STUDIES ON LANDFILL LEACHATE TRANSPORTATION AND ITS IMPACT ON SOIL CHARACTERISTICS

A Thesis

Submitted by

MERIL GEORGE

for the award of the degree

of

DOCTOR OF PHILOSOPHY

(Faculty of Engineering)

DIVISION OF CIVIL ENGINEERING
SCHOOL OF ENGINEERING
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
KOCHI, 682022

DECEMBER 2014

Studies on Landfill Leachate Transportation and Its Impact on Soil Characteristics

Ph. D. Thesis under the Faculty of Engineering

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December 2014

Dedicated to

My beloved Parents,

Late Mr. George Jacob, Mangattu

&

Elcy George, Mangattu

Certificate

Certified that this thesis entitled **"Studies on Landfill Leachate Transportation and its Impact on Soil Characteristics",** submitted to Cochin University of Science and Technology for the award of degree of Doctor of Philosophy under the Faculty of Engineering, is the bonafide research carried out by Smt. Meril George under my supervision and guidance at School of Engineering, Cochin University of Science and Technology, Kochi. This work did not form part of any dissertation submitted for the award of degree, diploma, associateship, fellowship or other similar title or recognition from this or any other institution.

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Declaration

I, Meril George, hereby declare that the work presented in this thesis entitled **“Studies on Landfill Leachate Transportation and its Impact on Soil Characteristics”,** being submitted to Cochin University of Science and Technology for the award of degree of Doctor of Philosophy under the Faculty of Engineering, is the outcome of original work done by me under the supervision of Dr. K. S. Beena, Professor of Civil Engineering, Cochin University of Science and Technology, Kochi. This work did not form part of any dissertation submitted for the award of degree, diploma, associateship, fellowship or other similar title or recognition from this or any other institution.

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Meril George

Acknowledgement

First and foremost, praises and thanks to the God, the Almighty, for his showers of blessings throughout my research work. Without him, I would not have the patience, wisdom or the physical ability to complete the research successfully.

Completion of this doctoral thesis was not possible without the support of several people. I would like to express my sincere gratitude to all of them.

With great pleasure, I record my deep sense of indebtedness and gratitude to my supervisor and guide Prof. Dr. K. S. Beena, for giving me the opportunity to do research and providing invaluable guidance throughout. Her dynamism, vision, sincerity and motivation have deeply inspired me. She has taught me the methodology to carry out the research and to present the work as clearly as possible. It was a great privilege and honor to work and study under her guidance. I am extremely grateful for her concern and support offered to me whenever I met with difficulties. She was the best choice I could have made for an advisor. I would also like to extend my heartfelt thanks to her family for their acceptance and patience during the discussions I had with her on research work and thesis preparation.

I express my sincere gratitude to Prof. Dr. G. Madhu, Principal, School of Engineering, Cochin University of Science and Technology, for his valuable and timely help. As a member of Doctoral Committee, his cordial support and suggestions helped me a lot in completing this task. I owe special thanks to Sri. Arunkumar T., Head of the Department, Civil Engineering, CUSAT, for his valuable suggestions and encouragement.

I also reserve special thanks to Prof. Dr. Krishna R. Reddy, University of Illinois at Chicago, Prof. Dr. B. V. S.Vishwanathan, IIT, Bombay, Prof. (Dr.) S. Chandrakaran, NIT, Calicut, Prof. Dr. K. Girish Kumar, Professor, School of Applied Chemistry, CUSAT and Prof. Dr. Solly George, Mar Athanasius College of Engineering, Kothamangalam, who responded to my every questions and queries promptly.

At this juncture, I must record my sincere gratitude to the Management of SCMS School of Engineering and Technology, Karukutty, for permitting me to do this research along with my duties in the college. In particular, I would like to thank Late Dr. Pradeep P. Thevannoor, Former Vice chairman, SCMS Group, who initiated my doctoral studies, by signing the no-objection certificate and who has backed me up in every stage of my career. The encouragement extended by him, is inestimable, more so as he cannot see me graduated.

I express my heartfelt gratitude to Prof. M. Madhavan, Principal, SCMS School of Engineering and Technology, Karukutty, for providing all the institutional facilities. The technical support offered by my colleagues, friends and students for my experimental work is duly acknowledged. I am particularly thankful to Mrs. Sanju Sreedharan, Mr. K. K. Gopalakrishnan, Mr. Sankarankutty B., Mr. A. K. Narayanan, Mr. Tomy P.V. and Mr. Benny V. T. who have lent their helping hands in this venture. I also place on record my sense of gratitude to some of my friends in particular, Mrs. Mini Tom, Mrs. Deepa K., Mr. Santhosh G., Mr. Unni Kartha G., Mrs. Kavitha P.V., Adv. Shibu P. R. and Adv. Alunkal George for their support and well wishes.

I am profoundly indebted to the Chief Environmental Scientist, Central Laboratory, Kerala State Pollution Control Board, Kadavanthara, Director, Sophisticated Test and Instrumentation Centre (STIC), CUSAT and Manager, Quality Assurance Department, FACT Ltd., Eloor, Udyogamandal, for extending their laboratory facilities for my work. The help provided by the laboratory staff of School of Engineering, CUSAT is also acknowledged. The technical support extended by UL Technology Solutions, Trivandrum and Laga systems, Hyderabad is remarkable. I also extend my special thanks to Dr. L. Surinaidu, Special Project Scientist, IWMI, Hyderabad, for the support extended by him. My thanks are due to Mrs. Lima Joshy, Professor, St. Paul's College, Kalamassery, who spared her valuable time for me during the thesis preparation.

I express my heartfelt thanks to my loving husband Adv. Sain Paul Alunkal, for his continuous encouragement, patience, and cheerful dispositions which helped me throughout this endeavor and in every aspect of my life.To my dear little ones, Meera, Paul and Aliz, a special hug and gratitude for their affectionate support, forbearance and co-operation. The sacrifice they made throughout my years here are simply ineffable.

The memory of my departed father, who has been an unfailing source of strength for me and my mother's concern during the course of my work, has been equally valuable for the successful completion of this research.

Finally, I thank all who in one way or another contributed in the completion of this thesis.

Meril George

Abstract

Leachate from an untreated landfill or landfill with damaged liners will cause the pollution of soil and ground water. Here an attempt was made to generate knowledge on concentrations of all relevant pollutants in soil due to municipal solid waste landfill leachate and its migration through soil and also to study the effect of leachate on the engineering properties of soil. To identify the pollutants in soil due to the leachate generated from municipal solid waste landfill site, a case study on an unlined municipal solid waste landfill at Kalamassery has been done. Soil samples as well as water samples were collected from the site and analysed to identify the pollutants and its effect on soil characteristics. The major chemicals in the soil were identified as Ammonia, Chloride, Nitrate, Iron, Nickel, Chromium, Cadmium etc.. Engineering properties of field soil samples show that the chemicals from the leachate of landfill may have effect on the engineering properties of soil.

Laboratory experiments were formulated to model the field around an unlined MSW landfill using two different soils subjected to a synthetic leachate. The Maximum change in chemical concentration and engineering property was observed on soil samples at a radial distance of 0.2 m and at a depth of 0.3 m. The pollutant (chemicals) transport pattern through the soil was also studied using synthetic leachate. To establish the effect of pollutants (chemicals) on engineering properties of soil, experiments were conducted on two types soils treated with the synthetic chemicals at four different concentrations. Analyses were conducted after maturing periods of 7, 50, 100 and 150 days. Test soils treated with maximum chemical concentration and matured for 150 days were showing major change in the properties.

To visualize the flow of pollutants through soil in a broader sense, the transportation of pollutants through soil was modeled using software ‘Visual MODFLOW’. The actual field data collected for the case study was used to calibrate the modelling and thus simulated the flow pattern of the pollutants through soil around Kalamassery municipal solid waste landfill for an extent of 4 km^2. Flow was analysed for a time span of 30 years in which the landfill was closed after 20 years. The concentration of leachate beneath the landfill was observed to be reduced considerably within one year after closure of landfill and within 8 years, it gets lowered to a negligible level.

As an environmensstal management measure to control the pollution through leachate, permeable reactive barriers are used as an emerging technology. Here the suitability of locally available materials like coir pith, rice husk and sugar cane bagasse were investigated as reactive media in permeable reactive barrier. The test results illustrates that, among these, coir pith was showing better performance with maximum percentage reduction in concentration of the filtrate. All these three agricultural wastes can be effectively utilized as a reactive material.

This research establishes the influence of leachate of municipal solid waste landfill on the engineering properties of soil. The factors such as type of the soil, composition of leachate, infiltration rate, aquifers, ground water table etc., will have a major role on the area of influence zone of the pollutants in a landfill. Software models of the landfill area can be used to predict the extent and the time span of pollution of a landfill, by inputting the accurate field parameters and leachate characteristics. The present study throws light on the role of agro waste materials on the reduction of the pollution in leachate and thus prevents the groundwater and soil from contamination.

Key Words: Municipal Solid Waste Landfill, Synthetic Leachate, Soil Contamination, Pollutant Transportation, Visual MODFLOW, Agro Waste Materials, Permeable Reactive Barrier.

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List of Abbreviations

The Abbreviations listed below are for general reference. Symbols which do not appear here are explained in the text where they first occur.

AMSL	Above Mean Sea Level
APHA	American Public Health Association
BDL	Below Detectable Level
BH	Bore Hole
BHC	Benzene Hexa Chloride
BOD	Biochemical Oxygen Demand
CEC	Cation Exchange Capacity
CETP	Common Effluent Treatment Plant
CGWB	Central Ground Water Board
CH	High Compressive Clay
CL	Low Compressive Clay
COD	Chemical Oxygen Demand
DDT	Dichloro Diphenyl Trichloroethane
EPA	Environmental Protection Agency
FDM	Finite Difference Method
GMS	Groundwater Modelling System
LL	Liquid Limit
M	Molarity
MDD	Maximum Dry Density
MH	High Plasticity Silts
MSW	Municipal Solid Waste
OMC	Optimum Moisture Content
PI	Plasticity Index
PRB	Permeable Reactive Barrier
RHA	Rice Husk Ash
SEM	Scanning Electron Microscopy
SM	Silty Sand
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
Total P	Total Phosphorous
TVD	Total Variation Diminishing
UCC	Unconfined Compressive Strength
VFA	Volatile Fatty Acid

List of Chemical Notations

The Chemical notations listed below are for general reference. Symbols which do not appear here are explained in the text where they first occur.

Ions

Ca^{2+}	Calcium
Cl^-	Chloride
Cu^{2+}	Copper (II)
Fe^{2+}	Iron (II)
H^+	Hydrogen
Hg^{2+}	Mercury (II)
K^+	Potassium
Mg^{2+}	Magnesium
Mn^{2+}	Manganese (II)
Na^+	Sodium
NH_4^+	Ammonium
Ni^{2+}	Nickel
NO_2^-	Nitrite
NO_3^-	Nitrate
OH^-	Hydroxide
Pb^{2+}	Lead (II)
SO_4^{2-}	Sulfate
Zn^{2+}	Zinc

Chemical Compounds

$CaCl_2$	Calcium Chloride
CH_3COOH	Acetic Acid
H_2SO_4	Hydrogen Sulfate or Sulfuric Acid
$MgCl_2$	Magnesium Chloride
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide

* * *

Chapter 1

INTRODUCTION

1.1 General

Analysing world population shows India in the second place. The pace of population growth is drastically rapid. Indian population increased by more than 1210 million during 2001 - 2011 as per 2011 census, which is approximately 17% of the world population. Population growth and rapid urbanization results in the consumption of more resources. This leads to a proportional increase in the annual municipal solid waste generation in the country. *Energy Alternatives India* (EAI), estimates that the municipal solid waste (MSW) generated by urban India is more than 55 million tons per year, with about 5% yearly increase. At this rate the total urban MSW generated in 2045 would be 250 million tons per year. It is estimated that, the solid waste generated in India is approximately 0.5 kg per capita per day with 1.33% annual increase (EAI, Mufeed et al., 2008)

India, one of the fastest growing economies in the world, faces a challenge of municipal solid waste (MSW) management when it comes to finding suitable locations for final disposal. It is reported by Maria (2009) that India is generating as much as 27 million tons more waste than the United States per year, although it has only one-third the land space when compared to United States. About 94 percent of waste in India is seemed to be disposed of unsafely, either burned in an uncontrolled manner, or dumped in untreated landfills, where contaminants can leach into ground and ground water.

In spite of the fact that the State of Kerala has the highest human development index (0.790) in India, the rapid urbanization, constant change in consumption pattern and social behavior has increased the generation of municipal solid waste (MSW) in Kerala beyond the assimilative capacity of our environment and management capacity of the existing waste management systems. Though the quantity of waste generated in the Kerala state is about 0.393 kg per capita per day (Mufeed et al., 2008), it is about 0.707 kg per capita per day in Kochi (Abraham, 2009), which is the second largest city of Kerala.

The commonly referred municipal solid waste (MSW) includes household wastes and commercial wastes. There is a misconception that MSW is relatively safe and would not adversely affect the environment. The most common waste disposal method which is more environmental friendly is landfill. Landfills are often subjected to generation of leachate. Landfill leachate is generated from liquids existing in the waste as it comes into a landfill or from rain water that passes through the waste within the facility. Leachate consists of water and water soluble compounds in the refuse that accumulate, as water moves through the landfill.

The contaminants present in the leachate of the MSW landfill can be classified as hazardous chemicals, conventional contaminants and non-conventional contaminants. As per United States Environmental Protection Agency (USEPA), a material is not classified as a hazardous waste, until a chemical is leached from it in concentrations at least 100-times the drinking water standard (40 CFR, 2005). Conventional contaminants include parameters such as total dissolved solids (TDS), hardness, alkalinity and presence of chemicals such as chloride, sulfate, iron, manganese and hydrogen sulfide. In addition, this group includes a variety of non-differentiated organics measured as COD (chemical oxygen demand), BOD (biochemical oxygen demand), and TOC (total organic carbon). Non-conventional contaminants are largely organic chemicals that have not been defined, and whose potential hazards to public health and ground water quality are not known. It is estimated that from 90% to 95% of the organic materials in municipal landfill leachate are of unknown composition. Those chemicals have not been identified and obviously their potential impacts on environment are unknown (Lee and Anne).

The risks of leachate generation can be mitigated by properly designed and engineered landfill sites, such as sites that are constructed on geologically impermeable materials or sites that use impermeable liners made of geomembranes or engineered clay. Landfill liners should properly function so that it prevents leachate from seeping through the bottom and contaminating the ground water. But in most of the cases, liners will not function properly and will lead to the spread of leachate to the soil beneath. This may tend to pollute the soil.

1.2 Scope of the Study

In an unlined landfill, the pollutants in soil remain in direct contact with the soil for relatively longer periods and hence the nature of soil pollution differs from that of air or water pollution. The unscientific management of municipal solid waste will lead to contamination of the soil. The presence of pollutants in the soil can change the desirable engineering properties of the soil. Reliable detection of leachate migration from the landfill is necessary to control widespread pollution of soil.

If the impact of leachate from municipal solid waste on engineering properties of soils can be assessed, the problems that geotechnical engineers face while placing new structures on sites near a MSW landfill with contaminated soils can be reduced.

Considering the importance of the problem discussed, this research mainly focuses on the following major objectives.

- To identify the pollutants in the soil due to leachate generated from a municipal solid waste landfill site.
- To detect the transportation pattern of pollutants in soil by conducting field study.
- To evaluate the effect of pollutants on soil characteristics by conducting laboratory experiments.
- To model the transportation of pollutants through soil using available software.

- To investigate the suitability of environmental friendly and locally available materials to reduce the extent of pollution.

The scope of the study is limited to the following with respect to materials used and methods adopted:

- Pollutants in soil due to leachate are identified based on the field data collected from one municipal solid waste landfill site only and due to non accessibility of site, samples cannot be collected from the river side.
- The laboratory studies are restricted to two types of soils with a representative synthetic leachate with mixed pollutants. Since the exact composition of leachate coming out of the landfill is not known, the synthetic leachate is prepared considering the chemical composition of polluted soil.

1.3 Methodology

An extensive literature review on the municipal solid waste landfills and soil pollution due to landfill leachate is to be carried out. Based on that, a systematic experimental investigation has to be conducted to study the effect of pollutants on soil characteristics and the transportation pattern of pollutants through soil. A pollutant transport modelling using suitable software is also intended to study the transportation of pollutants through soil.

Literature Review

Literature review has to be conducted to identify the existing situation of municipal solid waste disposal in India, issues and other problems on the surrounding areas, particularly on the surrounding soil. Thorough literature survey has to be carried out to analyse various studies conducted on polluted soil and modelling of pollutant transport through soil.

Field Investigation

A municipal solid waste landfill has to be identified for a case study and polluted soil samples and leachate has to be collected from the site. Chemical analysis of the soil samples and leachate at different extents and depths is proposed to identify the concentration of pollutants and to detect the transportation pattern of pollutants through soil.

Experimental Research

Based on the literature review, different experimental research programme has to be formulated to study the effect of pollutants in soil. As per the field investigation results, a model synthetic leachate has to be prepared and the experiments are proposed to be conducted using the model synthetic leachate to establish the effect of pollutants on geotechnical characteristics of soil. Experimental studies to determine the suitability of locally available natural materials to reduce the extent of pollution has also to be investigated.

Pollutant Transport Modelling

To simulate a wide range of flow in porous media with wide varieties of systems and standards including ground water flow and transport of contaminants, a three dimensional modelling of the landfill area has to be conducted using suitable modelling software.

1.4 Organisation of Thesis

This thesis consists of eight chapters. The contents of various chapters of the thesis are briefly described below.

Chapter 1 illustrates the brief description of the municipal solid waste management in India and the impact of landfill leachate on environment. Scope of the study, research objectives and methodology for the present study is also discussed.

Chapter 2 critically reviews the literature on previous studies in the area of municipal solid waste landfills and effect of chemicals on soil properties, pollutant transportation through soil and soil pollution control measures.

Chapter 3 presents a case study on a municipal solid waste landfill site at Kalamassery, Kerala for the identification of the major pollutants in the soil due to MSW landfill leachate.

Chapter 4 explains the investigations conducted on a small scale laboratory test set-up simulating an unlined MSW landfill with uniform dense, single layer soil.

Chapter 5 discusses the effect of chemicals in the synthetic leachate on the engineering properties of soil.

Chapter 6 deals with the visualization of flow of pollutants and prediction of fate of pollutants in the Kalamassery MSW landfill area using a computer software, 'Visual MODFLOW'.

Chapter 7 reports the suitability of locally available bio materials to control soil pollution due to MSW landfill leachate.

Chapter 8 presents the conclusions derived from the research.

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Chapter 2

REVIEW OF LITERATURE

Contents

2.1 Introduction

Being the second largest growing economy in the world, India's garbage generation stands at 0.2 to 0.6 kg of garbage per head daily. Waste disposal in India, simply involves rounding up the waste from different parts and dumping everything in a landfill. Once a landfill is completely occupied, new landfills are discovered at different places. The Energy Research Institute estimates that 1400 sq. km of land would be required in India by 2047 for municipal waste disposal. The landfill method is the one that creates land pollution and in some cases, ground water contamination. The waste is not subjected to recycling, composting, or any other form of environmental treatment. Hazardous toxic wastes lie side by side with the organic wastes in the landfill (Harshini, 2010).

Increased interest in the environment protection issues, such as ground and ground water protection, during the last decades, lead to an increase in the importance of design and maintenance of landfills for waste disposal. The landfill liner construction has developed with the innovation of new practices such as the addition of engineered clays, geomembranes, synthetic lining materials and introduction of advanced leachate collection systems etc., over the years. The main objective of such practices is to enhance the landfill liner performances as a hydraulic barrier and to minimize or prevent the migration of landfill leachate into surrounding hydro geological system (Jayasekera and Mohajerani, 2001). One major concern about landfill liners is that they may be attacked by the chemical wastes or leachates they contain. This may lead to the leakage of leachate from the landfill thereby generating chances for pollution of soil and ground water.

The literature relevant to the municipal solid waste landfill leachates and its effect on soil is reviewed in this chapter.

2.1.1 Municipal Solid Waste Landfill

A municipal solid waste (MSW) landfill unit is a discreet area of land or an excavation that receives household waste and that is not a land application unit, surface impoundment, injection well, or waste pile. A carefully designed and monitored landfill isolates waste from the ground water and will not be kept in contact with air. This isolation is accomplished with the use of a bottom liner and daily covering of soil (AP42, 1995).

2.1.1.1 Parts of a municipal solid waste landfill

The main components of any secured, permitted landfill as described by Freudenrich (2000) are:

Bottom liner-The bottom liner separates and prevents the buried waste from coming in contact with underlying natural soils and ground water.

Cell -Cell is the area in a landfill that has been constructed and approved for disposal of waste. Depending upon total quantity of waste received at the landfill, these cells range in size. Inside the larger cells there can be smaller cells known as the daily workface cell, which contain only one day's waste. This is where the waste coming into the landfill for disposal in a day is shredded and placed in layers. Thus prepared waste is then compacted by heavy landfill compaction machinery. Cells are arranged in rows of adjoining daily workface cells. A continuous row of cells is called a lift. The landfill is made up of many lifts.

Leachate collection system-The bottom surface of the landfill is sloped to a low point, called sump. This is where any liquids that are trapped inside the landfill (leachate) are collected and removed from the landfill. The leachate collection system typically consists of a series of perforated pipes, gravel packs and a layer of sand or gravel placed at the bottom of the landfill. Once the leachate is removed from the sump, it is typically pumped or gravity-flowed to a holding tank or leachate pond, where it is either treated on site or hauled off site to a public or private wastewater treatment facility.

Storm water drainage-To reduce the amount of leachate, the landfill has to be kept as dry as possible. Storm water drainage is an engineered system designed to control water runoff during rain or storm events. This is done by directing the runoff through a series of drainage pipes and storm liners to the drainage ditches surrounding the landfill. The ditches are either concrete or gravel-lined and carry water to collection ponds known as storm water ponds. In these ponds the runoff water flow is slowed down or held long enough to allow the suspended soil particles to settle before the water is discharged off site.

Methane collection system-Landfill methane is produced when organic materials are decomposed by bacteria under anaerobic conditions. Since, methane gas has the potential to burn or explode, it has to be removed from the landfill. To do this, a series of pipes are embedded within the landfill to collect the methane gas. This gas, once collected, can be either naturally vented or control-burned.

Cover (or cap)-Covering (or capping) is performed in order to isolate the waste from exposure to the air, pests and to control odours. Waste that is placed in a cell is covered daily with either 0.15 m of compacted soil or an alternative daily cover. When a section of the landfill is finished or filled to capacity, it is permanently covered with a polyethylene cap. The cap is then covered with a layer of compacted soil of 0.6 m thickness which will support growth of vegetation to prevent erosion.

Ground water monitoring stations-To directly access and test the ground water around the landfill for the presence of leached chemicals, ground water monitoring stations are set up. Typically a ground water monitoring system will have a series of wells that are located up-gradient of the landfill disposal area and a series of wells down-gradient. The up-gradient wells test the water quality before it moves under the disposal area in order to get a background analysis of the water. The down-gradient wells then allow testing of the water, after it has passed under the disposal area. So it can be compared to the quality of water in the up-gradient wells to study the impact of landfill on ground water (Freudenrich, 2000).

2.2 Waste Decomposition and Leachate Characteristics

A municipal solid waste landfill unit receives different types of wastes, such as household waste, commercial waste, combustion ash, infectious waste, waste tires, industrial non-hazardous waste, construction and demolition waste, agricultural wastes, oil and gas wastes, and mining wastes. But most of the landfills accept only a few of the above categories. (AP42, 1995)

The leachate characteristics mainly depends on the waste composition, age of waste, degree of compaction, decomposition phase, waste filling procedures, waste moisture content, rate of water movement and temperature (Armstrong and Rowe, 1999). In addition to that, leachate characteristics are also determined by the location, design and mode of operation of the landfill.

According to Cermak et al. (2004), a landfill can be considered as a bio-reactor, in which organic substances are degraded by bio-chemical and physical-chemical processes. Precipitation, surface run-off, infiltration of ground water percolating through a landfill and the inherent water content of wastes themselves will enhance successive biological, chemical and physical processes in landfill cells. This results in the generation of organic and inorganic compounds in the landfill leachate from the waste.

