses, local conveyance, staff welfare expenses, etc.	4900	58800
8	Operator – 6 persons	12000	864000
9	Electrician – 1 person	12000	144000
10	Security – 2 person	12000	288000
11	Labour & Transportation – sludge cleaning, time to time garbage collection & dumping etc. required work	18000	216000
12	Miscellaneous Expenses – monthly purchase of broom, detergent powder, old clothing etc.	1918	23018
	Total Project Value		5415592
13	Agency Profit – 10% of Profit Value	45130	541559
	Total Expenses	496429	5957151

Table 2A: O&M Cost of Leachate Treatment Plant at Closed Dumpsite

Operation & Maintenance of Bioremediation Project at Dhapa			
Serial No.	**Item Description**	**Rate (Rs./acre/yr.)**	**Cost for 30 Acres (Rs./yr.)**
1	Inspection & Certification (17%)	38000	1140000
2	Final Cover Repair (18%)	11552	346560
3	Vegetation Repair & Maintenance (16%)	46892	1406760
4	Grass Mowing (15%)	6080	182400
5	Gas Management (18%)	13680	410400
6	Leachate Management (19%)	15580	467400
7	Groundwater Monitoring (16%)	77824	2334720
8	Maintenance Cost (16%)	17024	510720
	Sub Total		6798960
9	Contingency @ 18%		1019844
	Net Total		7818804

Table 3A: Operation & Maintenance of Bioremediation Project at Dhapa

As per Report, the closure and containment of the closed dumpsite have to be under thorough monitoring and control for at least 5 years. The 300 KLD Leachate Treatment Plant has also been provided for the treatment of the leachate generating from the closed dumpsite. For this reason, an increment in the operation and maintenance cost of the Biocapping project will be observed over the 5 years. The table illustrating this increment (considering 5% increment for each year) in the Operational & Maintenance of Closure of 60 acre land including 300 KLD capacity of Leachate Treatment Plant is given below:

Table 4A: O&M Cost for Closure & Containment of Biocapped Dumpsite

O&M Cost for Closure & Containment of Biocapped Dumpsite (for 5 years)			
Years	**O&M Cost (Bioremediation)**	**O&M Cost (300 KLD LTP)**	**Amount (in INR)**
Year I	7818804.00	5957151.00	27551910.00
Year II	8209744.20	6255008.55	28929505.50
Year III	8620231.41	6567758.98	30375980.78
Year IV	9051242.98	6896146.93	31894779.81
Year V	9503805.13	7240954.27	33489518.80
Net Amount	43203827.72	32917019.73	152241694.89

Sample Calculation:

For Year I,

Operation & Maintenance Cost for Bioremediation project is = Rs. 7818804

Operation & Maintenance Cost for Leachate Treatment plant is = Rs. 5957151

Net Operation & Maintenance Cost for Closure of 60 acre land (including 300 KLD capacity of Leachate Treatment Plant) is = Rs. [(7818804 + 5957151) * 2] = Rs. 27551910.00

For Year II,

Operation & Maintenance Cost for Bioremediation project is = Rs. (7818804 + (5% * 7818804)) = Rs. 8209744.20

Operation & Maintenance Cost Leachate Treatment Plant is = Rs. (5957151 + (5% * 5957151)) = Rs. 6255008.55

Net Operation & Maintenance Cost for Closure of 60 acre land (including 300 KLD capacity of Leachate Treatment Plant) is = Rs. [(8209744.20 + 6255008.55) * 2] = Rs. 28929505.50

Annexure III: Detailed Estimation of Biomining of 260 acre of Dhapa Dumpsite

Table 5A: Capital Cost for Biomining Project(for Year – I & Year – II)

Total Capital Cost of Biomining Project (Land - 60 Acre)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Cost of excavation, loading, unloading, weighing, storage	180.00	4000000	720000000
2	Processing cost by mechanical means	320.00	4000000	1280000000