Different phases of decomposition are distinguished for municipal landfills within twenty years. In the first stage, after the first landfilling process where air comes in contact with waste, initial aerobic phase rapidly consumes the confined oxygen and water infiltration. At this stage degradation of organic substance to carbon dioxide and water occurs. This enhances acetogenic fermentation, producing leachate characterised by high values of BOD, COD and ammoniacal nitrogen contents. Volatile fatty acids (VFA) are the main components of the organic matter released. Gradually, the anaerobic phase of decomposition starts and consumes the simple organic compounds resulting from acetogenic process and generates landfill gas. Leachate and landfill gases contain substances that are harmful to human health and the environment (El-Fadel et al., 2002). The leachate escaping from landfills can contaminate soils, aquifers and surface waters. Landfill gas contains greenhouse gases that contribute to the global warming effect when they are released into the atmosphere. In this stage, the leachate composition represents the dynamic equilibrium between the microbiological mechanisms with lower BOD and COD values while the ammonia concentration remains high. Dissolved inorganic materials are continuously released. With landfill ageing, degradation is finished and all the organic substances are processed. Thus waste stabilisation takes place. As the volatile fatty acids leachate content decreases parallel to the BOD/COD ratio, the leachate organic matter made up of high molecular weight humic and fulvic substances increases. The duration of these phases may vary depending on several factors (e.g. climatic and environmental conditions, waste characteristics, operational factors, etc.) and may last from decades to centuries (Rodriguez et al., 2000). Based on the composition and landfill age, leachate can be classified into three (Table 2.1).

Table 2.1 *Classification of Leachate**

Leachate Type	Young	Intermediate	Stabilised
Landfill Age (Years)	<5	5-10	>10
pH	<6.5	6.5-7.5	>7.5
COD (mg/l)	>10,000	4000-10,000	<4000
BOD/COD	0.5-1	0.1-0.5	<0.1
TOC/COD	<0.3	0.3-0.5	>0.5
Ammoniacal nitrogen (mg/l)	<400	N.A	>400
Organic Matter	80% VFA	5%-30% VFA, Humic and fulvic acid	Humic and fulvic acids

* *(Wei et al., 2010)*

Generally, municipal solid waste landfill leachate may contain large amounts of organic matter as well as ammoniacal nitrogen, heavy metals (e.g. copper, iron, zinc, lead, manganese etc.), chlorinated organic and inorganic salts (e.g. chloride, sulfate, sodium etc.), which are a great threat to the surrounding soil, ground water and even surface water (Renou et al., 2008; Robinson, 2005). The concentrations of ions encountered in the municipal solid waste landfill leachate are summarised in Table 2.2.

Table 2.2 *Range of Various Inorganic Constituents in the Leachate from Municipal Solid Waste Landfill **

Constituent	Unit	Range
pH	-	4-8
K^+	(mg/l)	200-1000
Na^+	(mg/l)	200-1200
Ca^{2+}	(mg/l)	100-3000
Mg^{2+}	(mg/l)	100-1500
Fe^{2+}	(mg/l)	1-1000
Mn^{2+}	(mg/l)	0.01-100
Cu^{2+}	(mg/l)	<10
Ni^{2+}	(mg/l)	0.01-1
Zn^{2+}	(mg/l)	0.1-100
Pb^{2+}	(mg/l)	<5
Hg^{2+}	(mg/l)	<0.2
Cl^-	(mg/l)	300-3000
SO_4^{2-}	(mg/l)	10-1000
NH_4^+	(mg/l)	10-1000
TDS	(mg/l)	5000-40000

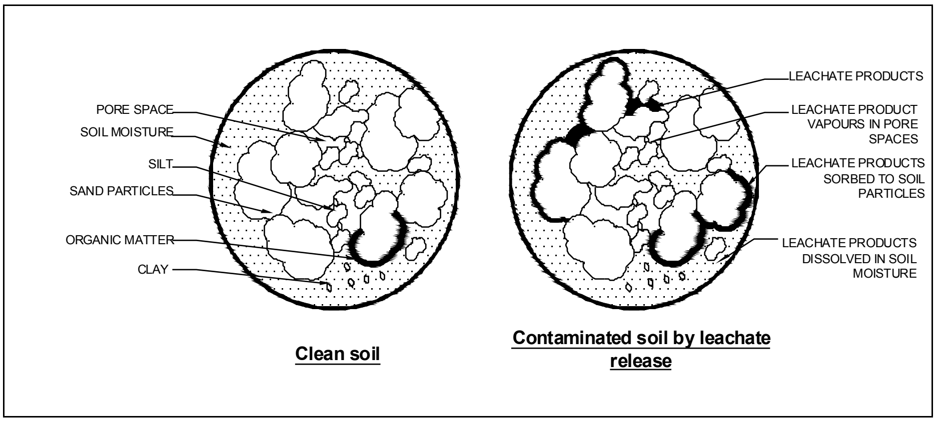
* *(Freeze and Cherry, 1979)*

In an actively decomposing waste, the temperature rises and the pH falls rapidly and many metal ions which are relatively insoluble at neutral pH can become dissolved in the developing leachate. Leachate also reacts with materials that are not themselves prone to decomposition such as fire ash, cement based building materials and gypsum based materials and will lead to change the chemical composition of leachate. In sites with large volumes of building waste, especially those containing gypsum plaster, the reaction of leachate with the gypsum can generate large volumes of hydrogen sulphide which may be released in the leachate and may also form a large component of the landfill gas (Keerthi, 2011).

Bhalla et al. (2013) has studied the effect of age and seasonal variations on leachate characteristics of municipal solid waste landfill leachate at a non-engineered low lying open dump landfill site of Ludhiana City. The study indicated that with the passage of time and with seasonal variations, particularly during rainy season, values of various chemical parameters increased. The reason is that, the solid waste material degrades as time passes and the waste constituents percolates down along with rainwater.

2.3 Effect of Chemicals in Municipal Solid Waste Landfill Leachate on Soil

The leachate from MSW dumping site is highly concentrated with carcinogens and toxic chemicals. In addition to that, MSW leachate contains a variety of conventional pollutants and non-conventional pollutants. These pollutants in the leachate can modify the soil properties and significantly alter the behaviour of soil. The soil functions most affected by contamination are its buffering, filtering and transforming capacities. Fig. 2.1 shows the pictorial representation of clean soil and contaminated soil.



Clean soil

Contaminated soil by leachate release

Fig. 2.1 *Pictorial Representation of Clean and Contaminated Soil.*

The impact of chemicals of leachates on the soil has given rise to a great number of studies in recent years.

Studds et al. (1998) studied the effects of salt solutions on the swelling behaviour and hydraulic conductivity of bentonite powder and bentonite-sand mixtures. Study was conducted with distilled water and different salt solutions at 0.01, 0.1 and 1 mol/l concentration. They concluded that swelling behaviour of bentonite-sand mixture is a function of pore fluid and can be predicted from swelling properties of bentonite and load deformation properties of sand. Also in dilute solutions, the bentonite in mixtures subjected to small confining stresses, swells sufficiently to separate the sand particles and reach a clay void ratio similar to that achieved by bentonite alone. At high stresses, or in strong solutions, the bentonite in a mixture has insufficient swelling capacity to force the sand particles apart and swelling is limited by the sand pore volume.

Jayasekera and Mohajerani (2001) investigated the effects of landfill leachate on the performance of a compacted basaltic clay soil, over a period of time. For this purpose, a typical Melbourne basaltic clay with varying percentages of montmorillonite clay was selected and a synthetic leachate was developed based on the composition of typical municipal waste landfill leachate. The clay - leachate interactions were allowed to take place under controlled anaerobic laboratory conditions. Samples were then tested at different time periods to identify possible variations of engineering properties such as volume change, consistency and grain size distribution due to the effect of leachate over time. The analysis of test results suggests that the behaviour of a basaltic clay liner could be significantly affected by clay leachate interactions over time, results in alterations to physical and mineralogical properties of the clay.

Mishra et al. (2005) studied the influence of sodium chloride and calcium chloride, at various concentrations on permeability and compressibility of mixtures of basalt soil and bentonite. Comparison of hydraulic conductivity for different salt solutions shows that the divalent cation has more effect than monovalent cation. Comparison of different salt concentrations for a particular salt on a particular soil mixture shows that the hydraulic conductivity decreases with decreasing salt concentration and compressibility reduces with increasing salt concentration of the pore fluid.

Ozcoban et al. (2006) studied the leachate removal rate and the effect of leachate on the hydraulic conductivity of natural (undisturbed) clays. The study presents the fact that change in hydraulic conductivity of clay is due to the chemical reactions between clay and a permeant. The change induced by such a reaction in the microstructure (micro fabric) of the clay was studied by scanning electron microscope. In order to determine the removal capability of the natural clay, COD, Suspended Solid, Volatile Suspended Solid, Total P, Total Kjedhal Nitrogen, copper, manganese and ferrous were also measured in the influent and effluent of the lab-scale reactor. It was seen that the structure of clay was changed to needle like due to chemical content and the hydraulic conductivity increased due to leachate action.

Nayak et al. (2007) presented the results of a laboratory testing program carried out to determine the hydraulic and compaction characteristics of lateritic soil contaminated by leachate at different percentages. The results indicated a small reduction in maximum dry density and an increase in hydraulic conductivity due to leachate-contamination. The change induced by chemical reaction in the microstructure of the soil was studied by scanning electron microscope before and after contamination of soil with leachate. The structure of the leachate contaminated soil sample appeared to be aggregated in scanning electron microscope analysis. The aggregated structure increases the effective pore space and thus increases the hydraulic conductivity. Compaction characteristics did not change much with the presence of leachate upto 10%. With 20% leachate the maximum dry density decreased slightly indicating excess leachate in the soil.

Arasan and Temel (2008) have performed experiments to investigate the effect of some leachate components on the consistency limits of clay liners. In the study, clays of low and high plasticity and salt solutions such as ammonium chloride, potassium chloride, copper sulphate were used. It was found that for CL clay, the liquid and plastic limits increased with increase in salt concentration upto around 0.2M. All of the salt solutions with concentration upto approximately 0.2M, significantly reduced the liquid limit and plastic limit of CH class clay.

Jia and Yang (2010) has conducted swelling pressures on calcium bentonite mixed with calcium chloride solutions of 0.001, 0.01, 0.1, 1M. The results indicate that swelling pressure will continue a long time, but the primary swelling completed within two hours. The swelling pressure decreases with the increasing of concentration of pore solution.

Singh and Prasad (2007) studied the effects of chemicals on compacted clay liners with inorganic and organic chemicals and bentonite. Experiments were performed using aluminium hydroxide and acetic acid and concluded that acetic acid leads to formation of flocs. Optimum moisture content and maximum dry density reduced when bentonite is added with acetic acid. But upon addition of aluminium hydroxide, MDD reduces but OMC increase by 5%. Strength parameter, Swelling pressure and Hydraulic conductivity decreased upon addition of aluminium hydroxide and acetic acid.

Vandana and Sivapullaiah (2011) studied performance of commercially available organo clay and natural bentonite and mixtures of them in different pore fluids. The pore fluids used for the study include deionised water, ethanol-water mixture pure ethanol and carbon tetra chloride. Organic sorption studies were carried out on synthetic leachate prepared with varying concentration of total organic carbon (TOC). They studied plasticity characteristics, free swell, and compressibility and found that addition of organo clay to bentonite reduces its plasticity characteristics, swelling and also its compressibility. Miscible organic fluid reduces the compressibility of bentonite, organo bentonite and mixture of organo bentonite and bentonite. Immiscible organic fluids increase the compressibility of clay moulded with water

Dhanyasree et al. (2011) has studied about the effect of pore fluids like sodium hydroxide, calcium chloride and acetic acid of different concentration on swelling, shrinkage and shear strength behavior of clay minerals like bentonite and kaolinite by conducting shrinkage limit, free swell test and UCC tests. They concluded that with increase in concentration of NaOH, shrinkage limit and free swell increases, but shear strength decreases for bentonite. In kaolinite, shrinkage limit and shear strength increases, but free swell decreases. Increase in concentration of $CaCl_2$ as pore fluid, increases shrinkage limit and shear strength, but free swell decreases. With increase in concentration of CH_3COOH free swell decreases for both kaolinite and bentonite.

Nader et al. (2011) studied the effect of three inorganic salts, NaCl, $CaCl_2$ and $MgCl_2$ on liquid limit, compaction, one dimensional consolidation and swelling behaviour of a commonly used clay soil in impermeable bottom barrier in Kahrizak landfill. Also the effect of bentonite content by adding different percentage of this special clay mineral, on these properties was investigated. Results indicated that increase in the salt concentration and cation valance increases the maximum dry density and hydraulic conductivity of the mixture. Also it decreases the optimum water content, liquid limit, compression index and swelling volume. They concluded that the main reason of such effects is the changes which occur in diffuse double layer of clay particles.

Ramakrishnegowda et al. (2011) studied the effect of interaction of shedi soil containing both kaolinite and smectite minerals with alkali on various geotechnical properties such as the index properties, compaction characteristics, volume change behaviour, strength characteristics and hydraulic conductivity. It was seen that the plasticity index of soil decreases and optimum moisture content increases with increasing concentration of alkali content. The shear strength of soil decreases due to decrease in the cohesion of the soil particles and the hydraulic conductivity of the soil increases with higher concentrations of alkali solution.

Olgun and Yildiz (2012) studied the shear strength and structural changes in two different clays- kaolinite and montmorillonite, with various precentage of acetic acid (20%, 40%, 60% and 80%) used as pore fluids. The experiment has shown significant increase in shear strength and shear strength parameter values in both clays with increasing acetic acid content. These increases were higher in the clay with montmorillonite. In kaolinite, liquid limit increased with increasing acetic acid, but decreased in the other clay. The optical microscope images and scanning electron photomicrographs indicated that lumpy formations occurred in both clays with the addition of acetic acid, and their structures began to resemble that of a silt and fine sand form.

Musa (2012) presented the results of a laboratory investigation of the effects of municipal solid waste on the geotechnical properties of soils. Soil samples were taken from three trial pits (two uncontaminated and one contaminated) at depths of 0.5, 1.0 and 1.5 m. Investigation results has shown that municipal solid waste lowers the specific gravity, maximum dry density with higher optimum moisture content, cohesion and angle of internal friction. Whereas it increases the natural moisture content, fine particles content, coefficient of permeability, coefficient of consolidation and coefficient of volume compressibility of the soil. These effects reduced with depth.

A laboratory testing program was carried out by Goswamy and Choudary (2013) in their study, to determine the properties of leachate contaminated soils. MSW samples and leachate contaminated soil samples are used in this study. Contaminated soil samples are prepared by mixing the soil with different concentration of contaminants by adding equivalent weight of molecular mass of contaminant in one litre of distilled water to get particular normality. The result shows that MSW samples and the leachate contaminated specimen effects the chemical characteristics of the soil. There is an increase in the cation exchange capacity of the soil also. This can be attributed to the increase in the pH value of the soil with leachate.

Pillai et al. (2014) have studied the effect of leachate on physicochemical and geo-engineering properties of soil by treating it with synthetic leachate. The study indicated that solid waste dumps can reduce the overall soil strength and consequently its usefulness as a foundation material. The general deterioration in soil properties is caused due to the chemistry of leachate and soil. Leachate from solid waste can also result in pollution of ground water sources due to percolation of toxic and hazardous chemical.

2.4 Leachate Migration in the Subsurface

Leachate that escapes from a landfill unit may migrate through the unsaturated zone and eventually reach the water table and then get transported through the saturated zone to a point of discharge (i.e., a pumping well, a stream, a lake, etc.).

Subsurface contaminant movement depends on factors such as the volume of the liquid component of the waste, the chemical and physical properties of the leachate constituents, the loading rate, climate, and the chemical and physical properties of the subsurface (saturated and unsaturated zones). A number of physical, chemical, and biological processes also may influence migration. Complex interactions between these processes may result in specific contaminants being transported through the subsurface at different rates.

The following sections describe the different processes controlling contaminant transport in the subsurface in detail.

2.4.1 Physical Processes

2.4.1.1 Advection

Advection is the process by which solute contaminants are transported by motion of ground water. The rate and direction of transport of a non-reactive solute will be same as that of ground water flow. Advective transport is a function of the subsurface hydraulic conductivity, porosity, and hydraulic gradients (Freeze and Cherry, 1979).

2.4.1.2 Hydrodynamic dispersion

Hydrodynamic dispersion is a non-steady, irreversible mixing process by which a contaminant plume spreads as it is transported through the subsurface. It is a combination of mechanical dispersion and molecular diffusion. Mechanical dispersion results from variations in pore velocities within the soil or aquifer. Dispersion results in the spreading of solute along (longitudinal dispersion) and perpendicular (transverse dispersion) to the direction of ground water flow. Longitudinal dispersion is typically one to two orders of magnitude greater than horizontal transverse dispersion. Increased dispersion results in a larger volume of contaminated aquifer with lower concentrations. Advective transport and associated mechanical dispersion dominate the contaminant transport in formations of medium to high hydraulic conductivity.

Molecular diffusion occurs as a result of contaminant concentration gradients. Chemicals will move from areas of high concentration to areas of low concentration. Diffusion is driven by the solute concentration gradients according to Fick’s Law and is a slow process relative to advection in the highly permeable aquifers. The result of diffusion is dilution or reduction in the contaminant concentration. In formations of low hydraulic conductivity, including clay liners, diffusive transport is frequently the controlling mechanism (Kehew, 2001; Zheng and Bennett, 1995; USEPA, 2011).

Fig. 2.2 presents some of the potential contaminant fate and transport mechanisms conceptually.

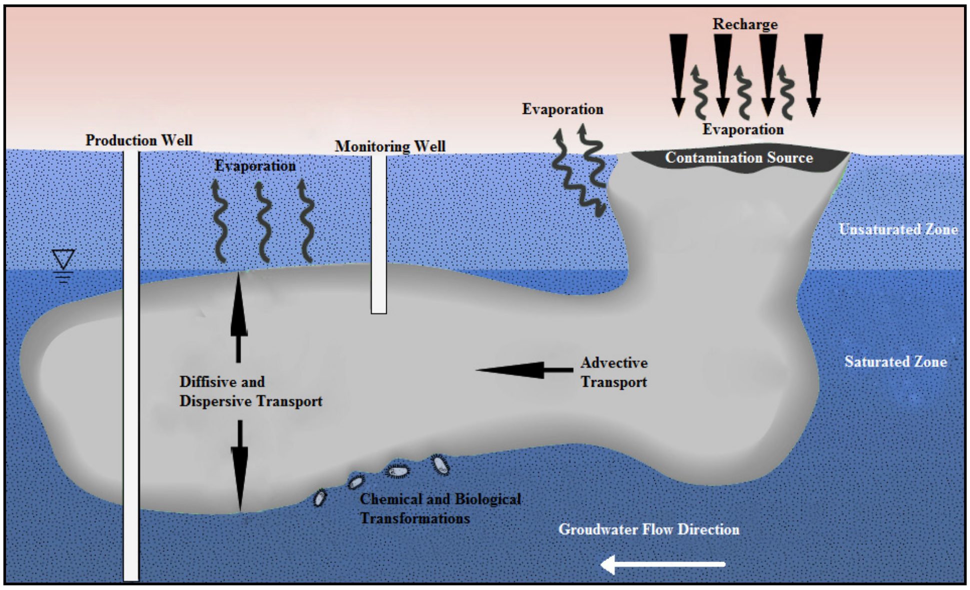


Fig. 2.2 *Conceptual Diagram of Contaminant Fate and Transport Mechanisms in the Subsurface*

2.4.1.3 Mechanical filtration

Mechanical filtration removes the ground water contaminants that are larger than the pore spaces of the soil. Thus, the effects of mechanical filtration increase with decreasing pore size within a medium. Filtration occurs over a wide range of particle sizes. The retention of larger particles may effectively reduce the permeability of the soil or aquifer (USEPA, 2011).

2.4.1.4 Physical sorption

Sorption is the tendency for a chemical to adsorb to the aquifer grains. It is a function of Van der Waals forces, and the hydrodynamic and electrokinetic properties of soil particles. Sorption onto mineral surfaces is difficult to quantify (Fetter, 1993; USEPA, 2011).

2.4.1.5 Multiphase fluid flowg

Multiphase fluid flow occurs because many solvents and oils are highly insoluble in water and may migrate in the subsurface as a separate liquid phase. If the viscosity and density of a fluid differ from that of water, the fluid may flow at a different rate and direction than the ground water. If the fluid is denser than water, it may reach the bottom of the aquifer (top of an aquitard) and alter its flow direction to conform to the shape and slope of the aquitard surface (USEPA, 2011).

2.4.1.6 Hydraulic conductivity

Hydraulic conductivity is a measure of the ability of geologic media to transmit fluids. It is a function of the size and arrangement of water-transmitting openings (pores and fractures) in the media and of the characteristics of the fluids like density, viscosity, etc. (USEPA, 2011).

2.4.1.7 Secondary porosity

Secondary porosity in rock may be caused by the dissolution of rock or by regional fracturing. In soils, desiccation cracks or fissures causes secondary porosity. Fractures or macro pores respond quickly to rainfall events and other fluid inputs and can transmit water rapidly along unexpected pathways. Secondary porosity can result in localized high concentrations of contaminants at significant distances from the facility. The relative importance of secondary porosity to hydraulic conductivity of the subsurface depends on the ratio of fracture hydraulic conductivity to inter-granular hydraulic conductivity (Kincaid et al., 1984; USEPA, 2011)

2.4.2 Chemical Processes

2.4.2.1 Precipitation/dissolution

When the soluble concentration of a contaminant in leachate is higher than that of the equilibrium state, precipitation occurs. When the soluble concentration is lower than the equilibrium value, the contaminant exists in solution. The precipitation of a dissolved substance may be initiated by changes in pressure, temperature, pH, concentration, or redox potential. Precipitation of contaminants in the pore space of an aquifer can decrease aquifer porosity (Aller et al., 1987; USEPA, 2011).

2.4.2.2 Chemical adsorption/desorption

Solutes become attached to the solid phase by means of adsorption. The organic carbon content of the porous medium and the solubility of the contaminant are the important factors that affect sorption (USEPA, 2011).

2.4.2.3 Oxidation and reduction reactions

Oxidation and reduction reactions involve the transfer of electrons and occur when the redox potential in leachate is different from that of the soil or aquifer environment. Redox reactions are important processes for inorganic compounds and metallic elements. It affects the solubility, complexing capacity, and sorptive behaviour of constituents, and thus controls the presence and mobility of different substances in water (USEPA, 2011).

2.4.2.4 Hydrolysis

Hydrolysis is the chemical breakdown of carbon bonds in organic substances by water and its ionic species H^+ and OH^-. Hydrolysis is dependent on pH and redox potential and is most significant at high temperatures, low pH, and low redox potential (USEPA, 2011).

2.4.2.5 Ion exchange

The capacity of soils to exchange cations is called the cation exchange capacity (CEC). CEC is affected by the type and quantity of clay mineral present, the amount of organic matter present, and the pH of the soil (USEPA, 2011).

2.4.2.6 Complexation

Complexation involves reactions of metal ions with inorganic anions or organic ligands. The metal and the ligand bind together to form a new soluble species called a complex. Complexation can either increase or decrease the concentration of a constituent in solution by forming soluble complex ions (USEPA, 2011).

2.4.3 Biological Processes

Bio degradation of contaminants may result from the enzyme-catalyzed transformation of organic compounds by microbes. Naturally occurring bacteria within ground water use organic chemicals as food sources and help break down of contaminants into degradation products. Contaminants can be degraded to harmless by-products or to more mobile and/or toxic products through one or more of several biological processes.

Depending on the types of organic compounds, degradation may occur under aerobic and anaerobic conditions. Oxygen is needed for aerobic organisms to degrade organic compounds. Under the aerobic degradation processes, electrons will be transferred from the organic material to oxygen (electron acceptor). This process reduces oxygen and transforms the organic material to carbon dioxide and a new compound. The anaerobic degradation process is similar to the aerobic degradation process except that other common electron acceptors, such as nitrate, sulfate, and inorganic carbon, are used instead of oxygen (Kehew, 2001; USEPA, 2011).

2.5 Leachate Migration Models

Models are a simplified representation of the real system, and hence cannot fully reproduce or predict all site characteristics. Errors are introduced as a result of simplifying assumptions, lack of data, uncertainty in existing data, poor understanding of the processes influencing the fate and transport of contaminants and, the limitations of the model itself. Therefore, model results should be interpreted as estimates of ground-water flow and contaminant transport. The model results should be calibrated to obtain the best fit to the observed data. The accuracy of the results obtained from modelling efforts should then be validated. Model validation, which is the comparison of model results with experimental data or environmental data, is a critical aspect of model application, and is particularly important for site-specific evaluations (USEPA, 2011).

Several reports present detailed discussions of the issues associated with model selection, application and validation:

EPA's Exposure Assessment Group has developed suggested recommendations and guidance on model validation (Versar, 1987). Weaver et al. (1989) discuss options for selection and field validation of mathematical models. Donigian and Rao (1990) address each of these issues, and present several options for developing a framework for model validation. A report by the National Research Council (1990) discusses the issues related to model application and validation and provides recommendations for the proper use of ground-water models. Based on the above reports to select an appropriate model, the complexity of the site hydrology and the availability of data should be considered. If data are insufficient, a highly sophisticated and complex model should not be used. As each site is unique, the modeller has to determine the important conditions and processes at a specific site and then select a suitable model. Computer models also can be used to make predictions about leachate generation and migration. But these predictions are highly dependent on the quantity and quality of the available data (USEPA, 2011). The great advantage of the computer modelling is large amount of data can be processed promptly, while experimental modification can be provided by minimal effort, in order that many possible situations for a given problem can be studied in great details.

In the last few decades, hundreds of computer codes for simulating various aspects of soil ground water systems have been developed. Some of these softwares are ‘Ground water Modelling System (GMS)’, ‘Ground water Vistas’, ‘Visual MODFLOW’, ‘MODFLOW SURFACT’, ‘POLLUTE’ etc. and they are being used all over the world by different environmentalists, hydrologists and hydrogeologists (Boulding and Ginn, 1995). Among these, MODFLOW (three-dimensional block-centred finite-difference ground water flow model), is a computer program, which has been developed by McDonald and Harbaughin, 1988 in the form of modular three- Dimensional ground water flow model for US Geological Survey. MODFLOW is able to simulate a wide range of flow in porous media with wide varieties of systems and standard including ground water flow, transport of contamination and mine dewatering. MT3DMS is a three dimensional multi-species contaminant transport model for simulating of solute transport processes. It is based on the advection-dispersion formulation for modelling of saturated and unsaturated zone and also interaction between surface water and subsurface water. MT3DMS contains different techniques including the third-order Total Variation Diminishing (TVD), fully implicit Finite-Difference Method (FDM), and particle tracking based Method of Characteristics (MOC). There has been a wide development in MT3DMS since the first released in 1990 which was known as MT3D. It supports simulation of different species mass transport. Visual MODFLOW combines MT3DMS and MODFLOW to flow and transport modelling under different condition. (Seyed et al., 2010; Harbaugh, 2005; Zheng, 2009).

Several case studies on modelling of contaminant transport and ground water flow using ‘Visual MODFLOW’ has been reported.

Mondal and Singh (2009) have investigated the contaminant migration at an industrial belt by constructing a mass transport model using ‘Visual MODFLOW’ and ‘MODPATH’. The study has indicated that even if the pollutant sources were reduced to 50% of the present level, TDS concentration level in the ground water, even after 20 years, would not be reduced below 50% of it.

Rajamanickam and Nagan (2010) has conducted a ground water quality model study using ‘Visual MODFLOW’ at Amaravathi River Basin of Karur District, Tamil Nadu. The model is used for simulation of the ground water quality for 15 years under different scenarios. The simulation results showed that, even if the effluent meets the discharge standards for the next ten years, ground water quality cannot be improved and if the units go for zero discharge, improvement in the quality of ground water can be observed in few years.

Seyed and Mustapha (2011) have presented a case study on the movement of phosphorus pollution in Seri Petalling Landfill leachate. ‘Visual MODFLOW’ was used to predict subsurface and surface migration of pollution within 10 years. The prediction shows phosphorus migrated widely to further places such as river and it has adverse effect on environment, animal and human.

Rao et al. (2011) assessed the ground water contamination from a hazardous dump site in Ranipet, Tamil Nadu, India. Tanneries located in an industrial development area of Ranipet manufactured chromate chemicals during the period of 1976-1996. Chromium levels in the ground water were found up to 275 mg/l in this area. The available hydrogeological, geophysical and ground water quality data bases have been used to construct a ground water flow and mass transport model for assessing the ground water contamination and it has been calibrated for the next 30 years. The migration has been found to be very slow, with a ground water velocity of 10m/year. It has been reported that the untreated effluent discharge adjacent to the chromium dump site is most influential in the migration of contaminants.

A study to assess ground water in Auja-Tamaseeh basin in Tulkarem area-West Bank was conducted by Samhan and Ghanem (2012). A steady state calibration flow model as well as solute transport model was built using the 'Visual MODFLOW' software. A stress period of 10 years (2005 - 2015) was assigned to study its tendency to contamination. The model results show that there is a pollution risk due to the human activities in the area.

2.6 Measures to Reduce Soil Pollution due to Landfill Leachate

Today, landfill sites are constructed and operated to strict technical standards in order to reduce environmental effects. When municipal solid waste landfills are filled to capacity, they are capped with a final cover that keeps out infiltration of water and keeps in gas and volatile components. In spite of many advantages of sanitary landfills, the major drawback is the generation of heavily polluted leachate, presenting significant variations in both volumetric and chemical composition of it. Leachate from the landfill, percolate through the soil and contaminate soil and ground water, thus presenting a risk to human and environmental health which should be prevented.

2.6.1 Liners

Landfill liners are designed and constructed to create a barrier between the waste and the environment and lead the leachate to collection and treatment facilities. This is done to prevent the uncontrolled release of leachate into the environment. Historically compacted clay layers having a hydraulic conductivity not greater than 1 x 10^{-7} cm/sec., were most frequently used hydraulic barrier layers in landfill cover. Compacted clay layers are to be of low cost, large leachate attenuation capacity and resistance to damage. Due to non-availability of suitable soil or to prevent the use of productive / fertile soil for compacted clay layers, it is necessary to develop alternative material by blending industrial process wastes, with local non-productive soils to achieve a suitable material for landfill cover. Various stabilization techniques are available to improve the properties of liner like addition of materials like cement, lime, bitumen etc.

Various studies on clay and other materials were reported to improve the liner properties

Daniel (1984) presented data from four projects in which rates of leakage from ponds lined with clay significantly exceeded the rates that would have been predicted on the basis of laboratory permeability tests. The actual hydraulic conductivities of the clay liners were generally found to be 10 to 1000 times larger than values obtained from laboratory tests on either undisturbed or re-compacted samples of the clay liner. The source of difficulty with laboratory permeability tests is the problem of obtaining a representative sample of soil for testing.

Daniel and Yung (1993) investigated whether a clayey soil from a site in Texas could be compacted to have low hydraulic conductivity, low potential to shrink and crack when dried and adequate shear strength to support structural loadings. Test specimens were compacted with different compactive energies over a range of water content. This study illustrates that a range of water content near the optimum value measured with the highest compactive energy proved to be suitable in meeting the objective of low hydraulic conductivity and shrinkage potential.

Abichou et al. (2000) conducted laboratory study to assess the suitability of foundry green sands as hydraulic barriers. Compaction test and permeability tests were conducted on the samples. It was found that foundry sands having liquid limit >20, plasticity index >2, or bentonite content >6% can be compacted to achieve hydraulic conductivities of $1x10^{-9}$m/s. But he reported that hydraulic conductivity of foundry sands is sensitive to the compaction water content, and compactive effort that affect hydraulic conductivity of compacted clays but not as sensitive to compaction conditions as compacted clays

Cho et al. (2002) has studied the effect of dry density and bentonite content on the hydraulic conductivity of soil-bentonite mixture. In the study the hydraulic conductivities for the soil-bentonite mixtures with a dry density of 1.6 mg/m^3 decrease rapidly with increasing bentonite content and are less than 1 x 10^{-9} m/s when the bentonite content is higher than 10% by weight. The study concludes that if the compaction density of the mixture is appropriate, the soil-bentonite mixture has a low hydraulic conductivity enough to inhibit contaminant transport by advection through landfill liner.

Osinubi and Charles (2006) conducted laboratory tests on three lateritic soil samples to illustrate some pertinent considerations in the design of compacted lateritic soil liners and covers. The three design parameters investigated are hydraulic conductivity, desiccation-induced volumetric shrinkage, and unconfined compressive strength. Test specimens were compacted at various molding water contents using four compactive efforts. The studies showed that these soils can be well compacted on the dry side of the line of optimum to obtain hydraulic conductivities less than or equal to $1\text{x}10^{-7}$ cm/s. The volumetric shrinkage strain was identified as one of the most important design parameter for lateritic soils. The shapes of the acceptable zones were affected by the fine contents of the soils.

Patil et al. (2009) investigated the suitability of Kolar soil and Granite polish wastes as an alternative material for landfill liners and covers. The performance of these materials under different physicochemical environments by adding sodium bentonite was examined. The result of the study has shown that addition of sodium bentonite brings the permeability to the required range to be used as an alternative material for landfill liners and covers.

Osinubi and Eberemu (2010) investigated the unsaturated hydraulic conductivity of compacted lateritic soil treated with bagasse ash at different percentages to a maximum of 12% and compacted at optimum moisture content and 2% wet and dry of optimum with different compactive efforts to check the suitability of the waste containment application. Unsaturated hydraulic conductivity was determined using Brooks - Corey and Van Genuchten models and has shown a decreased value with higher matric suction regardless of the bagasse ash content, compactive effort and molding water content. On the other hand, unsaturated hydraulic conductivity increased with bagasse content for the various matric suctions. But in all cases their values were less than 1 x 10^{-9} m/s even at a low suction value of 10 kN/m^2.

Osinubi and Moses (2011) have investigated the use of compacted foundry sand treated with bagasse ash as hydraulic barrier material. Foundry sand was mixed with different percentage of bagasse ash (2%, 4%, 6%, 8%, and 10%). Typical tests such as permeability test, UCC, shrinkage tests were carried out to access the suitability as liner material. Specimens treated with a minimum of 4% bagasse ash met the required minimum UCC value of 200 kN/m^2. Hydraulic conductivity values recorded for 2% and 4% bagasse ash treatment met the regulatory requirement of 1x10^{-9} m/s. The overall acceptable zone for bagasse ash treated foundry sand for use in waste containment application was achieved with 4% bagasse ash content

Moses and Oriola (2011) have investigated the suitability of compacted black cotton soil treated with cement kiln dust as hydraulic barrier material. Specimens were prepared at molding water contents of optimum moisture content and at 2% and 4% wet and dry of optimum the compactive energy levels of British Standard Light (BSL) and West African

Standard (WAS). Index properties, hydraulic conductivity, volumetric shrinkage strain and unconfined compressive strength tests were carried out. Results obtained showed slight changes in index properties. Hydraulic conductivity values recorded at both BSL and WAS produced satisfactory results that met the regulatory requirement of $1x10^{-9}$ m/s at all treatment levels.

Satyanarayana et al. (2013) investigated whether the red soil with additives like bentonite can be proposed as a liner material. The parameters studied are coefficient of permeability, unconfined compressive strength, compaction characteristics. It was found that 15% dosage of bentonite satisfies the hydraulic conductivity and other functions as a liner material. Increase in percentage of bentonite increases optimum moisture content and decreases maximum dry densities. There is an increase in the free swell Index and UCC with increase in bentonite content. But the permeability decreases with the increase in bentonite.

According to Mishra (2013), a mixture of soil-bentonite comprised of two contrasting soil with regards to the grain size, hydraulic conductivity, chemical activity and strength, when combined in the optimum proportion, can form an excellent seepage liner material that is dimensionally stable and have a low hydraulic conductivity. The performance of the clay barrier to leachate depends on the amount of bentonite present in it. He tried to study the effect of the variation of the bentonite amount in the two mixtures of soil and bentonite in different proportions. Two different salt solutions of NaCl and $CaCl_2$ were chosen for the study. The results showed that an increase in the bentonite fraction in the mixture decreased the hydraulic conductivity and increased the compressibility of the mixture. This decrease in hydraulic conductivity was quite significant for lower salt concentration range of NaCl and $CaCl_2$ solution. A brief review of literature of geosynthetic clay liners and the corresponding list of refence is appended in Appendix.

2.6.2 Permeable Reactive Barriers

Permeable Reactive Barrier (PRB) is a continuous, in-situ permeable treatment zone designed to intercept and remediate a contaminant plume. The treatment zone may be created by using reactive materials and as contaminated water passes through the reactive zone of the PRB, the contaminants are either immobilized or chemically transformed to a more desirable (e.g., less toxic, more readily biodegradable, etc.) state. Therefore, a PRB is a barrier to contaminants, but not to ground-water flow. Fig. 2.3 shows the pictorial representation of permeable reactive barrier for contaminant remediation.

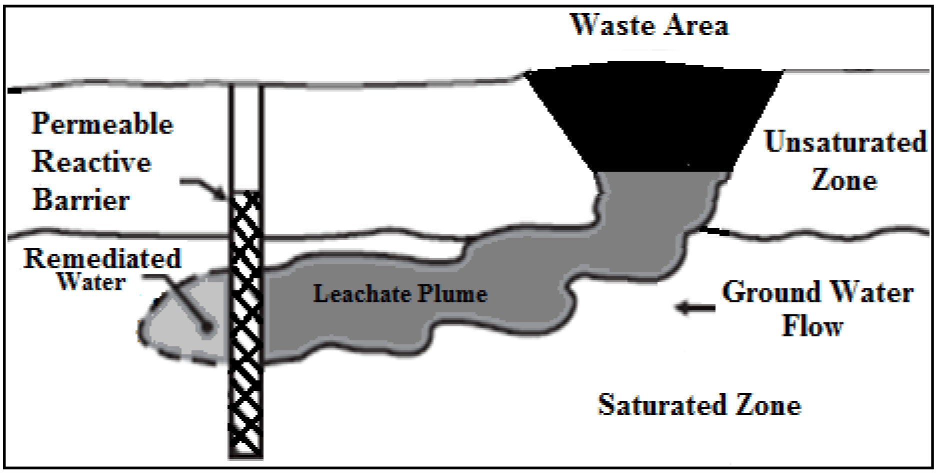


Fig. 2.3 *Permeable Reactive Barrier for Contaminant Remediation*

Various researches on the performance and effectiveness of different materials as reactive medium have been reported.

Johnson et al. (2008) has analyzed the physical and chemical characteristics of samples taken from a Zero-valent iron permeable reactive barrier at Cornhusker Army Ammunition plant, Nebraska. The initial hydraulic conductivity of the native materials was less than that of the PRB. The study indicates that flow through the PRB decreased significantly over time. So the choice of PRB fill materials with higher hydraulic conductivity values than the native aquifer materials may not be sufficient to ensure good long-term hydraulic performance of the PRB.

Henderson and Demond (2007) have studied the long-term performance of Zero-valent iron as reactive medium of permeable reactive barriers. They analyzed data from field installations of in-situ Zero-valent iron PRBs to determine the parameters contribute to PRB failure. The quantitative analyses performed here suggest that high influent pH, internal redox potential, high influent concentrations of nitrate, chloride, and alkalinity, are problematic for PRBs. As many PRBs begin their second decade of operation, they may be nearing the end of their estimated life spans. Thus, more detailed and comprehensive field monitoring is crucial to determine modes of failure and cost effectiveness of PRBs as a long term treatment technology.

2.7 Agro Industrial Waste as Alternative Reactive Medium

Awareness and knowledge of environmental concerns and sustainability have never been as acute as now. This is particularly true, if we are to provide responsible land management for waste handling and natural resource management.

The management of waste materials can be achieved by utilizing them to reduce the concentration levels of the pollutants on site below critical by containment or deactivation of the pollutants on site.

Several previous studies have been reported on the utilization of the waste materials for reduction of chemical concentration**.**

Ash et al. (2006) has studied the application of activated carbon prepared from waste coir pith for the decolourisation of dye industry effluents and removal of toxic metals from their aqueous solutions. It has been proved that the activated carbon prepared from waste coir pith with phosphoric acid treatment is very effective for the decolourisation and removal of toxic metals from effluents. Thus the coir pith, which is regarded as a waste and pollutant, can be converted to a value added product.

Chattopadhyay and Chakravarty (2009) investigated the role of a natural geotextile from jute as a liquid barrier for the containment of sulfate. The study shows that an impregnated jute geotextile may aid in containing sulfate/similar pollutants present in soils.

Violet et al. (2012) in their study investigated the utilization of the activated carbons obtained from agricultural waste materials namely coir pith, rice husk and bagasse, for the removal of Congo red dye. The effect of pH, contact time and adsorbent dosage was studied for the activated carbons obtained from the three agricultural wastes. The decolourizing ability of them is higher for coir pith and followed by rice husk and bagasse, in order.

Mohammed et al. (2013) presents the results of experimental study on the clayey soil samples mixed with different percentages of rice husk materials for the improvement of clayey soil characteristics. It was found that the liquid limit of the three soils has been decreased by about (11% to 18%) with the addition of 9% RHA, while the plasticity index decreased by about (32% to 80%). Treatment with rice husk showed a general reduction in the maximum dry unit weight with increase in the rice husk content to minimum values at 9% rice husk content. The optimum moisture content generally increased with increase in the RHA content. There is enormous increase in the unconfined compressive strength with increase in rice husk content for the soil to its maximum at RHA between (6% to 8%).

Bhalla et al. (2014) has investigated the feasibility of industrial by-products as potential alternative medium to conventional gravel in the drainage layer of leachate collection system as permeable reactive barriers (PRBs) for landfill leachate treatment. Industrial waste, such as steel plant by-product (waste slag), tire industry by-product (scrap-tire-shreds) and rice sheller by-product (rice husks) were studied. The availability and are the important criteria in selecting a reactive material. These Industrial waste materials are inexpensive and abundant, and are, therefore, ideal for low cost leachate treatment. Leachate treatment efficiency was evaluated on the basis of percentage reduction in concentration of leachate parameters before and after treatment by passing through test cells having different combinations of conventional gravel and various Industrial by-products with total thickness 500 mm of PRBs (multi-barrier). Treated leachate samples were collected from test cells at different periods. The percentage reduction in various leachate parameters was maximum with test cell having combination of rice husk, waste slag, scrap-tire-shreds and gravel layer in equal proportion as PRBs (multi-barrier). It has been observed that leachate sample after passing through combined beds of industrial by-products and conventional gravel gave better results in comparison to conventional gravel bed singly.

2.8 Summary and Need for Present Study

The critical review of literature showed that the chemical composition of the leachate from a municipal solid waste landfill site depends upon the age, characteristics of waste, seasonal variation, subsurface condition, decomposition rate etc.. All these factors decide the toxicity of the leachate. According to the literature, it is proved that a municipal solid waste landfill leachate is a composition of mixed contaminants. While transporting leachate through surrounding soil, the chemicals present in that is liable to change the properties of soil. The effect of the leachate on soil properties may depends upon the concentration of chemicals, period of contact of the soil with the chemicals and type of the soil. From the study of literature, it is observed that the research on changes in engineering properties of soil due to the presence of mixed contaminants in leachate is limited. Hence it is desirable to study the effect of leachate with mixed contaminants on soil properties. The transportation pattern of the leachate may also have effect on the surroundings. If the path of pollutant transport and its effect of soil properties can be established, precautions to reduce the extent of pollution can be made.

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Chapter 3

A CASE STUDY ON MUNICIPAL SOLID WASTE LANDFILL

Contents

3.1 Introduction

The greatest environmental risk that unsanitary land filling of solid waste creates is the contamination of ground water and soil. Hence, to decide whether the leachate is to be collected and treated, or may be allowed to discharge into the adjoining soil or surface water body, it is essential to have an estimate on the composition and strength of the leachate and variation of leachate contaminants with distance from landfill. Most of the landfills in developing countries do not have any liner at the base, or a drainage layer or a proper top cover, which results in the potential problem of ground water/surface water contamination due to the leachate (Dinesh and Babu, 2003; Raman and Sathiya, 2008).

Enormous amount of solid waste produced in and around Kalamassery area were dumped to a solid waste landfill site at Kalamassery. This municipal solid waste was an inevitable byproduct of human and small scale industrial activity, which was disposed through dumping. The landfill site nearer to Kalamassery was open dumpsite and such dumpsites require only low operating costs. Because of the lack of expertise and equipment there were no systems for leachate collections. This open dump was unsightly, unsanitary and smelly and, attracted scavenging animals, rats, insects, pigs pests etc.. Surface water, percolating through the waste, dissolves out and leaches harmful chemicals, and was carried away from the dumpsites in surface or subsurface runoff. These chemicals were insidious and lead to the phenomenon of bio-accumulation and bio-magnifications. These chemicals may cause environmental problems, if the leachate migrates into the ground water**.** The people in and around the dumping site are depending upon the ground water for drinking and other domestic purposes. As the public health concern, the ground water should be free from physical and chemical hazards (Raman and Sathiya, 2008).

In the present investigation, the typical unlined MSW landfill area was selected for a case study which is situated at Kalamassery municipality, Cochin, Kerala. The chemical composition of leachate was estimated from the water samples collected from bore holes near MSW landfill. The degree of soil contamination is analyzed by conducting various physical and chemical parameters in the soil samples at different depths and distance from the landfill.

3.2 Description of Site

Ernakulam district is about 38 km from north to south and 48 km from east to west, and it is bounded by a 46.2 km coast line of the Arabian Sea on the west, Kottayam and Alappuzha districts on the south, Idukki on the east and Thrissur on the north. It lies between latitude 9° 42' to 10' 18' 00" north and longitude 76° 12' 00" to 76° 46' 00".

Kalamassery is a municipality in Ernakulam district which sprawls over 27 km^2. It is also a part of the Kochi metropolitan area. As of 2001 India Census, Kalamassery had a population of 63,176 and having a density of 2013/km^2. The soil consists mainly of recent sediments like Alluvium, Teri's Brown sand which had a sticky nature etc.. Red colored sticky soil also found some places in this area. Climate is generally tropical, heavy rains accompanied by thunder are common from June through September. The average annual rainfall is about 3500 mm. The Periyar river flows through Kalamassery. It is a region of industrialization with several factories manufacturing chemicals and fertilizers, as well as IT companies. Fig. 3.1 shows the study area.