3	Processing cost by manual means & other manpower	100.00	4000000	400000000
4	Statutory clearance cost	1.00	4000000	4000000
5	Leachate treatment cost	9.02	4000000	36080000
6	Environmental monitoring system cost	2.00	4000000	8000000
7	Fire fighting system cost	2.00	4000000	8000000
8	Miscellaneous cost including contingency	54.00	4000000	216000000
Net Capital Cost (in Rs.)				**2672080000**

Detailed Calculation for Capital Cost, Operational Cost, & Revenue Generated of the Biomining Project:

Calculation for Capital Cost of the Biomining Project:

Item Description: Cost of excavation, loading, unloading, weighing & storage of legacy waste

Calculation of Item Quantity & Estimated Cost:

Estimated Item Quantity = 4000,000 MT

Market Rate considered (as per Rate Analysis) = Rs. 180/MT

Estimated Cost for this Item is = (4000000MT * Rs. 180/MT) = Rs. 554400000

Item Description: Processing Cost by Mechanical means [or setup required at the beginning & for the entire tenure of the Biomining Project]

Calculation of Item Quantity & Estimated Cost:

Estimated Item Quantity = 4000000 MT

Market Rate considered (as per Rate Analysis) = Rs. 320/MT

Estimated Cost for this Item is = (4000000 MT * Rs. 320/MT) = Rs. 985600000

Calculation for the Operational Cost for the Biomining Project:

Table 6A: Net Operational Cost for Biomining Project (Year – I)

Total Operational Cost of Biomining Project (Land - 60 Acre)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Non-combustible material operational cost	49.45	106350.48	5259031.24
2	Recyclable material operational cost	0.21	7090.03	1488.91
3	RDF & Combustible material operational cost	23.54	53175.24	1251745.15

4	Inert operational cost	12.96	35450.16	459434.07
5	Compostable material operational cost	103.67	81535.37	8452771.81
Net Operational Cost for Processing Waste Fractions (in Rs.)				**15424471.17**

Item Description: Operational/Processing Cost of the Non-combustible (C&D) waste fraction of the excavated legacy waste

Calculation of Item Quantity & Estimated Cost:

Estimated Item Quantity = 106350.48 MT

Market Rate considered (as per Rate Analysis) is = Rs. 49.45/MT

Estimated Cost for this Item is = (1200000 MT * Rs. 49.45/MT) = Rs. 5259031.24

Item Description: Operational/Processing Cost of the Combustible (RDF) waste fraction of the excavated legacy waste

Calculation of Item Quantity & Estimated Cost:

Estimated Item Quantity = 53175.24 MT

Market Rate considered (as per Rate Analysis) is = Rs. 23.54/MT

Estimated Cost for this Item is = (53175.24 MT * Rs. 23.54/MT) = Rs. 1251745.15

Calculation of the Revenue Collection from the Biomining Project:

Table 7A: Net Revenue Collection from Biomining Project (Year – I)

Net Revenue Collected from the Biomining Project (Land - 60 Acre)				
Sl. No.	**Item Description**	**Rate (Rs/MT)**	**Quantity (MT)**	**Total Projected Cost (Rs.)**
1	Revenue from compost product	156.25	81535.37	12739901.56
2	Revenue from combustible materials	349.00	53175.24	18558158.76
3	Revenue from Non-combustible materials	1000.00	106350.48	106350480.00
4	Revenue from recyclable materials	5.24	7090.03	37151.76
Net Revenue generated from Recovered Materials				**137685692.08**

Item Description: Net Revenue Collected from the processed Non-combustible fractions for the constructional purposes like for lowland filling or as road aggregates

Calculation of Item Quantity & Estimated Cost:

Estimated Item Quantity is = 106350.48 MT

Market Rate considered (as per Rate Analysis) is = Rs. 1000/MT

Estimated Cost for this Item is = (1200000 MT * Rs. 1000/MT) = Rs. 106350480.00

Item Description: Net Revenue Collected from the processed Combustible (RDF) fractions after selling to the Waste-to-Energy Facilities like Cement Kilns

Calculation of Item Quantity & Estimated Cost:

Estimated Item Quantity is = 53175.24 MT

Market Rate considered (as per Rate Analysis) is = Rs. 349/MT

Estimated Cost for this Item is = (600000 MT * Rs. 349/MT) = Rs. 18558158.76