This site is spread over an area of about 4 km^2 and situated near the National Highway, NH-47. The volume of waste being dumped at the dump yard was approximately 50000 kg/day in 2008. The waste dumped at this site includes domestic waste, which include kitchen waste, paper, plastic, glass, cardboard, cloths, etc. and, construction and demolition waste consists of sand, bricks and concrete block. Further waste from the poultry market, fish market, slaughter house, dairy farm and non-infectious hospital waste were also dumped. Thus the site was a non-engineered low lying open dump with a huge heap of waste up to a height of 10-18 m. The waste disposal was in an uncontrolled manner with respect to frequency of deposition and quantity, and without any segregation. It was not possible to get the cross section of the landfill within the dump area whereas a typical sub soil profile and ground water table location is shown in Fig. 6.2

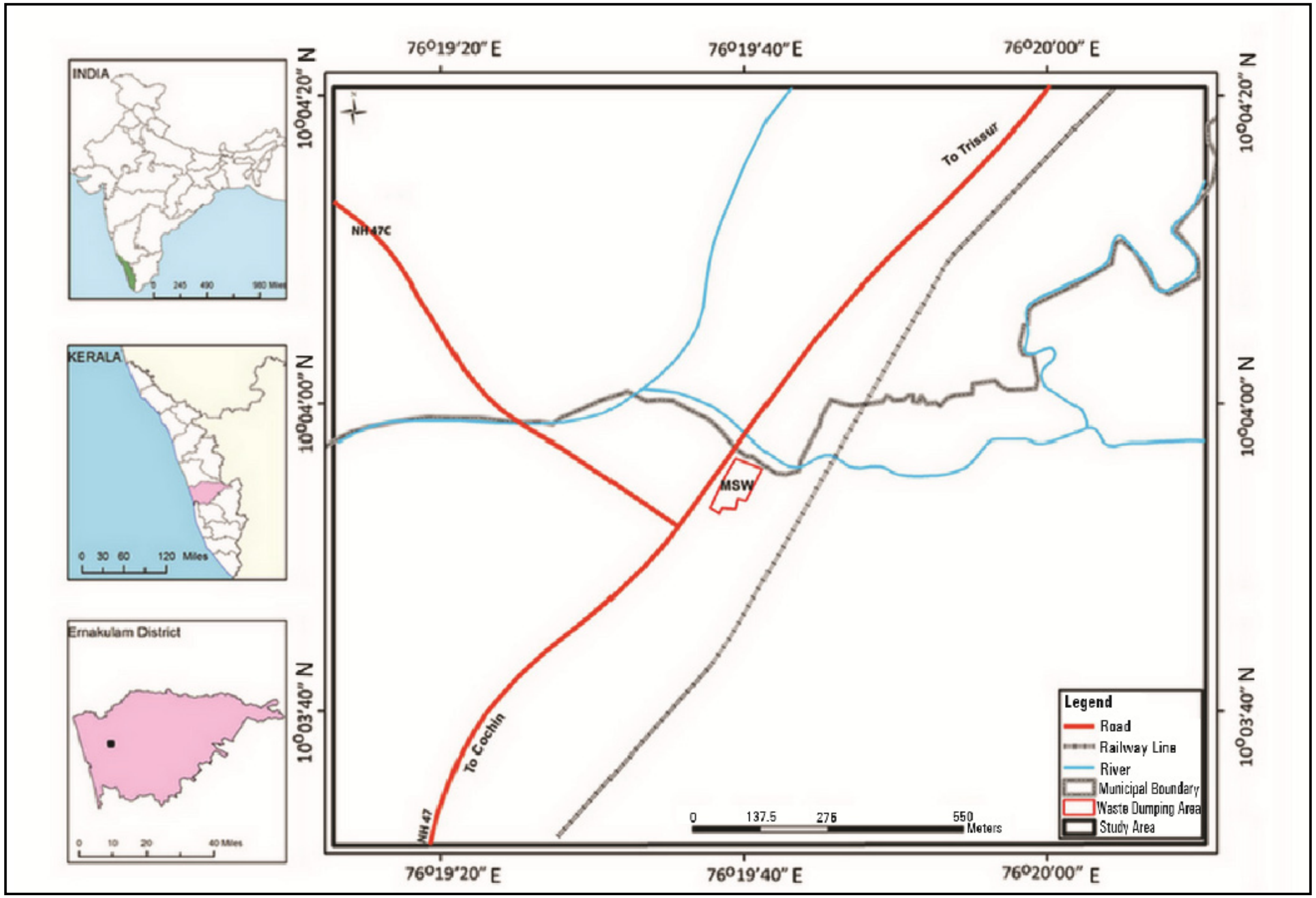
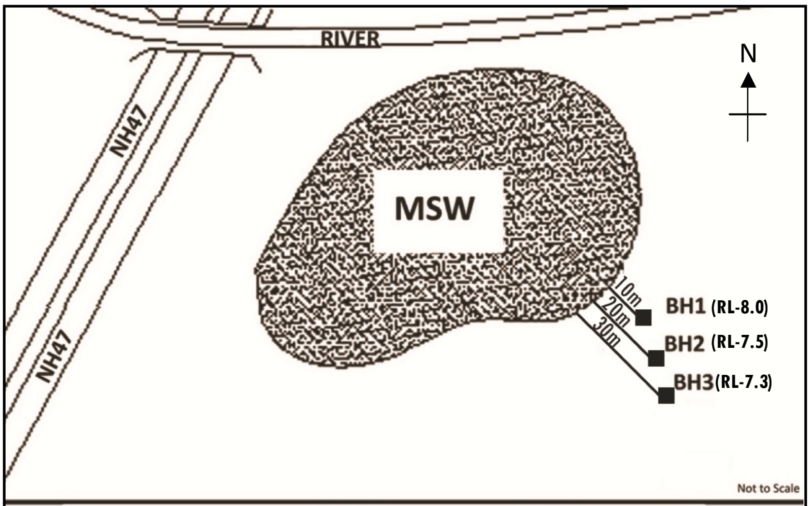


Fig. 3.1 *Study Area*

Fig. 3.2 *Photograph of Study Area*

3.3 Collection of Soil and Leachate Samples

The photograph of the study area is shown in Fig.3.2. Since the landfill site was not equipped with a leachate collecting system, the leachate from the base of the landfill was collected randomly from three different locations at 10 m lateral spacing from the boundary of landfill (Fig. 3.3) for the study purpose. Polluted soil and water samples were collected from three bore holes after removing the surface debris. Sample collection was done as per the IS: 3025 (Part 1) (1987). The subsurface soil dug with a hand auger (Fig. 3.4) to a depth of about 1.5 m (the depth at which water table was noted). The samples were collected directly from the auger. Three sets of soil samples (5 kg each) were recovered at 0.5 m depth intervals from each bore hole and it were taken into the sterile containers and labeled.



	Latitude (N)	Longitude (E)
BH1	10°3’53.23”	76°19’41.52”
BH2	10°3’53.17”	76°19’41.77”
BH3	10°3’53.03”	76°19’41.91”

Fig. 3.3 *Location of Bore Holes*

Fig. 3.4 *Sample Collection using Hand Auger*

3.4 Preparation of Leachate and Soil Samples for Chemical Analysis

According to American public health association, methods of sample preservation are intended generally to retard biological action, hydrolysis of chemical compounds and complexes and reduce volatility of constituents. Preservation methods are limited to pH control, chemical addition, refrigeration and freezing (APHA, 1995). Table 3.1 lists the standard preservation methods by constituents.

Table 3.1 *Standard Preservation Methods by Constituents**

Sl.No.	Parameters	Preservation method	Maximum storage as per EPA regulatory
1	pH	Analyse immediately	2 hours
2	TDS	Refrigerate at 4°C till analysis and analyse as soon as possible	-
3	BOD	Refrigerate	48 hours
4	COD	Analyse as soon as possible or add H_2SO_4 to $pH<2$	28 days
5	Alkalinity	Refrigerate	14 days
6	Chloride	None required	-
7	Nitrate	Add H_2SO_4 to $pH<2$ and refrigerate	48 hours

**(APHA 1995)*

Sample preservation using preservatives is difficult because almost all preservatives interface with some of the tests. Storage at low temperature (4°C) is the best way to preserve most samples (APHA, 1995). After the soil sampling, the leachate samples (water samples) were collected from each bore holes and immediately transferred to the lab and refrigerated at 4°C.

The analysis was done as per the standard methods for the examination of water and wastewater, prescribed by American Public Health Association (APHA, 1995). Various physico-chemical parameters examined in leachate samples include pH, total dissolved solids (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), alkalinity, chloride and nitrates. The dissolved oxygen content of liquid was determined by the azide modification of the Winkler's method before and after incubation for five days at 20^0C. The difference gave the BOD of the sample. For optimum biochemical oxidation, the sample was oxidized under reflux with a known amount of potassium dichromate in strong sulphuric acid with silver sulphate as a catalyst. The reduced part of the dichromate by organic matter and the remainder was determined by titration with iron sulphate using Ferroin as indicator. Interferences from chloride were suppressed by the addition of mercuric sulphate to the reaction mixture. The chemical oxygen demand was expressed as milligrams of oxygen absorbed from standard dichromate per litre of sample (APHA, 1995).

The collected soil sample was air dried, crushed with a wooden mallet and passed through 2.36 mm sieve. 0.1 kg of soil was taken and was treated with one litre distilled water and kept for 48 hours. The supernatant was then filtered and used for soil chemical analysis. For pH determination, soil passing through 425 micron IS sieve is used (APHA 1995). The chemical analysis of each leachate samples and soil samples were carried at Kerala State Pollution Control Board, Kadavanthara, Cochin.

3.5 Results and Discussions

The leachate generated at bottom of landfill carries different contaminants. During percolation of leachate through the soil, leachate undergoes various processes such as physico-chemical decomposition process, ion exchange reactions, chemical alterations, oxidation, hydrolysis etc. These reactions alter the original soil properties.

The collected leachate samples (water samples from bore holes) from MSW dumping site was examined in laboratory. The characteristics of leachate samples (Table 3.2) were compared with the standards of treated leachate into the land disposal (Table 3.3). It was found that the some of the chemical parameters of the leachate exceeded the specified permissible standards.

Table 3.2 *Characteristics of Leachate Samples (Water Samples from Bore Holes)*

Sl.No.	Parameters	Unit	BH1*	BH2	BH3
1	pH	–	6.3	5.8	5.9
2	TDS	mg/l	1.87×10^7	6.59×10^6	2.56×10^6
3	BOD	mg/l	600	608	210
4	COD	mg/l	17440	16400	2400
5	Alkalinity	mg/l	195	156	100
6	Chloride	mg/l	354	310	240
7	Nitrate	mg/l	12	10	5

**BH1, 2, 3 – Bore hole No: 1, 2, 3 at 10 m lateral spacing*

Table 3.2 shows that the observed values of pH in the leachate samples from all the three bore holes are slightly acidic and within the standard range of pH of treated leachate. But parameters such as TDS, COD, and BOD are showing high values. TDS is generally considered not as a primary pollutant, but it is rather used as an aggregate indicator of presence of a broad array of chemical contaminants (Kaur, 2008).

Table 3.3 *Standards for Treated Leachates**

Sl.No.	Parameters	Unit	Standards for Land disposal
1	pH	–	5.5 to 9.0
2	TDS	mg/l	2100
3	BOD	mg/l	100
4	COD	mg/l	-
5	Chloride	mg/l	600

**(Municipal Solid Waste (Management and Handling) Rules-2000)*

The relatively high values of TDS in leachate samples indicate the presence of inorganic materials in the samples. The high levels of BOD and COD could create potential pollution problems to our water bodies since they contain organic compounds that will require a large quantity of oxygen for degradation. Chlorides are not usually harmful to people. The observed chloride concentration did not exceed the standard value of treated leachate for land disposal. Nitrate is one of the most common ground water contaminant. The excess levels can cause methemoglobinemia, or “blue baby” disease. The nitrate levels indicate the possible presence of other more serious residential or agricultural contaminants, such as bacteria or pesticides. Nitrate in ground water originates primarily from fertilizers, septic systems, and manure storage or spreading operations. The permissible limit for the nitrate in drinking water is 45 mg/l (Raman and Sathiya, 2008). The nitrate content of all the leachate samples was within the permissible limit.

Table 3.4 gives the chemical concentration of landfill soil and result is compared with the maximum allowable concentrations of chemical constituents in uncontaminated soil as per IEPA, 2012 (Table 3.5).

Table 3.4 *Chemical Concentration of Landfill Soil*

Parameters	**BH1*(@ 10 m)**			**BH2 (@ 20 m)**			**BH3 (@ 30 m)**		
	BH1$_A^*$	**BH1$_B$**	**BH1$_C$**	**BH2$_A$**	**BH2$_B$**	**BH2$_C$**	**BH3$_A$**	**BH3$_B$**	**BH3$_C$**
pH	6.2	6	5.8	6.1	5.9	5.8	6	5.8	5.7
TOC (mg/kg)	24000	13900	11943	13900	13870	13714	3506	2827	2805
Ammonia (mg/kg)	512.6	525	534.2	181.4	237.2	286.4	79.6	141.8	183.6
Nitrates (mg/kg)	16.3	45	75.6	30.5	50.3	75.6	49.6	53	113
Chloride (mg/kg)	5000	10000	10500	3500	9000	9500	2500	3800	4600
Cadmium (mg/kg)	6	6.4	7.2	4.8	4.8	5.4	2	2.8	3.8
Copper (mg/kg)	14.6	11.4	11.2	13.8	11	9.4	11	9	7.8
Iron (mg/kg)	15926	13140	12972	13616	11348	9980	11634	6852	6822
Chromium (mg/kg)	42.8	35.8	26	39.6	32.6	22.4	26.4	23.8	21.6
Manganese (mg/kg)	177.6	166.2	141.2	167.8	111.2	100.4	82.6	64.8	57
Zinc (mg/kg)	100.2	30.2	25.2	63.8	25	23.6	31.6	23.4	21
Nickel (mg/kg)	34	33.4	32.6	31	30.4	30	22.4	22	20.8
Total P (mg/kg)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Lead (mg/kg)	BDL	BDL	BDL	2	BDL	BDL	BDL	BDL	BDL
Sulphate (mg/kg)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BHC (mg/kg)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
DDT (mg/kg)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Endosulphan(mg/kg)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

**BH1, 2, 3 – Bore hole No:1, 2, 3 at 10 m lateral spacing and suffix A, B, C- different depths in each bore hole.*

Table 3.5 *Maximum Allowable Concentrations of Chemical Constituents in Uncontaminated Soil**

Chemical Constituents	Unit	Maximum Allowable Concentration
pH	-	6.25-9
Total Organic Carbon	mg/kg	-
Nitrates	mg/kg	200
Chloride	mg/kg	4000
Cadmium	mg/kg	5.2
Copper	mg/kg	2900
Iron	mg/kg	15900
Lead	mg/kg	107
Total Chromium	mg/kg	21
Manganese	mg/kg	636
Sulphate	mg/kg	8000
BHC	mg/kg	0.4
DDT	mg/kg	2
Endosulphan	mg/kg	18
Zinc	mg/kg	5100
Nickel	mg/kg	100

(IEPA, 2012)

Total organic carbon is a measure of the carbon contained within organic matter of soil. Micro-organisms, breakdown the organic carbon of soil and this occurs faster when the soil is moist and warm. Total organic carbon influences many soil characteristics including colour, nutrient holding capacity (cation and anion exchange capacity), nutrient turnover and stability, which in turn influence water relations, aeration and workability. In soils with high clay content the contribution to cation exchange from the organic fraction is generally small. In sandy soils the relative contribution of the organic fraction is higher because there is less clay, even though the amount of total organic carbon present may be similar or less to that in clays (Njar et al. 2011). In the given sample TOC varies from 2805-24000 mg/kg and is showing higher concentration near to the landfill. The increased TOC level can be related to the presence of waste and decomposition. As the decomposition gets completed, TOC will get lowered. Thus the result showing decrease in TOC as the distance and depth increases is related to the completion of decomposition of waste.

Table 3.4 and Table 3.5 indicate that the parameters such as nitrates, copper, iron, lead, chromium, manganese, sulfate etc. in the soil sample from the landfill site are within the allowable concentration in uncontaminated soil. Slight variation in Chloride and Cadmium is visible. Among the metals present in the soil sample, it is found that iron is showing maximum concentration upto 15926 mg/kg and is gradually reducing to a low value of 6822 mg/kg. The locality of the landfill site is an industrial belt with a number of small scale industries. The waste from these industries can contribute a good amount of iron concentration in the MSW. It may produce a higher concentration of iron in the wastewater from the landfill and the surrounding soil may take up good amount of iron from it and hence high concentration of iron in soil near the landfill. According to University of Wisconsin-Madison, the allowable concentration of ammonia in soil is between 0.25-40 mg/kg. But in the soil samples from the landfill area, concentration of ammonia is exceeding this limit. The variation in concentration of each chemical is visible with respect to the depth and distance from landfill in Fig. 3.5.

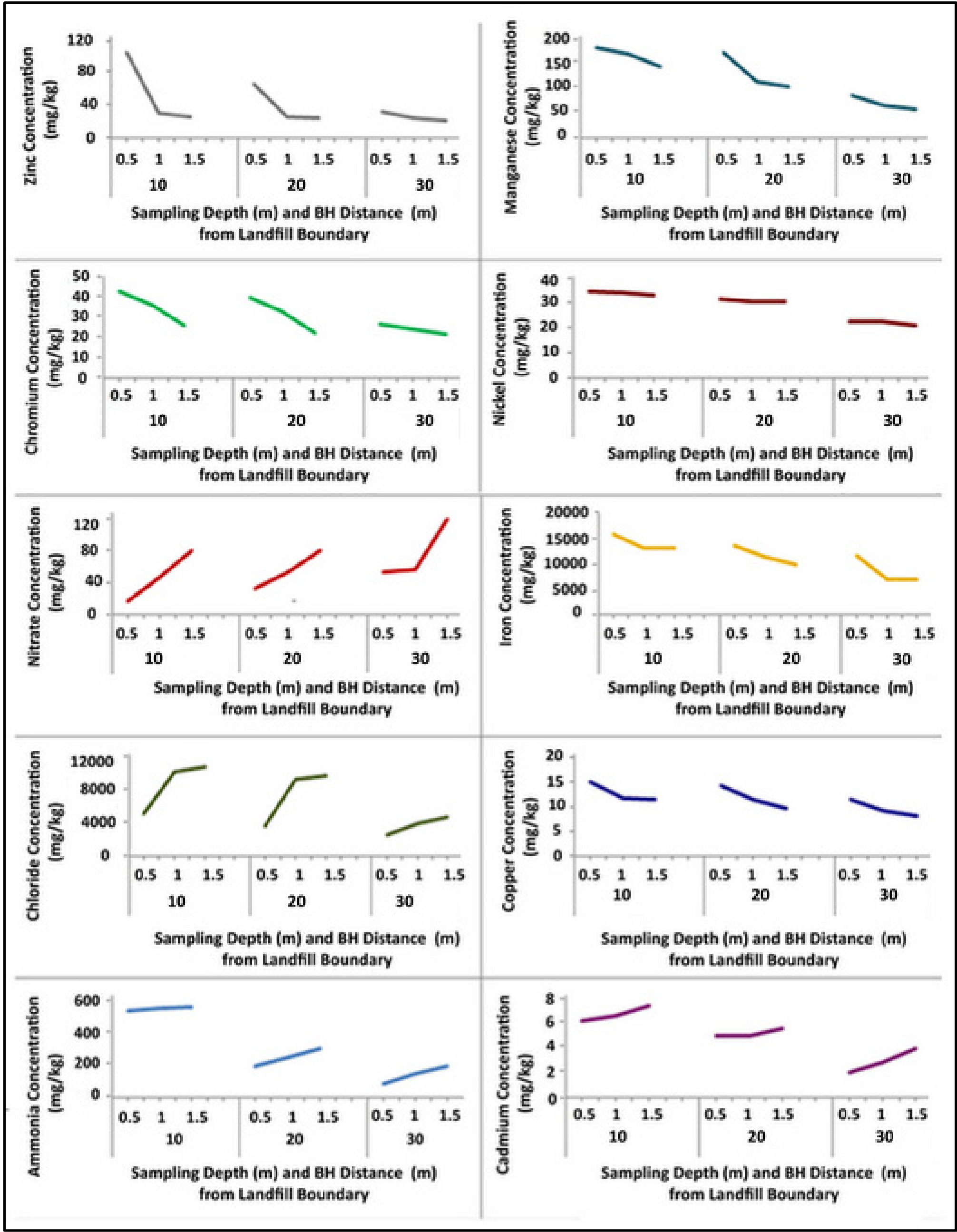


Fig. 3.5 *Variation in Concentration of Chemical with respect to the Depth and BH Distance from Landfill Boundary*

Fig. 3.5 gives an idea on the transportation pattern of the chemicals in soil from the landfill. It also shows that the concentrations of most of the chemicals in the soil are relatively high till 20 m and then decreases. This can be inferred that, beyond 30 m the soil is not affected by the leachate.

Presence of nitrogen in soils is in organic and inorganic forms. There is a wide variation in the types of organic compounds that contain nitrogen. Organic compounds can be small and easily degraded by micro-organisms like amino acids, or large complex molecules that are quite resistant to microbial decay. Inorganic forms of nitrogen are nitrate, nitrite, ammonium, and ammonia. Nitrate and ammonium are readily taken up by plants and beneficial for plant growth. Nitrite and ammonia are toxic to plants. Ammonia is also produced by the degradation of waste in landfills. Thus landfill leachates and soil at landfill sites contain very high levels of ammonia. Ammonia react with water in the soil is very quickly converted into ammonium (NH_4^+). Nitrification is the conversion of ammonium (NH_4^+) to nitrate (NO_3^-). But this is an aerobic reaction and as the leachate released to the sub-landfill, nitrification does not occurs and ammonium (NH_4^+) remains in soil as it is. As ammonium is positively charged and is therefore retained in soils by sticking to the negatively charged clay particles (James, 2001). This may be the reason for increase in concentration of ammonia in study area.

Engineering properties of soil such as consistency limits and hydraulic properties are determined for each sample. For the determination of soil properties the soil sample was air dried in laboratory. Soil sample sieved through 425 micron IS sieve is used for determination of consistency limits. Table 3.6 gives the engineering properties of collected soil samples.

Table 3.6 *Engineering Properties of Soil Samples*

Parameters / Location		Specific gravity	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)	Hydraulic Conductivity (m/sec)
BH1	BH1$_{A}^{*}$	2.66	85	47	38	1.961x10^{-5}
	BH1$_B$	2.68	85	48	37	
	BH1$_C$	2.68	86	50	36	
BH2	BH2$_A$	2.69	90	50	40	2.003x10^{-6}
	BH2$_B$	2.69	91	51	40	
	BH2$_C$	2.70	91	52	39	
BH3	BH3$_A$	2.82	92	52	40	2.879x10^{-6}
	BH3$_B$	2.83	94	54	40	
	BH3$_C$	2.83	95	56	39	

BH1, 2, 3 – Bore holes at 10 m lateral spacing and suffix A, B, C- different depths in each bore hole.

In conventional soil mechanics, it is assumed that Atterberg limits remain constant for a given soil, but these properties are subject to change when the pore fluid changes. The changes in Atterberg limits depend on intensity, duration, type of contaminant and type of interaction or reaction which happens in soil. According to Arasan (2010), the geotechnical properties of clay liners are closely related to the chemistry of the leachate. The chemicals significantly affect the geotechnical properties of clay. The liquid limit and swelling decreases with increasing chemical concentration for high plasticity clay. However, the liquid limit and swelling increases with increasing chemical concentration for low plasticity clay. The hydraulic conductivity increases with increasing chemical concentration for high plasticity clay. However, the hydraulic conductivity decreases with increasing chemical concentration for low plasticity clay. In this study the variation in Atterberg limits and other properties of polluted soil is examined. It shows that, as distance of landfill increases, liquid limit increases. The lower value at BH1 and BH2 is due to the influence of presence of waste and property of soil used to cover the landfill. The hydraulic conductivity of soil is decreasing as bore hole distance increases. As it is inferred before that, the soil beyond 30 m distance is not affected by the leachate, the value shown by soil from BH3 can be treated as the property of uncontaminated soil. Thus it is evident that solid waste dumps have some effect on the engineering and chemical properties of soil. Also it may affect the usefulness of soil as a foundation material. It also can result in pollution of ground water sources due to percolation of toxic and hazardous chemical.

3.6 Summary

A typical chemical composition of soil affected by MSW landfill leachate estimation and its effect of on the engineering and chemical properties of soil are discussed in this chapter with respect to a case study on a landfill at Kalamassery. To establish the effect of leachate on the soil properties, further studies on different soils treated with leachate is required. But most of the landfill leachates are unstable and rapidly degrade unless stored in cold anaerobic conditions. So, most of the researchers have used synthetic leachate for their studies. Considering the quantity of leachate that would be required for the further experiments, the testing period and also the need for easy reproducibility, it was decided to formulate a synthetic leachate based on the obtained chemical composition of soil, which would stay stable at room temperature. The following chapter deals with the laboratory studies using this synthetic leachate.

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Chapter 4

LABORATORY MODELLING OF LEACHATE TRANSPORT

Contents

4.1 Introduction

The irrational disposal of waste is a major source of soil pollution. Soil pollution leads to modification of the physical, chemical and biological properties of soil. It restricts or prevents the use of soil in various applications where it normally plays a part. Leachate from an improperly constructed landfill contributes to an extensive contamination of soil beneath and adjacent to the dumping area. Leachate is generated in landfill sites by the process of hydrolysis due to the water penetration. Leachate is composed of both organic and inorganic compounds, and their concentration depends on the age of a landfill site (Renou et al., 2008; Park et al., 2001). Organic compounds are bio-degradable and its susceptibility to biologic attack varies between different compounds. Many organic contaminants are lipophilic with low water solubility. It implies that they are strongly adsorbed to soil particles and has a low bioavailability. On the other hand, inorganic contaminants cannot be degraded. But their distribution, speciation etc., depends on the environmental factors such as pH and redox potential (McBride, 1994; Alexander, 1999; Kristin, 2009).

As the municipal solid waste landfill leachate is a combination of various contaminants, soil nearby a municipal solid waste landfill is found to be affected with more than one type of contaminant. Because of presence of physically and chemically different contaminants and possibility for interaction between them, sorption and leaching characteristics of chemicals in the mix contaminated soil would be complex. Also only scanty literature is available on the soil affected with mixed contaminants.

This chapter presents the results of a laboratory testing program carried out to determine the effect of leachate, composed of various contaminants, on the geotechnical characteristics of soils.

4.2 Laboratory Investigations

4.2.1 Materials Used

In general, the soils of Kerala are acidic, kaolinitic and gravelly with low cation exchange capacity, low water holding capacity and high phosphate fixing capacity. Climate, topography, vegetation and hydrological conditions are the dominant factors of soil formation. For the present study lateritic soil and clayey soil which are more commonly occurring soil types in Kerala are considered.

4.2.1.1 Lateritic soil

Lateritic soil is one of the most extensive soil groups found in Kerala, which are rich in iron and aluminium. They are formed by intensive and long-lasting weathering of the underlying parent rock. In general they contain small amounts of nitrogen, phosphorus and potassium. They have poor water-holding capacity, cation exchange capacity and high phosphate fixing capacity with low organic matter content. They are generally acidic with pH ranging from 4.5 to 6.2. Heavy rainfall and high temperature prevalent in the state are conductive to the process of laterisation. The most important characteristic of laterisation is the decomposition of ferro-alumino silicate minerals and the permanent deposition of sesquioxides, which are the oxides of iron and aluminium (Bello, 2012). Due to the presence of iron oxides lateritic soils are generally red in colour. Within the tropics and subtropics where lateritic soils occur widely, there is a good scope of using them for the construction of covers and liners in the engineered landfill for waste containment. Also large areas of land with lateritic soil are currently used for open dumping of municipal solid waste. Thus the lateritic soil is selected for carrying out the laboratory testing program to determine the effect of leachate contamination on the geotechnical characteristics.

The experiments were conducted in lateritic soil which was procured from Karukutty, a place near Cochin, which was a lateritic quarry, and the test soil was collected from a depth of 6 m. Here after this soil is named as Test soil-I and is shown in Fig. 4.1.

4.2.1.2 Clayey soil

Clayey soils are grayish to blackish in color. They contain montmorillonite clay mineral which has high expansive characteristics. Because of the presence of montmorillonite, they exhibit large swell-shrink tendency and possess high strength in summer. They have low shrinkage limit and high optimum moisture content. It is highly sensitive to moisture changes, and is highly compressible by nature. The soil used for the present study was from Kakkanad, Cochin and it was collected from a depth of 30 m. Air drying of the entire soil was done before conducting all the laboratory tests. Here after this soil is named as Test soil-II and is also shown in Fig 4.1.

(a) Test Soil-I (b) Test Soil-II

Fig. 4.1 *Soil Samples for the Study*

The initial physical characterization of both test soils were performed through the determination of specific gravity, Atterberg limits, particle size analysis, unconfined compressive strength, coefficient of permeability etc., as per the prevailing Indian standards (Table 4.1). Particle size distribution curves of each test soils are shown in Fig 4.2. The initial chemical contents of the representative samples of test soils were tested at Central Chemical laboratory of FACT, Udyogamandal, Ernakulam, Kerala and tabulated in Table 4.2.

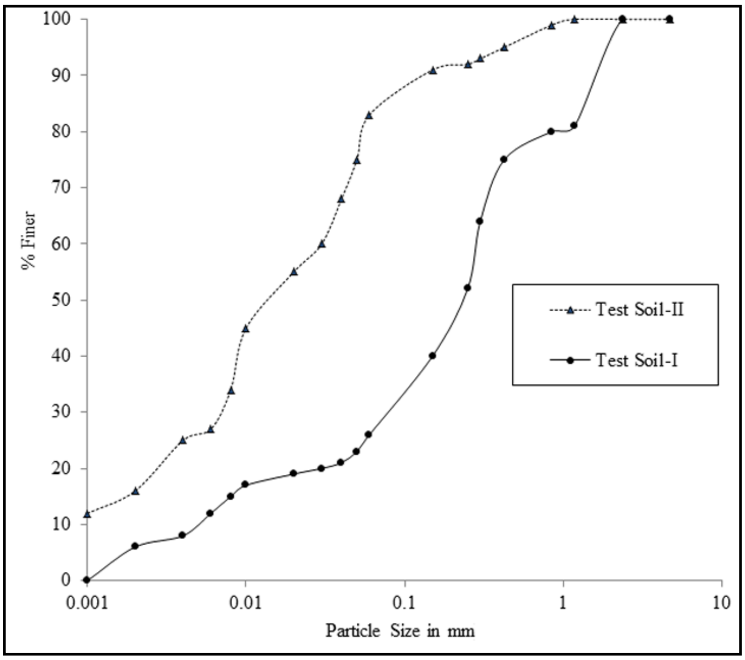


Fig. 4.2 *Particle Size Distribution Curves of Test Soils*

Table 4.1 *Engineering Characteristics of Test Soils*

Parameters	**Test Soil-I** (Lateritic Soil)	**Test Soil-II** (Clayey Soil)
Specific Gravity	2.64	2.48
Gravel size (%)	0	0
Sand size (%)	66	25
Silt size (%)	28	59
Clay size (%)	6	16
OMC (%)	19	23.5
Maximum Dry Density (kN/m^3)	19.3	15.0
Liquid Limit (%)	31	50
Plastic Limit (%)	23	25
Shrinkage Limit (%)	15	13
Unconfined Compressive Strength (kN/m^2) @MDD	96.33	78.28
Coefficient of Permeability (mm/s) @MDD	2.7x10^{-3}	1x10^{-6}
Soil Classification	SM	MI - MH

Table 4.2 *Chemical Characteristics of Test Soils*

Parameters	**Test Soil-I** (Lateritic Soil)	**Test Soil-II** (Clayey Soil)
pH	4.5	7.3
Chloride (mg/kg)	Nil	53.5
Ammonia (mg/kg)	224	19.6
Nitrate (mg/kg)	42	30.8
Iron (mg/kg)	608	1056
Manganese (mg/kg)	30.9	13.74
Zinc (mg/kg)	Nil	Nil
Chromium (mg/kg)	Nil	Nil
Cadmium (mg/kg)	Nil	Nil
Copper (mg/kg)	4.2	2.3
Nickel (mg/kg)	Nil	Nil
TOC (mg/kg)	5500	1209

4.2.1.3 Synthetic leachate

Accumulated urban solid wastes in landfills decompose by a combination of physical, chemical, and biological processes. Leachate is generated when water penetrates through the waste in the landfill. The water coming in the landfill can be from all sources of water that fall from the air or flow from the surrounding land into the landfill or from the waste itself. Leachates are considered to be wastewater which has a major environmental influence. The landfill leachate is one kind of wastewater with high concentration of organic compounds, in-organic compounds and sometimes non-trivial level of toxic contaminants such as arsenic and chlorinated organic compounds (Amin and Hamidi, 2012). The composition of the leachate generated depends on many factors namely type of waste, precipitation rates, temperature, food habits of general population etc. (Jayasekera and Mohajerani, 2001). From the case study described in the previous chapter and from the available literature (Nanda et al., 2011; Nayak et al., 2007; Goswamy and Choudary, 2013; Musa, 2012; Mishra et al., 2005), it was observed that the concentration of each constituent in the real leachate can vary within a wide range. The difficulty of producing reproducible solutions and the instability of real leachate as well as the unstable concentration of parameters favour the use of a more stable and controlled synthetic leachate (Robert et al., 1979)

As discussed in section 3.5, the chemical concentration in the soil very near to the Kalamassery, landfill area is much different from that obtained at about 30 m from the landfill site, which can be considered as the soil which is not affected by the leachate. From Table 3.4 we can observe that this can be due to the influence of wastewater leaching from the landfill. Since there is no controlled leachate collecting system in the landfill, it was not possible to obtain the sample of leachate coming out right from the landfill site and hence the actual composition of it is not known.

Further the major objective of this research is to study the effect of the chemicals which may influence the engineering properties of soil near a landfill area. Comparing the chemical characteristics of soil selected for this study (Table 4.2) and the chemical constituents in the soil near the landfill (Table 4.3), it can be observed that the latter is having a very high concentration level for most of the constituents. In order to simulate this effect, we have to input a synthetic leachate which can provide an approximate range of chemical concentration in test soil that is similar to original landfill area. Therefore we have to consider the concentration of chemicals in the affected soil near the landfill, while preparing a synthetic leachate.

Table 4.3 *Chemical Concentration in the Soil from the Open MSW Landfill at Kalamassery, Kerala*

Substances extracted	Obtained range
pH	5.7-6.1
Chloride (mg/kg)	2500-10500
Ammonia (mg/kg)	79.6-534.2
Nitrate (mg/kg)	16.3-113
Iron (mg/kg)	6822-15926
Manganese (mg/kg)	57-177.6
Zinc (mg/kg)	21-100.2
Chromium (mg/kg)	21.6-42.8
Cadmium (mg/kg)	2-7.2
Copper (mg/kg)	7.8-14.6
Nickel (mg/kg)	20.8-34
TOC (mg/kg)	2827-24000

Chemical compounds used in the preparation of synthetic leachate are given in Table 4.5. Distilled water was used for its dissolution and dilution. A balance with a sensitivity of 1 mg is used for measuring the chemicals quantity.

Table 4.4 *Chemical Composition of Synthetic Leachate*

Parameters	Concentration (mg/l)
Chloride	6500
Ammonia	300
Nitrate	57
Iron	11300
Manganese	119
Zinc	38
Chromium	30
Cadmium	4.8
Copper	11
Nickel	28
TOC	11160

Table 4.5 *Chemical Compounds used in Synthetic Leachate*

Chemical Compounds	Unit	Quantity used
Manganese Chloride	mg/l	284
Zinc Chloride	mg/l	79
Chromium Chloride	mg/l	92
Cadmium Nitrate	mg/l	22
Copper Nitrate	mg/l	33
Nickel Nitrate	mg/l	87
Ferric Nitrate	mg/l	218
Ferric Chloride	mg/l	9552
Iron Oxide	mg/l	11382
Ammonia	mg/l	300
Sugar	mg/l	168048

4.2.2 Test Set-up

A laboratory test set-up was designed and constructed to simulate the leachate transport in an unlined municipal solid waste landfill on a homogeneous and isotropic soil. A circular concrete test tank of 1 m diameter and 0.8 m depth is constructed and filled with soil to represent the area surrounding a landfill. An overhead tank is provided to supply leachate to the soil through a flexible pipe system where rate of flow can be controlled. From the overhead tank the leachate is supplied to a perforated container, from which it percolates to the soil. The schematic representation of the test set-up is shown in Fig 4.3. The head of the water in perforated container can be made constant by an overflow arrangement. Hydraulic gradient maintained during the experiment was in the range of 1 in 1.35 to 1 in 1.53.

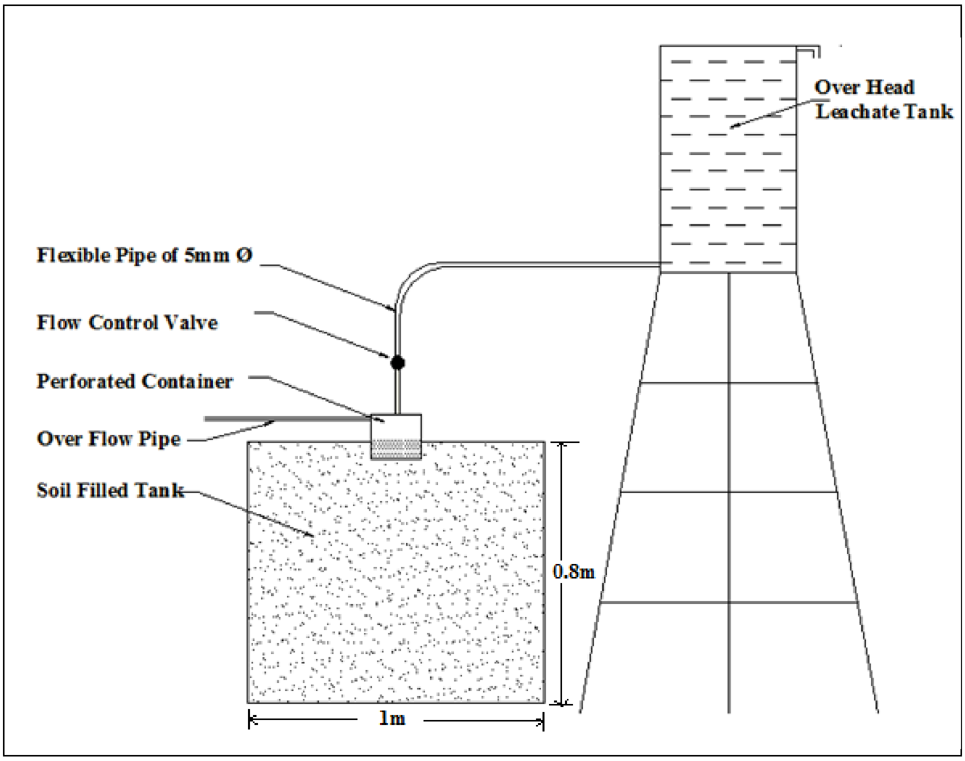


Fig. 4.3 *Schematic Representation of Laboratory Test Set-up.*

4.2.3 Experimental Procedure

Two sets of model tests were conducted in the developed laboratory set-up with Test soil-I and Test soil-II to study the leaching process. Test soils were air dried for 7 to 15 days and filled in the concrete circular test tank at a uniform density of 18 kN/m^3 (matching with their field density). At the centre of the tank, above the filled soil, a circular pit of 100 mm diameter and 80 mm depth was prepared. This pit resembles the solid waste dumping place. A circular container of 100 mm diameter and 150 mm depth was placed at this pit. Perforations were made on the portion of the container where it is having contact with the soil. Leachate was transferred to the soil through this perforated container. Perforations facilitate the uniform passage of the leachate to surrounding soil, as described in the previous section. The quantity of each chemical compound was calculated in proportion to the quantity of water required to achieve a degree of saturation of 50% (Approximately, the degree of saturation obtained in the field sample). Each chemical compound was added one by one to the water. While adding each chemical compounds the solution was continuously stirred and found that it is completely dissolved in the water. After the preparation of synthetic leachate solution, it was kept for 24 hours and found that all the compounds have dissolved. The entire leachate (9.5 l) was transferred to the soil from the overhead leachate tank to the perforated container at a constant rate so as to achieve 50% saturation in 100 days. The leachate treated soils were collected from the positions corresponding to 200 mm and 400 mm radial distances from the point of application of leachate. The samples were collected after 100 days (i.e., the day at which the application of leachate stopped) and 150 days from the commencement of experiment. Fig. 4.4 shows the photograph of the experimental set-up.

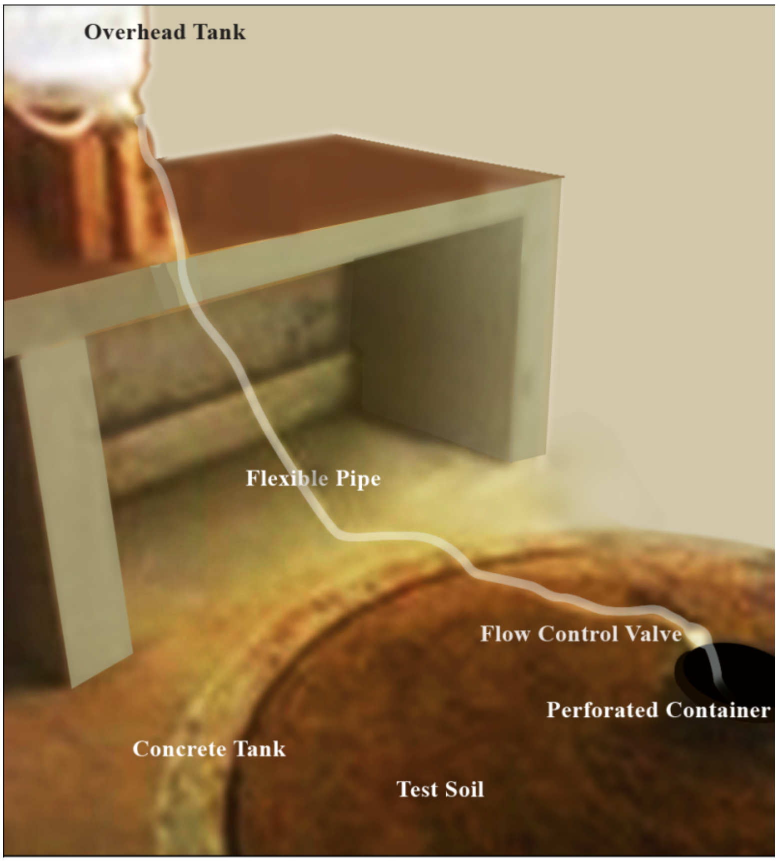


Fig. 4.4 *Photograph of Test Set-up*

To collect samples at different depths, PVC pipe of 100 mm diameter and 1m long was introduced at the required positions and was taken out with minimum disturbance. Four samples were separated corresponding to different depths (150 mm, 300 mm, 450 mm and 600 mm) as shown in the Fig. 4.5 and analysed for chemical and geotechnical properties.

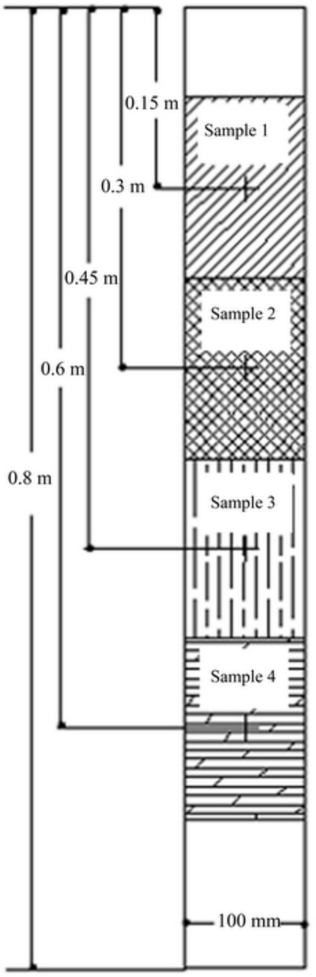


Fig. 4.5 *Samples at Different Depths*

4.2.4 Geotechnical and Chemical Analysis of Samples

The relevant geotechnical engineering properties of the selected soils were determined in the laboratory as per current Bureau of Indian Specifications (IS: SP: 36 (Part 1) 1987). The chemical characteristics of the samples were determined as per standard methods published by APHA (1995) (Table 4.6).

Table 4.6 *Methodology and Reference for Determination of Chemical Characteristics*

Parameter	Instrument Used	Methodology	Reference
Chloride	-	Titration	APHA (1995), 4500B
Ammonia	-	Distillation	APHA (1995), 3030C
Nitrate	-	Distillation	APHA (1995), 3030C
Iron	Atomic absorption Spectroscopy	-	APHA (1995), 3111D
Manganese			APHA (1995), 3111D
Zinc			APHA (1995), 3111D
Chromium			APHA (1995), 3111B
Cadmium			APHA (1995), 3111D
Copper			APHA (1995), 3111B
Nickel			APHA (1995), 3111D
Total Organic Carbon		Spectrometry	APHA (1995), 3030D

4.3 Results and Discussions

4.3.1 Chemical Concentration of Test Soils

The results of the chemical anlaysis of the test soils treated with leachate, recovered at 0.2 m and 0.4 m radial distances away from the point of application of synthetic leachate are discussed herein.

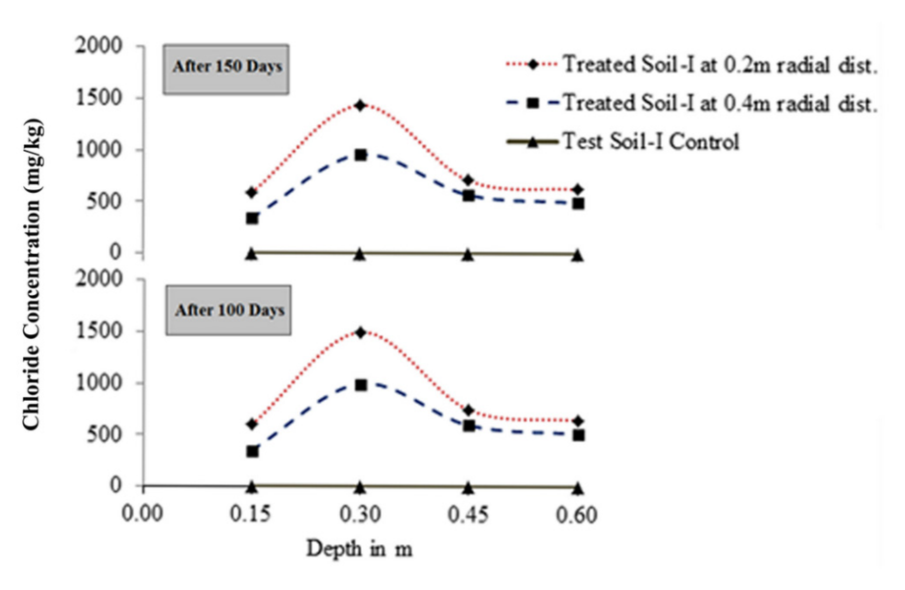


Fig. 4.6 *Chloride Vs. Mid Depth of Soil Samples (Test Soil-I)*

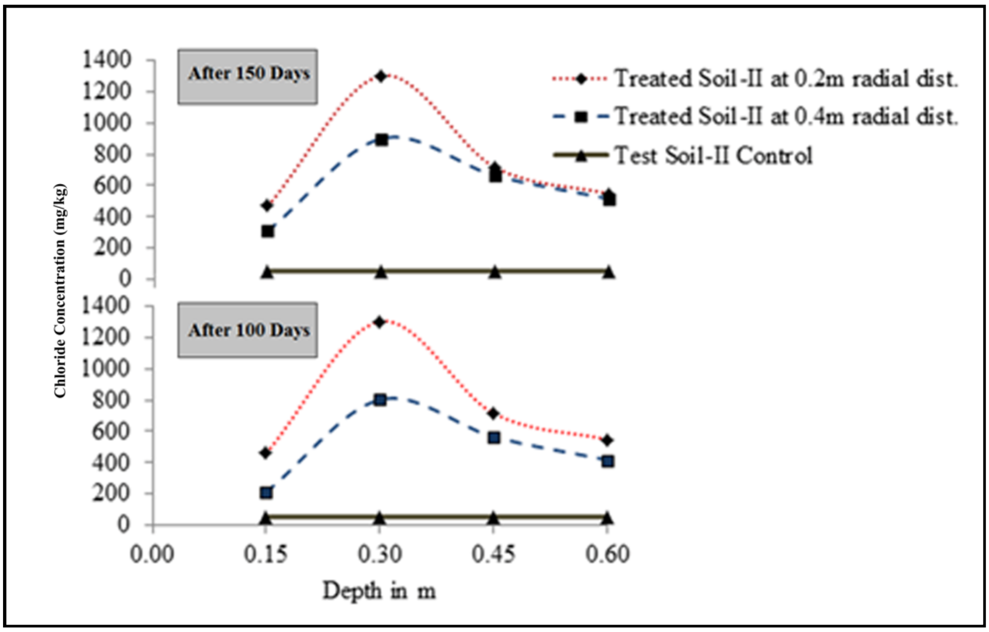


Fig. 4.7 *Chloride Vs. Mid Depth of Soil Samples (Test Soil-II)*

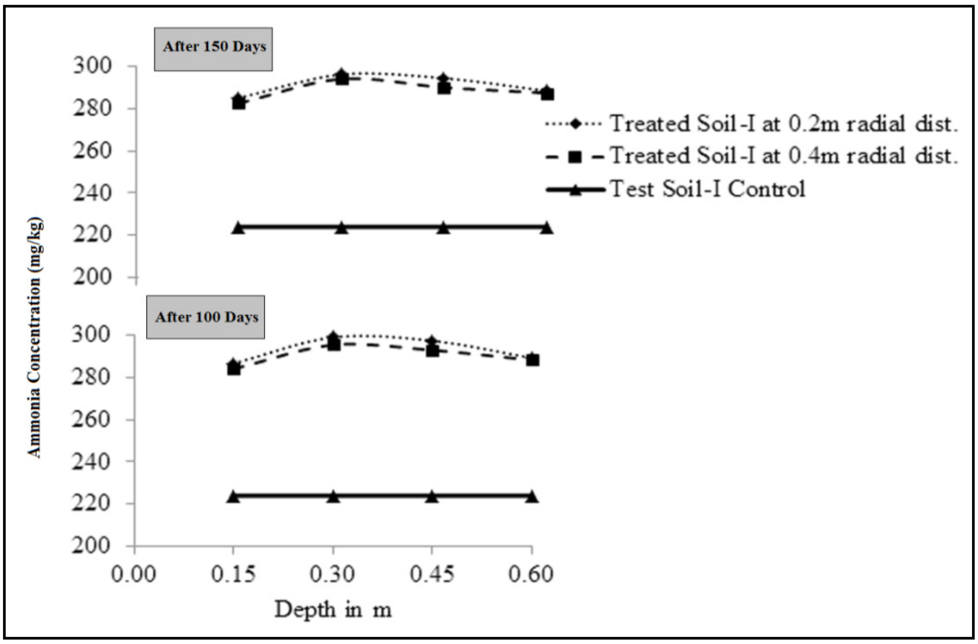


Fig. 4.8 *Ammonia Vs. Mid Depth of Soil Samples (Test Soil-I)*

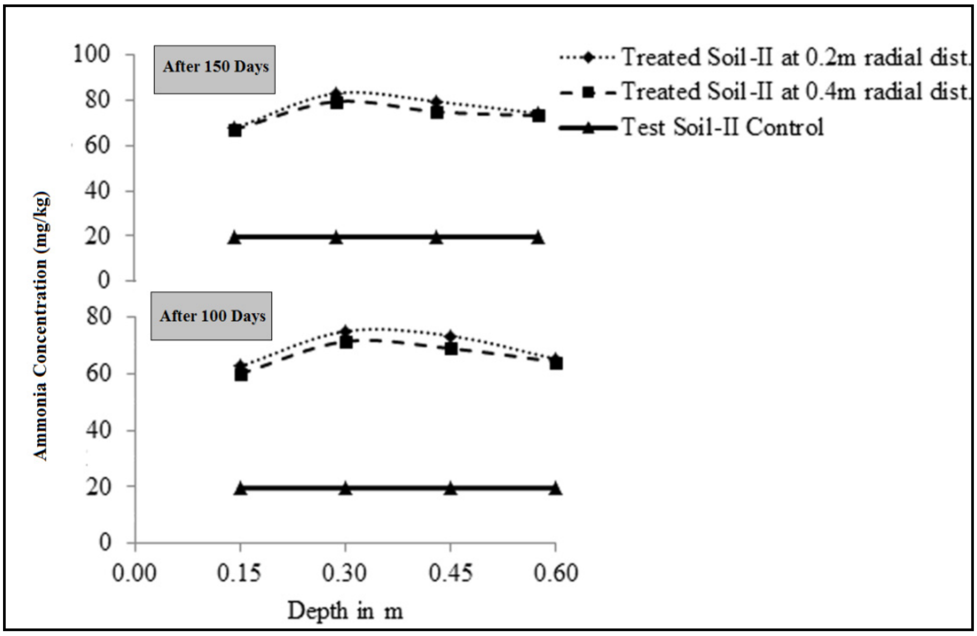


Fig. 4.9 *Ammonia Vs. Mid Depth of Soil Samples (Test Soil-II)*

Figs. 4.6 to 4.9 show the concentration of Chloride and Ammonia in the test soils in mg/kg. As the leachate penetrates through the soil, it is observed that the Chloride and Ammonia concentration in the soil sample changes. From the test results, the maximum concentration of both Chloride and Ammonia was observed at 0.3 m depth at a radial distance of 0.2 m. As depth increases, the concentration decreases and after a certain depth the values remain almost constant. As the radial distance increases to 0.4 m, it is found that the Chloride concentration decreases at every depth when compared to that observed at 0.2 m radial distance. As time passes there is a slight reduction in Chloride concentration for test soils is observed. The variation in Ammonia concentration with respect to depth, radial distance and the duration of contact is only marginal.

In leachate treated Test soil-I, Chloride concentration and Ammonia concentration was found to vary from 343 mg/kg to 1500 mg/kg and 282.5 mg/kg to 299 mg/kg respectively (Fig. 4.6 and Fig. 4.8). Maximum concentration of Chloride and Ammonia was observed at 0.3 m depth of 0.2 m radial distance from the point of application of leachate immediately after the stoppage of leachate application and minimum was at 0.15 m depth of 0.4 m radial distance after 150 days from the start of leachate application. A slight decrease in both Chloride and Ammonia concentration is observed on maturing of 50 days after 100 days leachate application.

Concentration of Chloride and Ammonia was varying from 212 mg/kg to 1303 mg/kg and 60 mg/kg to 83 mg/kg respectively in leachate treated Test soil-II (Fig 4.7 and Fig. 4.9). Maximum Chloride concentration was observed at 0.3 m depth of 0.2 m radial distance from the point of application of leachate after 100 days and 150 days from the start of leachate application. 50 days maturing does not make significant change in the chloride concentration in some of the samples. Minimum Chloride concentration was at 0.15 m depth of 0.4 m radial distance after 50 days maturing. Maximum and minimum concentration of Ammonia was observed at 0.3 m depth of 0.2 m radial distance after 100 days and 0.15 m depth of 0.4 m radial distance after 150 days from the start of experiment.

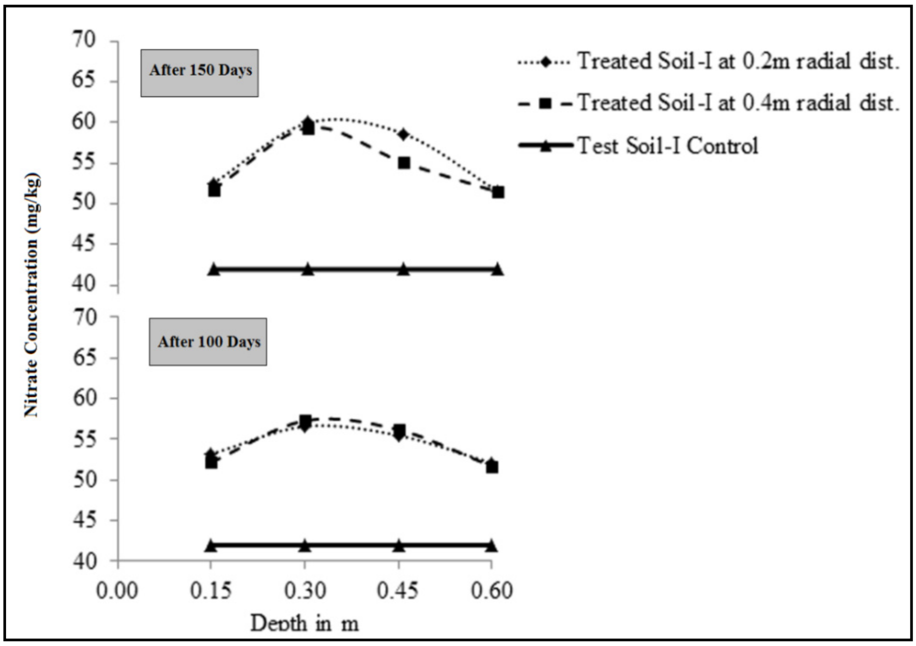


Fig. 4.10 *Nitrate Vs. Mid Depth of Soil Samples (Test Soil-I)*

Observing the Figs. 4.10 and 4.11, it can be seen that there is not much variation in the Nitrate concentration as radial distance changes. As depth increases reasonable change in the Nitrate concentration is observed. The effect of maturing on the concentration of Nitrate is also marginal.

Nitrate concentration in leachate treated Test soil-I, was observed to vary from 51.5 mg/kg to 60 mg/kg (Fig. 4.10). Maximum and minimum Nitrate concentration was observed at 0.3 m depth of 0.2 m radial distance, and 0.6 m depth of 0.4 m radial distance respectively from the point of application of leachate. Both results were observed after 150 days from the start of leachate application.

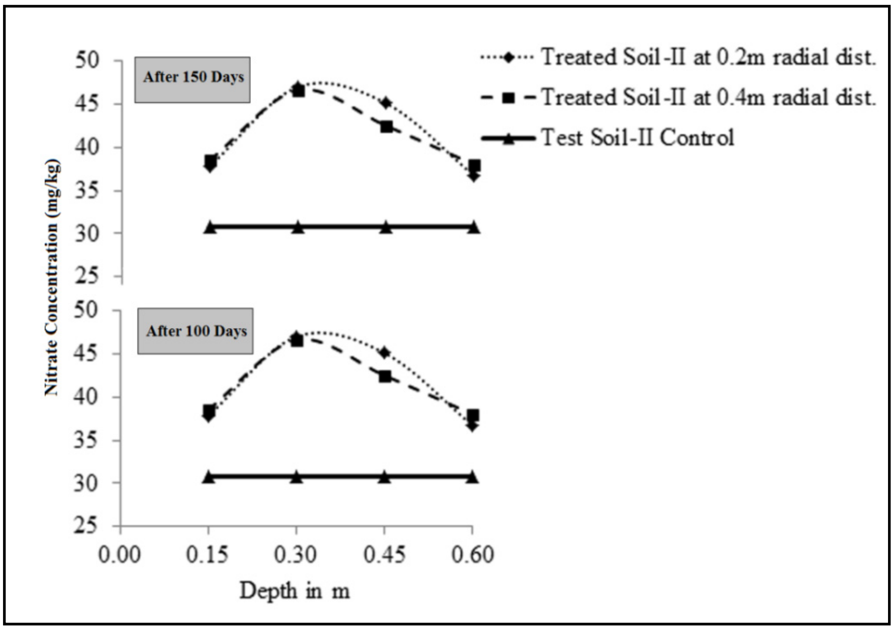


Fig. 4.11 *Nitrate Vs. Mid Depth of Soil Samples (Test Soil-II)*

Fig. 4.11 shows that, the Nitrate concentration in leachate treated Test soil-II varies from 36.7 mg/kg to 48 mg/kg. Maximum Nitrate concentration was observed at 0.3 m depth and minimum was at 0.6 m depth. Both the values are observed after 150 days from the start of experiment and at a radial distance of 0.2 m from the point of application of leachate. Slight increase in Nitrate concentration of Test soil-II was observed after 50 days of maturing.

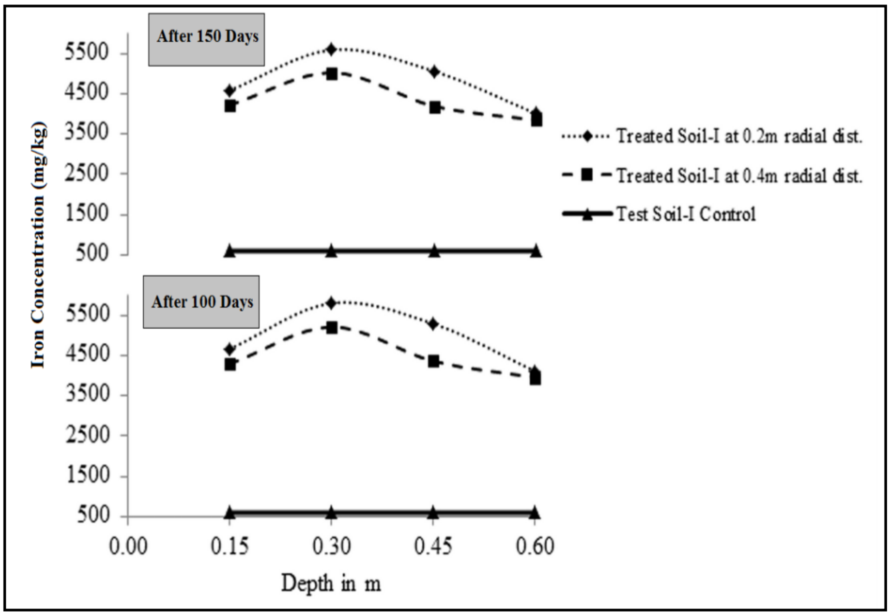


Fig. 4.12 *Iron Vs. Mid Depth of Soil Samples (Test Soil-I)*

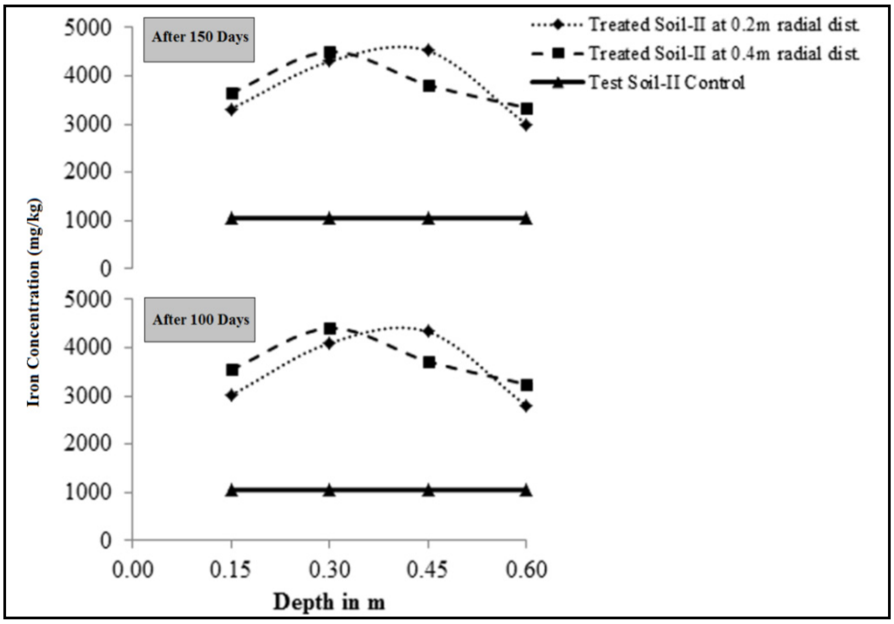


Fig. 4.13 *Iron Vs. Mid Depth of Soil Samples (Test Soil-II)*

According to Fig 4.12 and Fig. 4.13, a considerable change in the concentration of Iron was observed with respect to depth and radial distance. But ageing makes only a marginal effect on the Iron concentration.

Fig. 4.12 shows that, in leachate treated Test soil-I, Iron concentration was observed to vary from 4003.9 mg/kg to 5802.3 mg/kg. Maximum quantity of Iron was observed at 0.2 m radial distance and 0.3 m depth from the point of application of leachate after 100 days and minimum was at 0.4 m radial distance and 0.6 m depth after 150 days from the start of leachate application. Slight decrease in concentration of iron was observed after 100 days due to ageing, which can be seen from results after 50 days of maturing.

In leachate treated Test soil-II, concentration of Iron was varying from 2799 mg/kg to 4522.8 mg/kg (Fig. 4.13). Maximum concentration was observed at 0.2 m radial distance and 0.45 m depth from the point of application of leachate after 150 days and minimum was at 0.2 m radial distance and 0.15 m depth after 100 days. Iron concentration has increased slightly after 100 days on 50 days maturing. Thus the effect of Iron on Test soil-II was different from that of the lateritic soil.

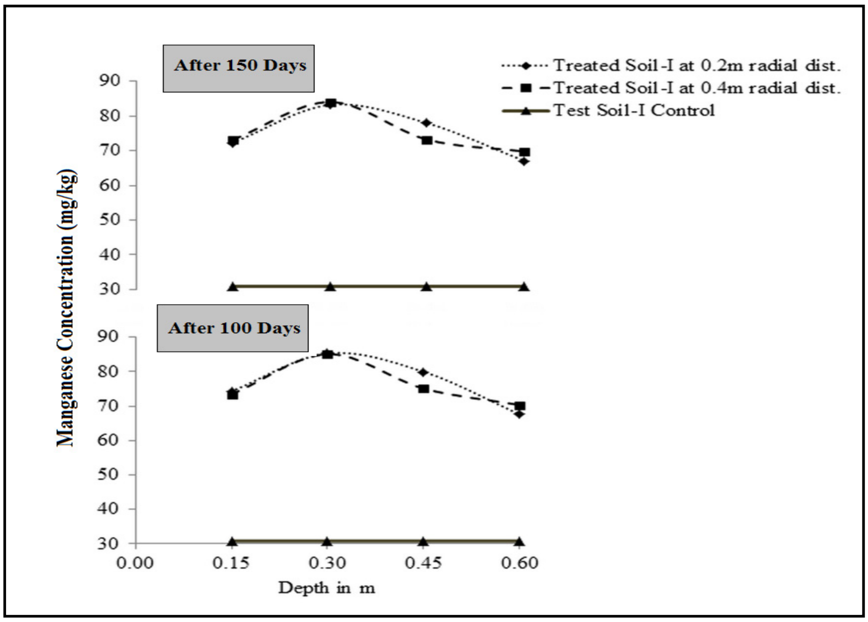


Fig. 4.14 *Manganese Vs. Mid Depth of Soil Samples (Test Soil-I)*

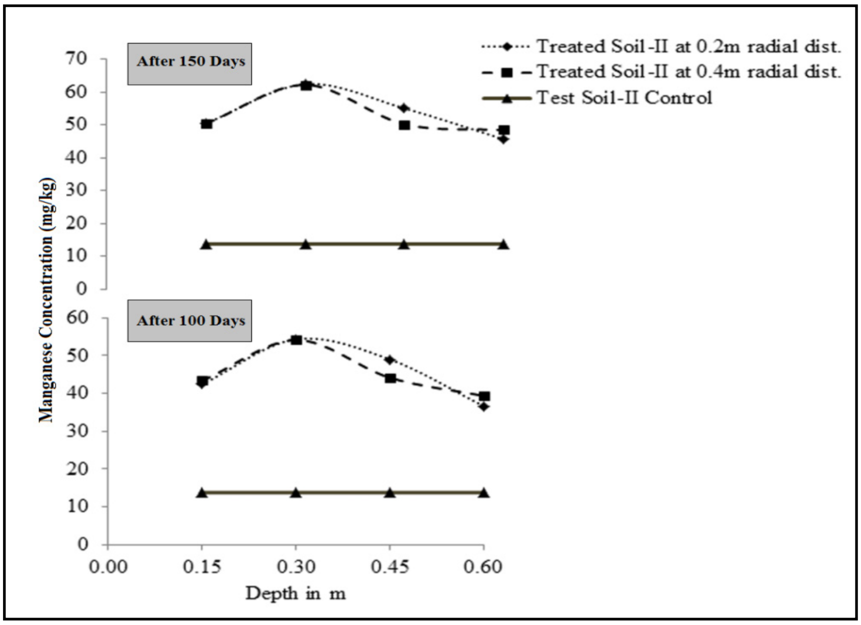


Fig. 4.15 *Manganese Vs. Mid Depth of Soil Samples (Test Soil-II)*

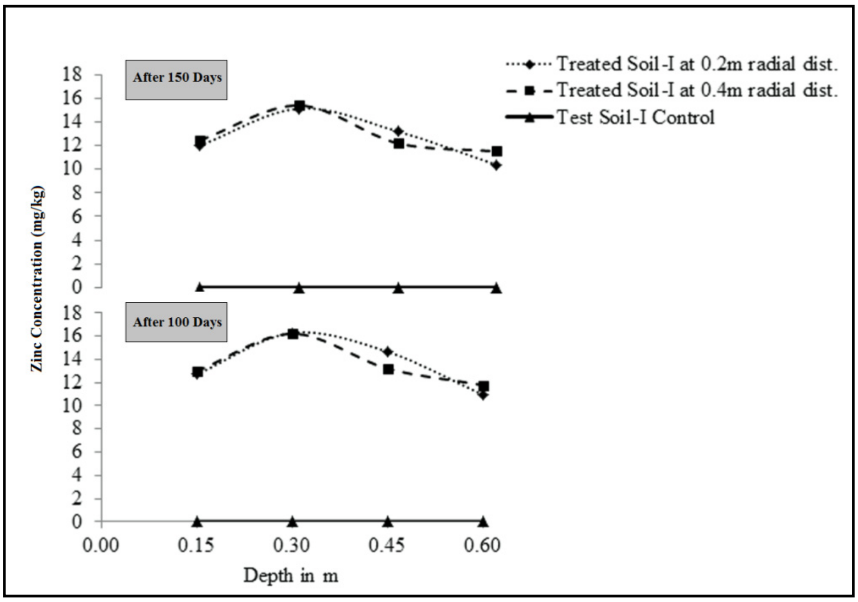


Fig. 4.16 *Zinc Vs. Mid Depth of Soil Samples (Test Soil-I)*

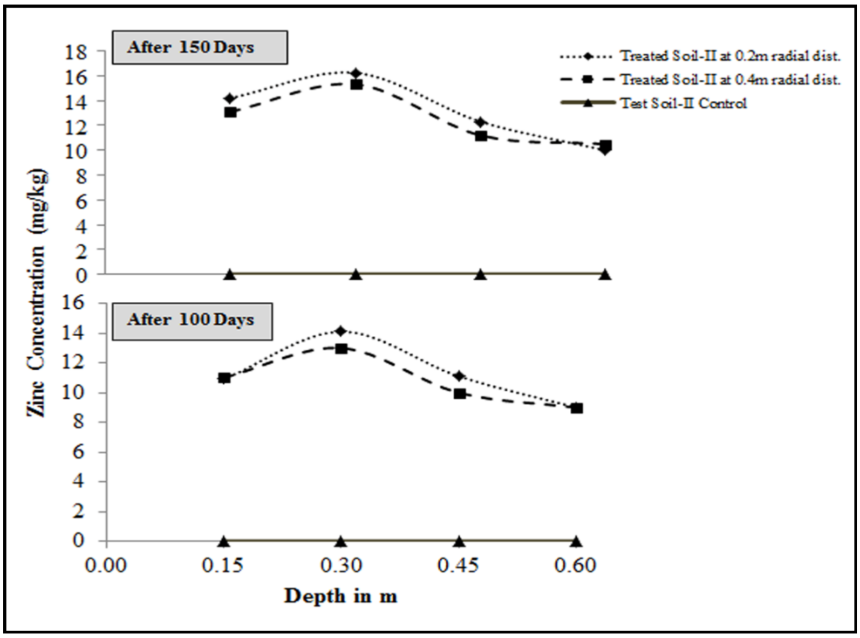


Fig. 4.17 *Zinc Vs. Mid Depth of Soil Samples (Test Soil-II)*

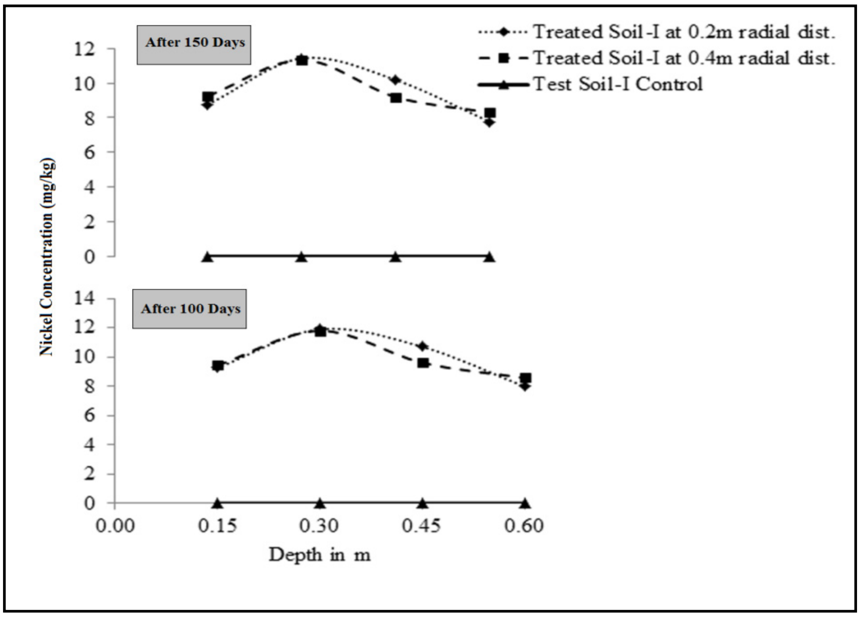


Fig. 4.18 *Nickel Vs. Mid Depth of Soil Samples (Test Soil-I)*

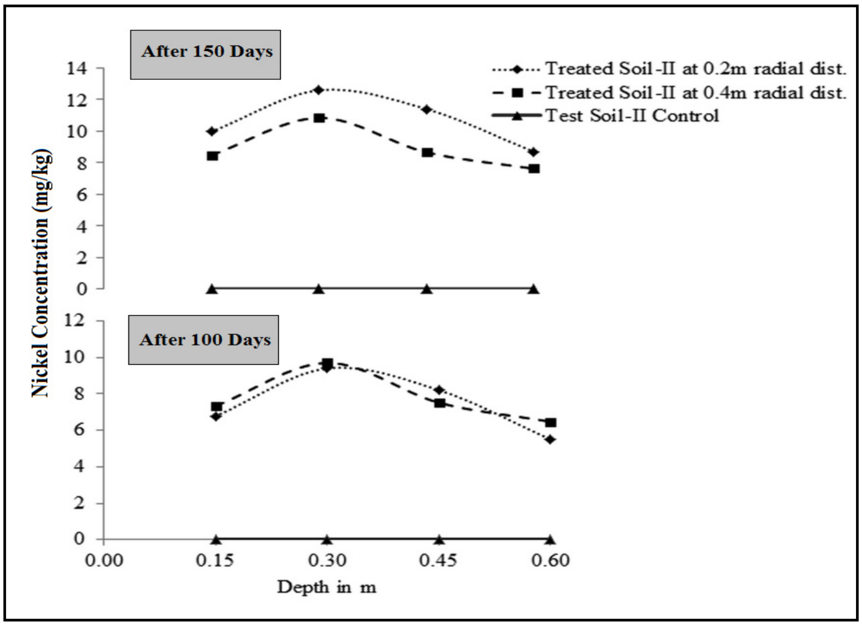


Fig. 4.19 *Nickel Vs. Mid Depth of Soil Samples (Test Soil-II)*

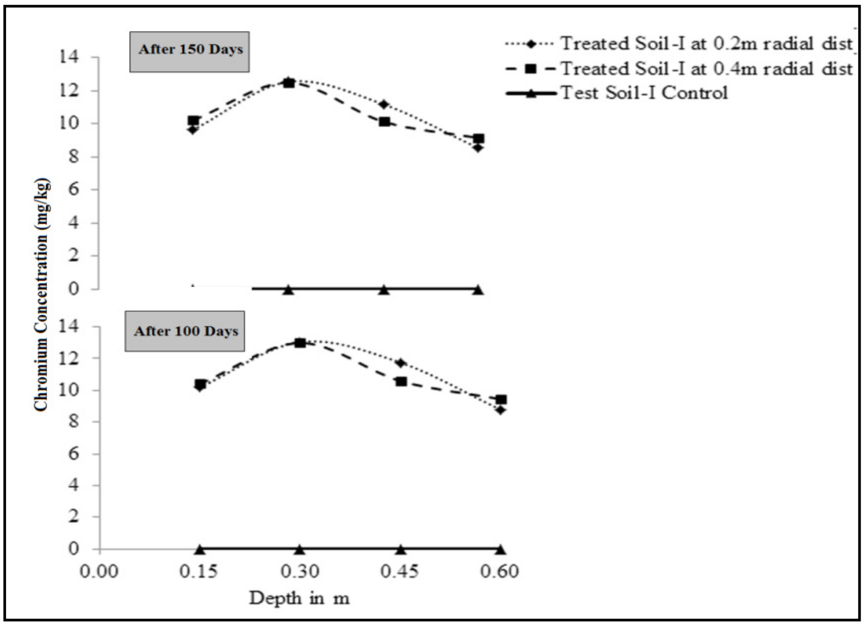


Fig. 4.20 *Chromium Vs. Mid Depth of Soil Samples (Test Soil-I)*

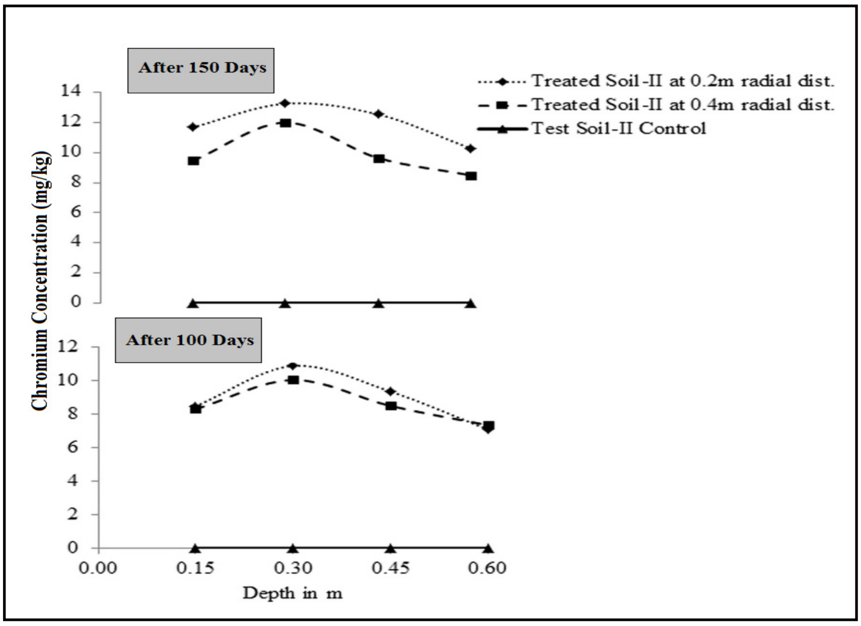


Fig. 4.21 *Chromium Vs. Mid Depth of Soil Samples (Test Soil-II)*

In leachate treated Test soil-I, concentration of Manganese (Fig. 4.14) is found to vary from 67.1 mg/kg to 85.3 mg/kg and that of Zinc (Fig.4.16) varies from 10.4 mg/kg to 16.3 mg/kg. Whereas, concentration of Nickel and Chromium (Figs. 4.18 and 4.20) is observed to vary from 7.8 mg/kg to 11.9 mg/kg and 8.5 mg/kg to 13.1 mg/kg respectively. Maximum concentration of all these chemicals were observed at 0.2 m radial distance and 0.3 m depth from the point of application of leachate after 100 days and minimum was at 0.2 m radial distance and 0.6 m depth after 150 days from the start of leachate application. All these chemicals are showing slight decrease in concentration on 50 days maturing after stopping the leachate application.

In treated Test soil-II concentration of Manganese and Zinc are observed to vary from 36.7 mg/kg to 62.4 mg/kg and 9 mg/kg to 16.2 mg/kg respectively (Figs. 4.15 and 4.17). Also the concentration of Nickel and Chromium is found to vary from 5.5 mg/kg to 12.6 mg/kg and 7.1 mg/kg to 13.3 mg/kg respectively (Figs. 4.19 and 4.21). After 150 days from the commencement of the experiment, maximum concentration of these chemicals were observed and is at 0.3 m depth of 0.2 m radial distance from the point of application of leachate and minimum concentration was observed at 0.6 m depth of 0.2 m radial distance immediately after the stoppage of leachate application. Concentration of these chemicals was found to be increased in Test soil-II on maturing of 50 days.

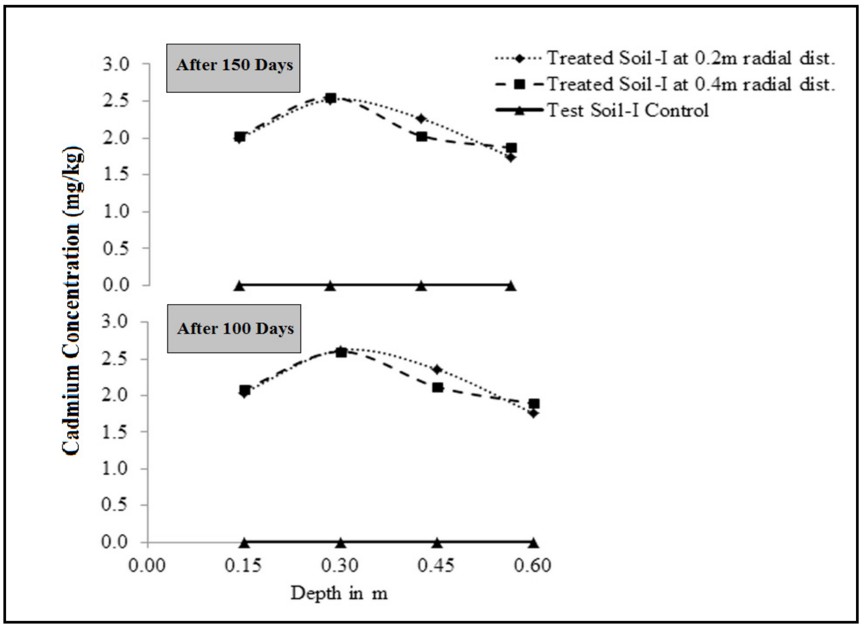


Fig. 4.22 *Cadmium Vs. Mid Depth of Soil Samples (Test Soil-I)*

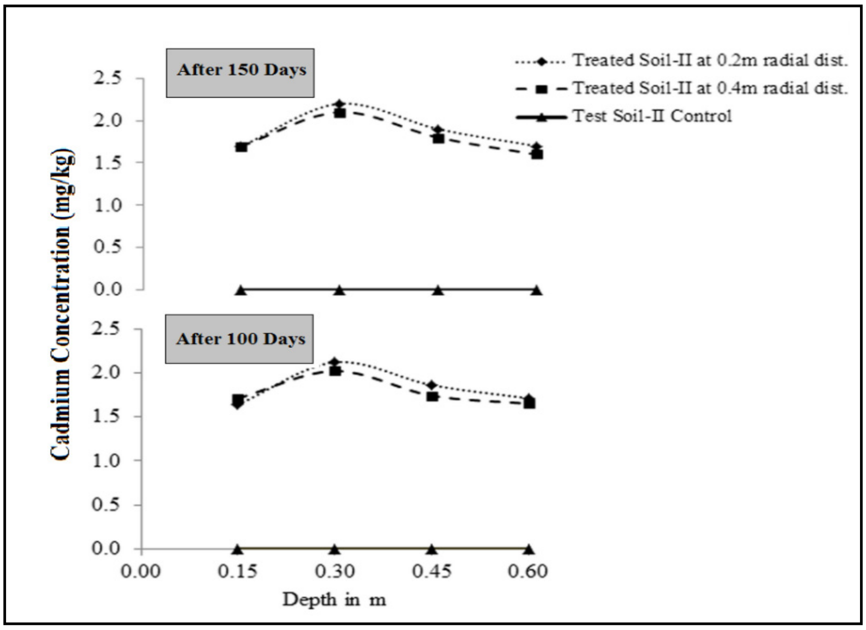


Fig. 4.23 *Cadmium Vs. Mid Depth of Soil Samples (Test Soil-II)*

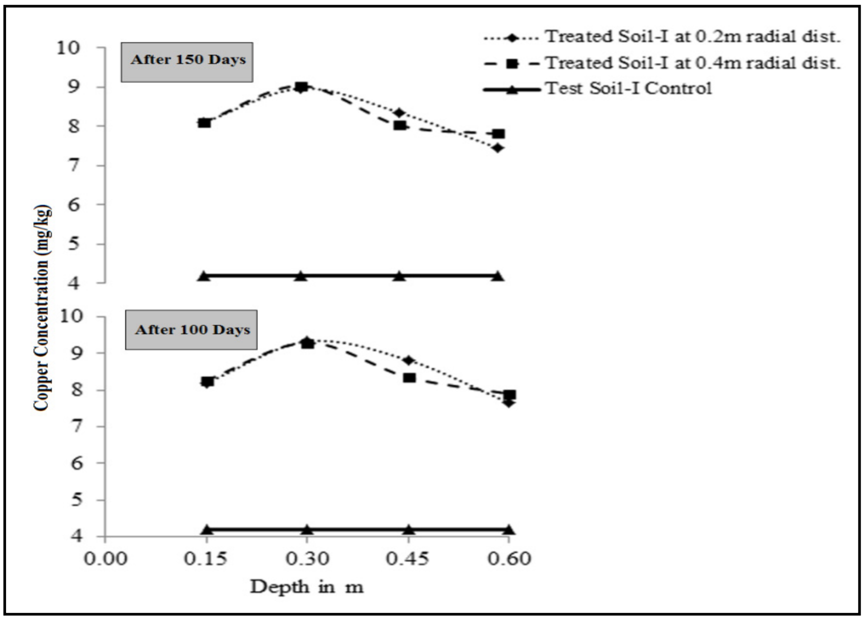


Fig. 4.24 *Copper Vs. Mid Depth of Soil Samples (Test Soil-I)*

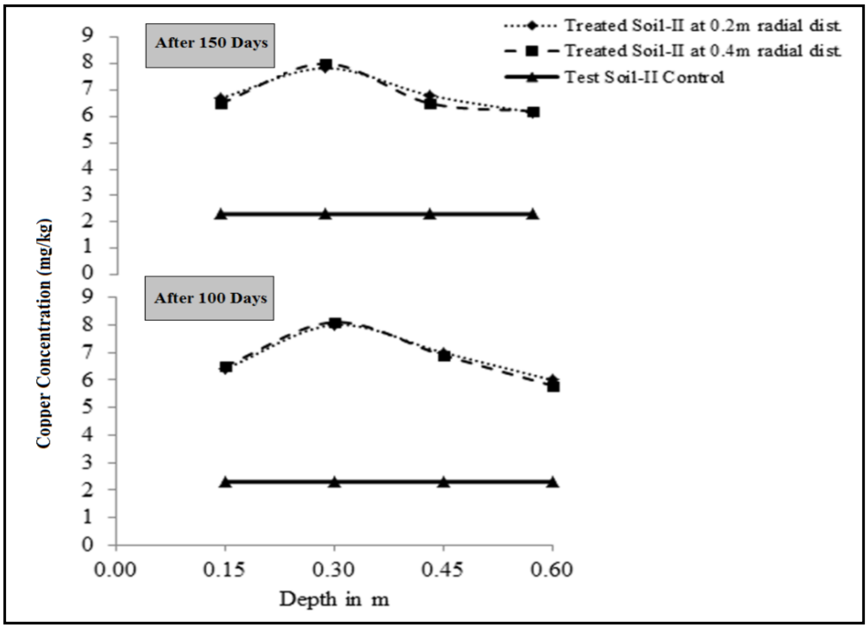


Fig. 4.25 *Copper Vs. Mid Depth of Soil Samples (Test Soil-II)*

Fig. 4.22 and Fig. 4.25 shows the variation of Cadmium concentration and Copper concentration in leachate treated Test soil-I. In that concentration of Cadmium and Copper was found to vary from 1.7 mg/kg to 2.6 mg/kg and 7.7 mg/kg to 9.3 mg/kg respectively. Maximum Cadmium and Copper concentration was observed at different positions such as 0.3 m depth at 0.2 m radial distance and 0.4 m radial distance immediately after the stoppage of leachate application. Maximum Cadmium concentration was also observed at 0.3 m depth at 0.4 m radial distance and that of Copper at 0.3 m depth at 0.2 m radial distance after 150 days from the start of experiment. Minimum Cadmium concentration was observed at 0.6 m depth at 0.2 m radial distance and that of Copper was at 0.6 m depth at 0.2 m radial distance after 100 days from the start of the experiment. A slight decrease of Cadmium and Copper concentration in Test soil-I was observed after 100 days on 50 days of maturing.

In leachate treated Test soil-II, Cadmium concentration varies from 1.6 mg/kg to 2.2 mg/kg and that of Copper varies from 6 mg/kg to 8.1 mg/kg (Figs. 4.23 and 4.25). Maximum Cadmium concentration was observed at 0.2 m radial distance and 0.3 m depth from the point of application of leachate after 150 days and minimum was at 0.15 m depth at 0.4 m radial distance after 100 days from the commencement of the experiment. Maximum and minimum Copper concentration was observed at 0.3 m depth at 0.4m radial distance and 0.6 m depth at 0.2 m radial distance respectively after 100 days from the start of the experiment.

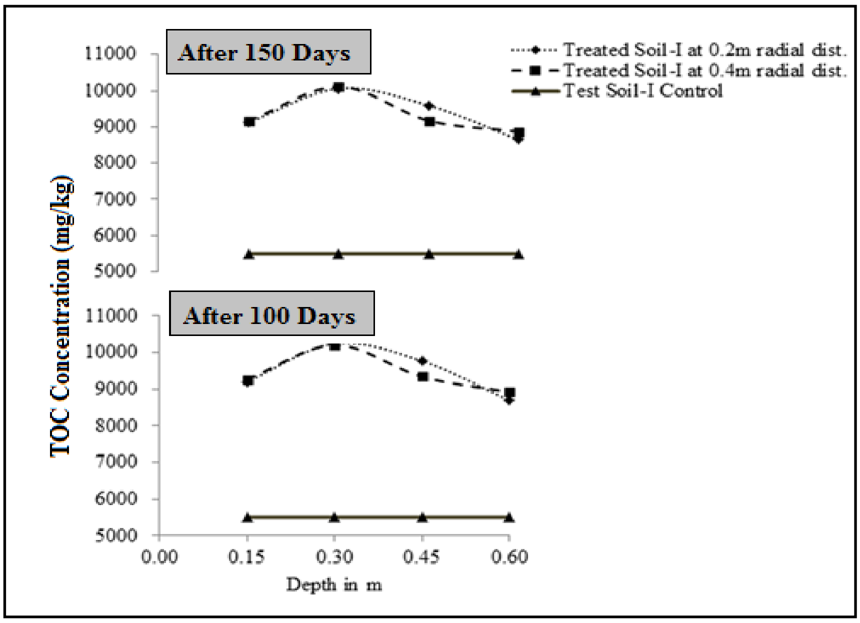


Fig. 4.26 *TOC Vs. Mid Depth of Soil Samples (Test Soil-I)*

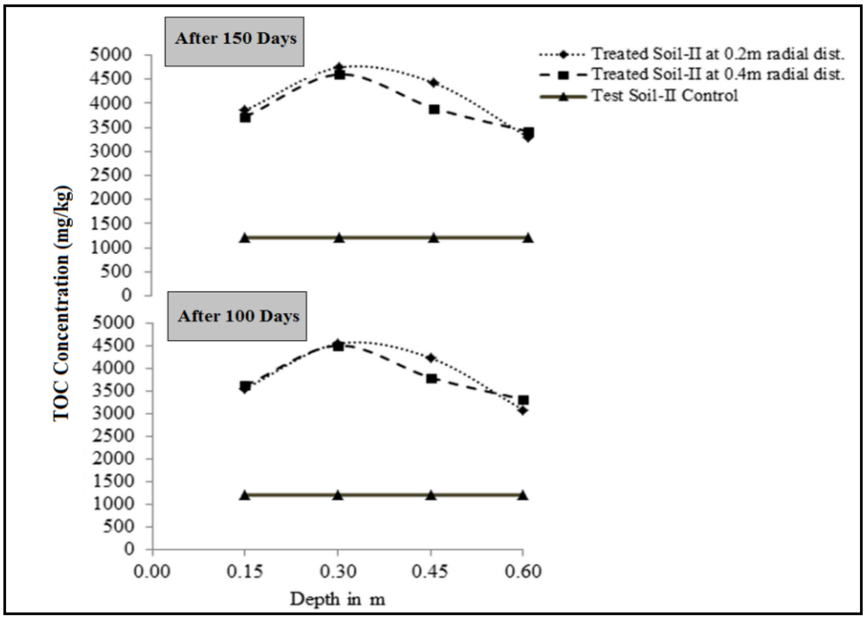


Fig. 4.27 *TOC Vs. Mid Depth of Soil Samples (Test Soil-II)*

TOC of leachate treated Test soil-I was varying from 8649 mg/kg to 10241 mg/kg (Fig. 4.26). Maximum TOC was observed at 0.3 m depth at 0.2 m radial distance from the point of application of leachate after 100 days and minimum TOC was at 0.6 m depth at 0.2 m radial distance after 150 days from the start of experiment. Slight increase in TOC was observed after 50 days maturing.

In leachate treated Test soil-II, TOC varies from 3087 mg/kg to 4748 mg/kg (Fig. 4.27). Maximum and minimum TOC was observed at 0.3 m depth at 0.4 m radial distance and 0.6 m depth at 0.2 m radial distance from the point of application of leachate immediately after the stoppage of leachate application. As in Test soil-I, slight increase in TOC was observed on 50 days of maturing in Test soil-II.

The results of chemical analysis are tabulated in Table 4.7 to 4.10.

Table 4.7 *Chemical Concentration of Test Soil-I after 100 Days*

	0.2 m Radial Distance				0.4 m Radial Distance				Control
Depth in m	**0.15**	**0.30**	**0.45**	**0.60**	**0.15**	**0.30**	**0.45**	**0.60**	
Manganese (mg/kg)	74.3	85.3	79.9	67.6	73.4	85.1	75.1	70.3	30.9
Zinc (mg/kg)	12.7	16.3	14.7	11.0	13.0	16.2	13.2	11.8	0
Cadmium (mg/kg)	2.0	2.6	2.4	1.8	2.1	2.6	2.1	1.9	0
Nickel (mg/kg)	9.3	11.9	10.7	8.0	9.4	11.8	9.6	8.6	0
Iron (mg/kg)	4665.7	5802.3	5290.8	4108.7	4295.5	5210.8	4362.3	3956.7	608
Ammonia (mg/kg)	286.6	299.0	297.4	289.2	284.0	295.4	292.9	288.2	224
Chromium (mg/kg)	10.2	13.1	11.8	8.8	10.4	13.0	10.6	9.5	0
Copper (mg/kg)	8.2	9.3	8.8	7.7	8.3	9.3	8.4	7.9	4.2
Chloride (mg/kg)	600.0	1500.0	750.0	650.0	350.0	1000.0	600.0	520.0	0
Nitrate (mg/kg)	53.2	56.6	55.5	52.1	52.2	57.3	56.2	51.7	42
TOC (mg/kg)	9197	10241	9767	8689	9261	10201	9333	8918	5500

Table 4.8 *Chemical Concentration of Test Soil-I after 150 Days*

	0.2 m Radial Distance				**0.4 m Radial Distance**				**Control**
Depth in m	**0.15**	**0.30**	**0.45**	**0.60**	**0.15**	**0.30**	**0.45**	**0.60**	
Manganese (mg/kg)	72.3	83.2	77.9	67.1	73.2	84.0	73.2	69.8	30.9
Zinc (mg/kg)	12.0	15.1	13.2	10.4	12.5	15.4	12.2	11.5	0
Cadmium (mg/kg)	2.0	2.5	2.3	1.7	2.0	2.6	2.0	1.9	0
Nickel (mg/kg)	8.8	11.4	10.2	7.8	9.3	11.3	9.2	8.3	0
Iron (mg/kg)	4584.5	5594.5	5056.7	4003.9	4221.7	5026.7	4193.4	3846.2	608
Ammonia (mg/kg)	285.0	296.2	294.4	288.4	282.5	294.1	290.0	287.4	224
Chromium (mg/kg)	9.6	12.5	11.2	8.5	10.2	12.5	10.1	9.1	0
Copper (mg/kg)	8.3	9.3	8.4	7.9	8.1	9.0	8.0	7.8	4.2
Chloride (mg/kg)	588.0	1440.0	712.5	630.5	343.0	960.0	573.0	502.8	0
Nitrate (mg/kg)	52.6	60.0	58.7	51.5	51.8	59.4	55.1	51.5	42
TOC (mg/kg)	9123	10062	9594	8649	9165	10113	9172	8876	5500

Table 4.9 *Chemical Concentration of Test Soil-II after 100 Days*

	0.2 m Radial Distance				0.4 m Radial Distance				Control
Depth in m	**0.15**	**0.30**	**0.45**	**0.60**	**0.15**	**0.30**	**0.45**	**0.60**	
Manganese (mg/kg)	42.5	54.4	49.0	36.7	43.4	54.2	44.2	39.4	13.7
Zinc (mg/kg)	10.9	14.1	11.1	9	11	13	10	9	0
Cadmium (mg/kg)	1.6	2.1	1.9	1.7	1.7	2.0	1.7	1.7	0
Nickel (mg/kg)	6.8	9.4	8.2	5.5	7.3	9.7	7.5	6.5	0
Iron (mg/kg)	3020	4097	4333	2799	3549	4406	3719	3247	1056
Ammonia (mg/kg)	62.6	75	73.4	65.2	60	71.4	68.9	64.2	19.6
Chromium (mg/kg)	8.5	10.9	9.4	7.1	8.3	10.1	8.5	7.4	0
Copper (mg/kg)	6.4	8	7	6	6.5	8.1	6.9	5.8	2.3
Chloride (mg/kg)	462	1303	715	548	212	803	565	418	53.5
Nitrate (mg/kg)	37.8	47	45.1	36.7	38.5	46.6	42.5	38	30.8
TOC (mg/kg)	3559	4544	4232	3087	3857	4748	4422	3292	1209

Table 4.10 *Chemical Concentration of Test Soil-II after 150 Days*

	0.2 m Radial Distance				**0.4 m Radial Distance**				**Control**
Depth in m	**0.15**	**0.30**	**0.45**	**0.60**	**0.15**	**0.30**	**0.45**	**0.60**	
Manganese (mg/kg)	50.5	62.4	55.0	45.7	50.4	62.2	50.2	48.4	13.7
Zinc (mg/kg)	14.2	16.2	12.3	10	13.1	15.3	11.3	10.5	0
Cadmium (mg/kg)	1.7	2.2	1.9	1.7	1.7	2.1	1.8	1.6	0
Nickel (mg/kg)	10.0	12.6	11.4	8.7	8.5	10.9	8.7	7.6	0
Iron (mg/kg)	3317.7	4301.3	4522.8	3003.7	3647.5	4503.8	3817.3	3344.7	1056
Ammonia (mg/kg)	67.6	83.0	79.4	74.2	67.0	79.4	74.9	73.2	19.6
Chromium (mg/kg)	11.7	13.3	12.6	10.3	9.5	12.0	9.7	8.5	0
Copper (mg/kg)	6.7	7.8	6.8	6.2	6.5	8.0	6.5	6.2	2.3
Chloride (mg/kg)	470	1303	715	548	310	901	663	516	53.5
Nitrate (mg/kg)	41.0	47.6	48.0	39.9	39.7	47.8	43.7	41.2	30.8
TOC (mg/kg)	3623	4504	3798	3316	3721	4602	3896	3414	1209

Among the chemicals in the synthetic leachate applied to the soil, 43% to 55% of heavy metals (Manganese, Zinc, Chromium, Cadmium, Copper and Nickel) were found to be adsorbed by the Test soil-I and, in Test soil-II the corresponding value was observed as 41% to 51%. From the discussions in the previous sections, it can be observed that the presence of chemicals is found to be maximum at 0.2 m radius and 0.3 m depth rather than that in the nearest point, i.e., at 0.2 m radius and 0.15 m depth. This may be due to the pattern of flow path of the leachate through the soil. There are different factors which controls the pattern of flow through soil such as layers of soil, types of soil in each layers, rate of precipitation etc.. A study in this respect can be found elsewhere (Chapter 6).

4.3.2 Effect of Radial Distance and Maturing Period on Chemical Adsorption of Soil

From the result of chemical analysis it can be generalized that the maximum concentration of majority of chemicals in each sample is observed at a depth of 0.3 m.

The percentage of different chemicals with respect to the concentration of synthetic leachate at 0.3 m depth at 0.2 m and 0.4 m radial distance from the point of application of the leachate in test soils are plotted and shown in Figs 4.28 and 4.29, for 100 days and 150 days respectively after the commencement of experiment.

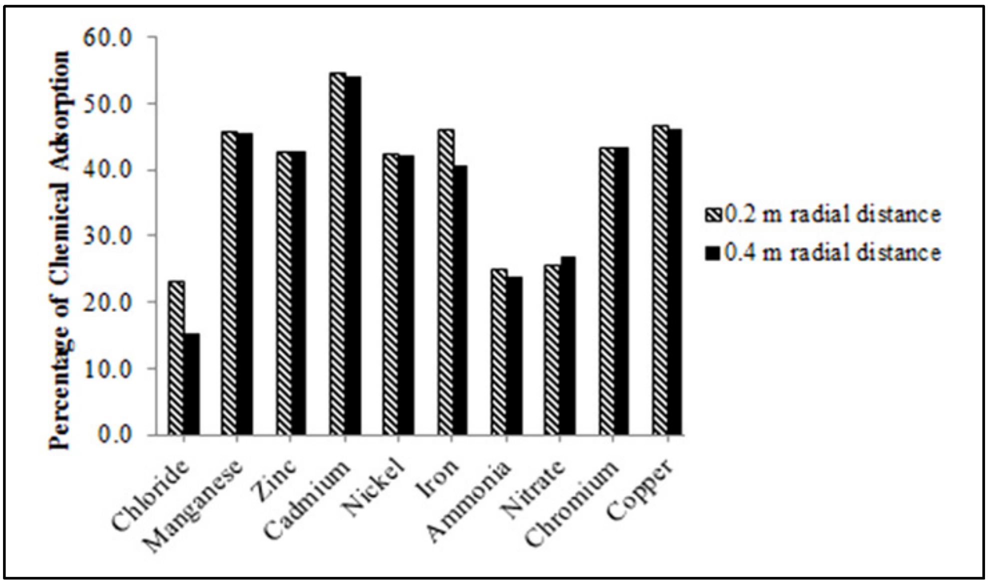


Fig. 4.28 (a) *Percentage of Chemical Adsorption of Test Soil-I at 0.3 m Depth in 100 Days*

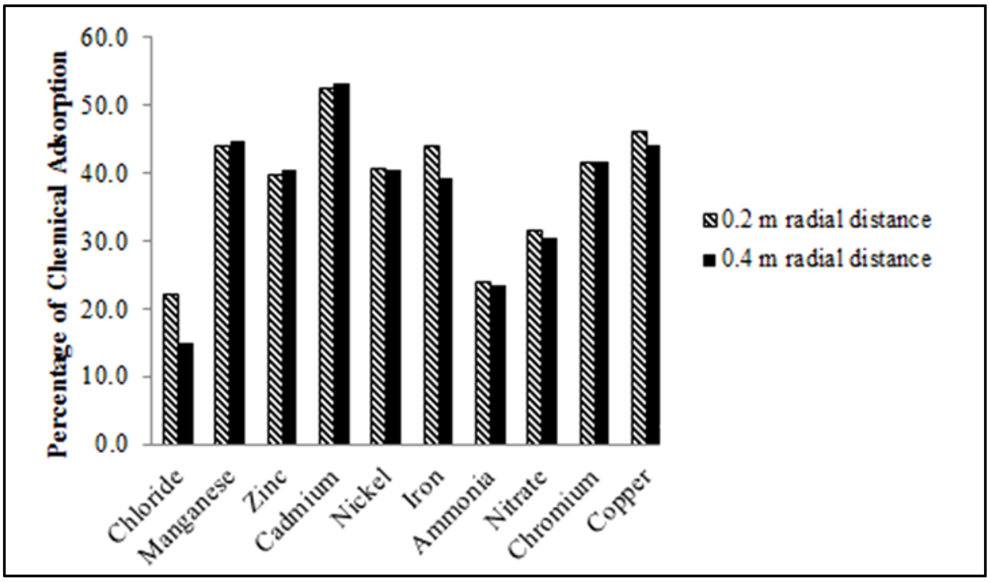


Fig. 4.28 (b) *Percentage of Chemical Adsorption of Test Soil-I at 0.3 m Depth in 150 Days*

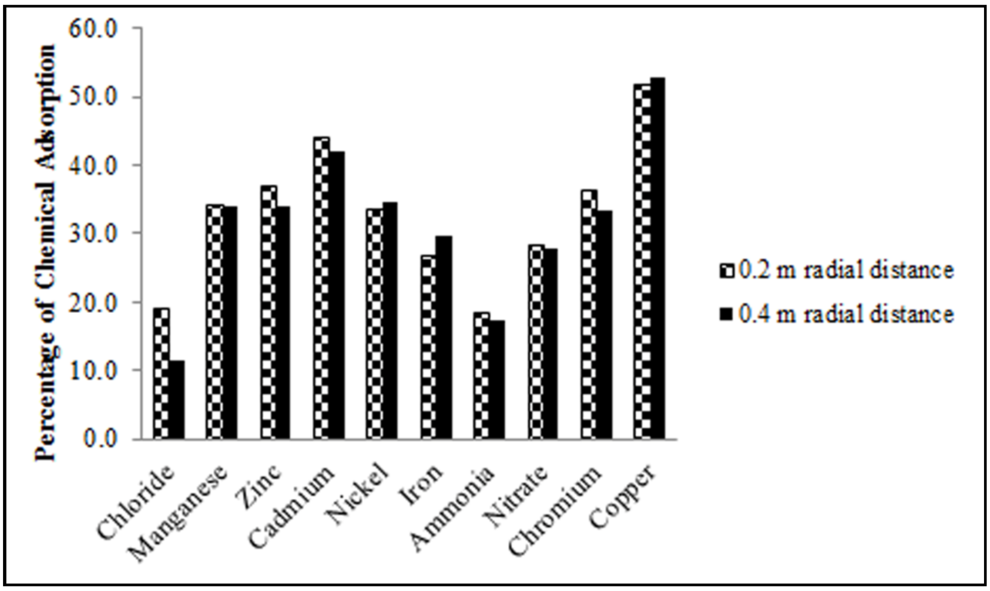


Fig. 4.29 (a) *Percentage of Chemical Adsorption of Test Soil-II at 0.3 m Depth in 100 Days*

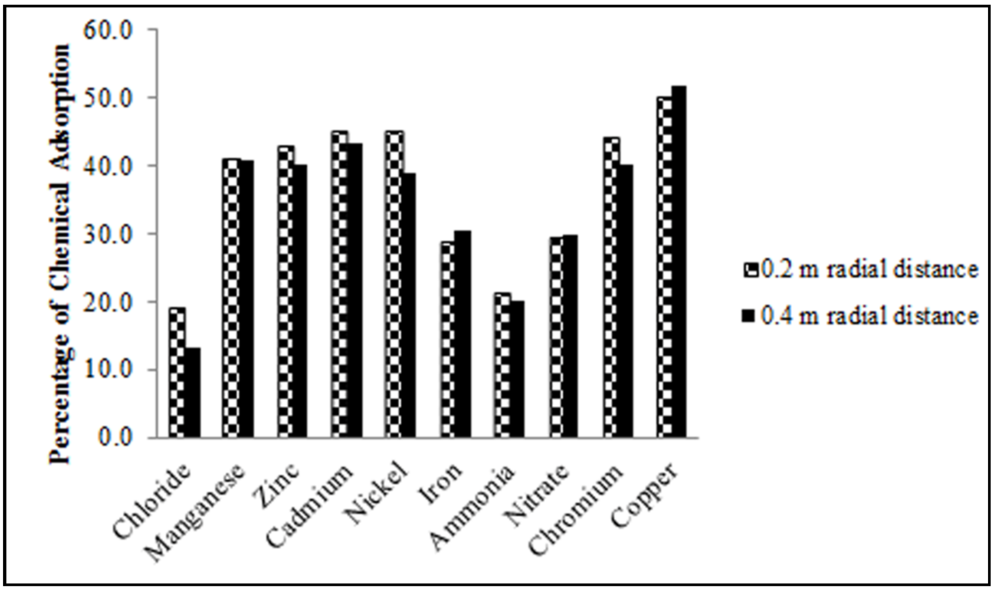


Fig. 4.29 (b) *Percentage of Chemical Adsorption of Test Soil-II at 0.3 m Depth in 150 Days*

According to Figs. 4.28 and 4.29, much variation in the concentration of chemicals cannot be observed in the soil samples at 0.2 m and 0.4 m radial distances at 0.3 m depth. It is also observed that percentage concentration of Cadmium, Copper, Chromium, Manganese, Zinc, Iron and Nickel are high. All these belong to heavy metal category. Among these, Cadmium, Nickel, Copper, Zinc, Chromium, and Manganese are most problem causing cationic metals. As most of these metals do not degrade, if once it is introduced to the soil, they will remain as they are. Mobility of metals depends on sorption characteristics of the soil and solubility of the metals. Soluble and un-adsorbed metal complexes can leach from soil into groundwater. Excess heavy metal accumulation in soils is toxic to humans and other animals.

All the cations in the soil belong to metal category other than Ammonia. When Ammonia reacts with water in the soil, it is converted into its ionic form Ammonium (NH_4^+) and adsorbed to the soil. The percentage of Ammonia in the test soil shows the adsorbed percentage of Ammonium by the soil.

The available anions, i.e., Chloride and Nitrate are highly soluble and eventually cause contamination of the ground water. The mobility of Chlorides and Nitrates are highly dependent on soil texture.

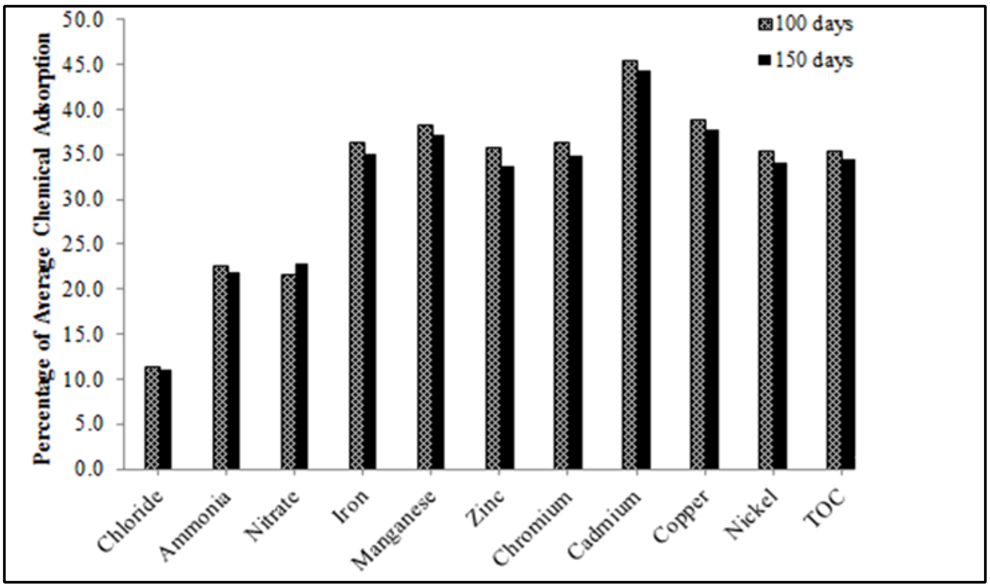


Fig. 4.30 *Effect of Maturing Period on Chemical Adsorption of Test Soil-I*

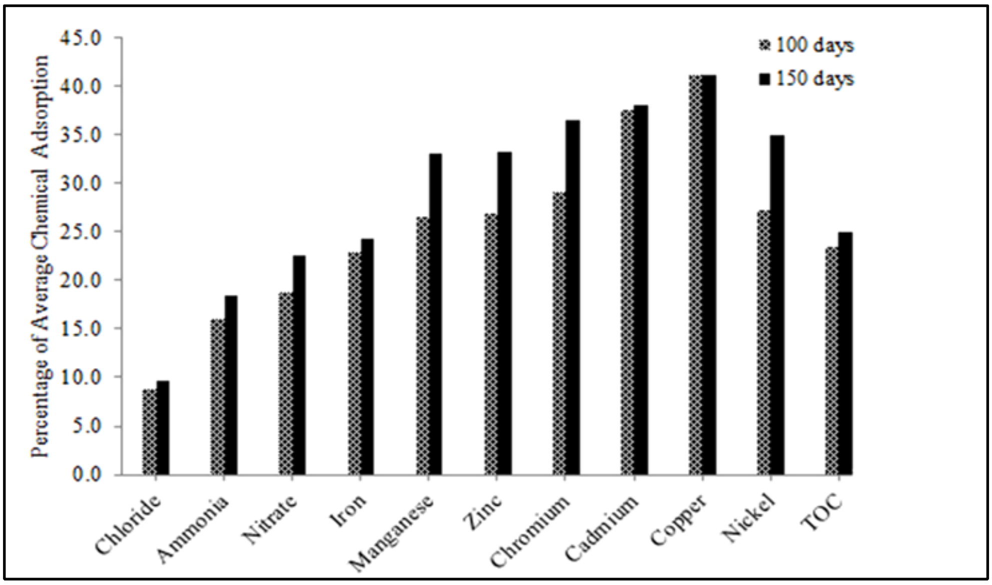


Fig. 4.31 *Effect of Maturing Period on Chemical Adsorption of Test Soil-II*

Figs. 4.30 and 4.31 represent the typical variation in percentage of average chemical adsorption as maturing period changes. It shows that the variation of chemical concentration in Test soil-I is marginal after maturing of 50 days. This may be due to the stoppage of application of leachate by 100 days from the start of experiment and has attained only 50% saturation by that time, the possibility of movement of chemicals through pore water gets lowered after 100 days. But in Test soil-II, 50 days maturing increases the chemical concentration. This may be due to the difference in the sorption and dispersion characteristics of chemicals and Test soil-II.

4.3.3 Effect of Leachate on Engineering Properties of Test Soils.

Engineering properties such as specific gravity, Atterberg limits and unconfined compressive strength of test soils applied with synthetic leachate for 100 days in the test tank, recovered from 0.2 m and 0.4 m radial distances from the point of application of leachate after 100 days and 150 days from the start of leachate application were also analysed. The variation in the engineering properties should be due to the influence of chemicals in the leachte used for the experiments. As the synthetic leachate prepared is a combination of different chemicals (to simulate the actual leachate), we cannot distinguish the role of each chemicals on the engineering properties. The net change will be due to the result of combined effect of these mixed contamiants. In order to generalise the effect of the mixed contaminants on the engineering properties of soil, the variation of the engineering properties were plotted graphically with respect to the total cation (ΣMn^{2+}, Zn^{2+}, Cd^{2+}, Ni^{2+}, Fe^{2+}, Cr^{2+}, Cu^{2+}, NH_4^+) and anion (ΣCl^-, NO_3^-) concentrations in mg/kg in the soil.

4.3.3.1 Specific Gravity

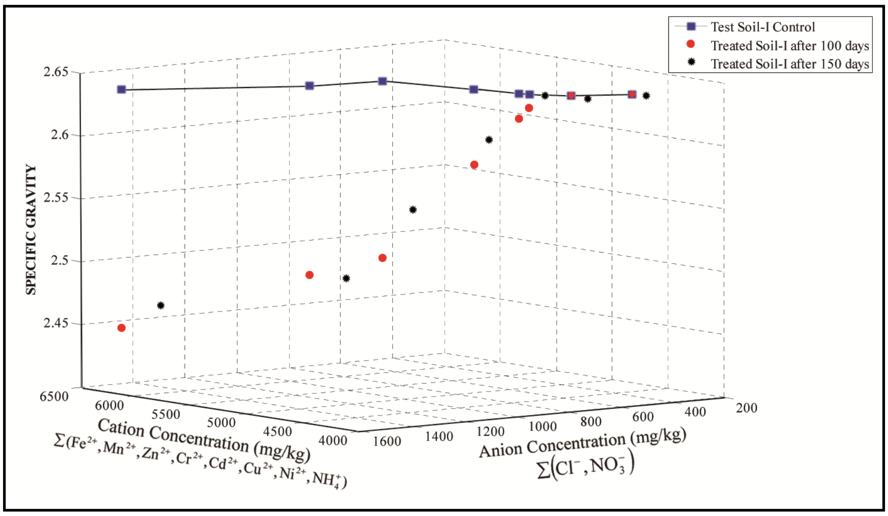


Fig. 4.32 *Specific Gravity Vs. Ion Concentrations of Test Soil-I*

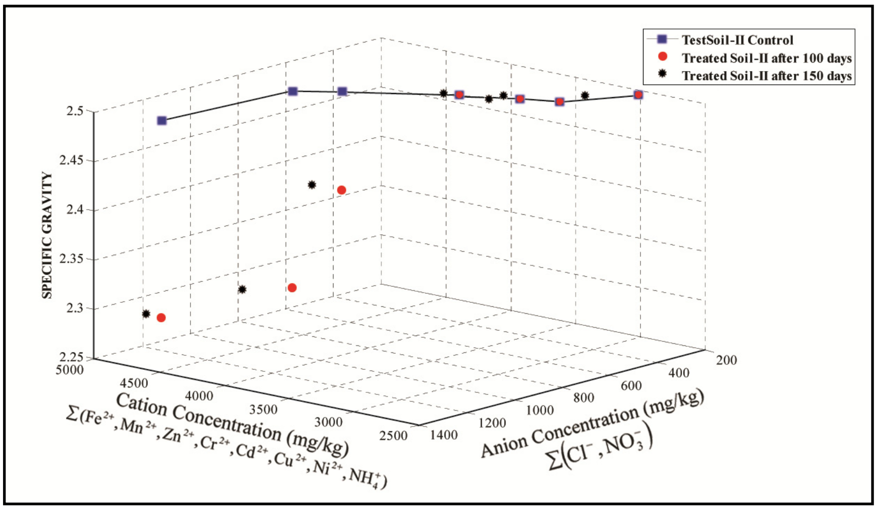


Fig. 4.33 *Specific Gravity Vs. Ion Concentrations of Test Soil-II*

Figs. 4.32 and 4.33 show that, as cation and anion concentrations in the test soils increases, specific gravity decreases. The maximum difference in specific gravity is observed at the positions where the cation and anion concentrations are maximum.

Specific gravity of Test soil-I decreases from 2.64 to 2.47 after 100 days and further to 2.45 after 150 days from the start of the experiment, corresponding to the total cation - anion concentration of 6240 mg/kg - 1556 mg/kg and 6024.8 mg/kg - 1500 mg/kg of soil. Whereas the total cation - anion concentration of the control soil-I was 867 mg/kg - 42 mg/kg of soil.

Specific gravity of control Test soil-II is 2.48 in which the concentration of cations and anions are 1092 mg/kg and 84 mg/kg respectively. The Specific gravity decreases to 2.31 after 100 days and 2.29 after 150 days from the start of the experiment. These values are observed at positions where the total cation - anion concentration were 4675 mg/kg - 1350 mg/kg and 4700 mg/kg - 1350 mg/kg of soil respectively.

4.3.3.2 Liquid limit

Figs. 4.34 and 4.35 show the spatial contours of cation and anion concentrations along with the liquid limit at salient points. From the spatial contours of cation and anion concentrations, approximate direction of flow of leachate in the test set up is assumed to follow a slopping downward pattern. As the horizontal hydraulic conductivity of soil is less than vertical hydraulic conductivity and the flow is due to gravitational force, fast dissipation of leachate through the soil is in vertical direction compared with horizontal direction. But the leachate dissipated from the side perforations, will tend to follow sloping direction. Thus the soil at 0.15 m depth will get contacted with less leachate compared to lower depth.

According to Jassam et al., 2014, the diffusion has a clear effect on contaminant transportation of an unsaturated zone. The diffusion mechanism leads to increase in the contaminant zone. According to Shackelford and Daniel (1991), diffusive transport in soil is slower than diffusive transport in free solution because of the reduced cross-sectional area of flow and the more tortuous pathways experienced by solutes diffusing through soil.

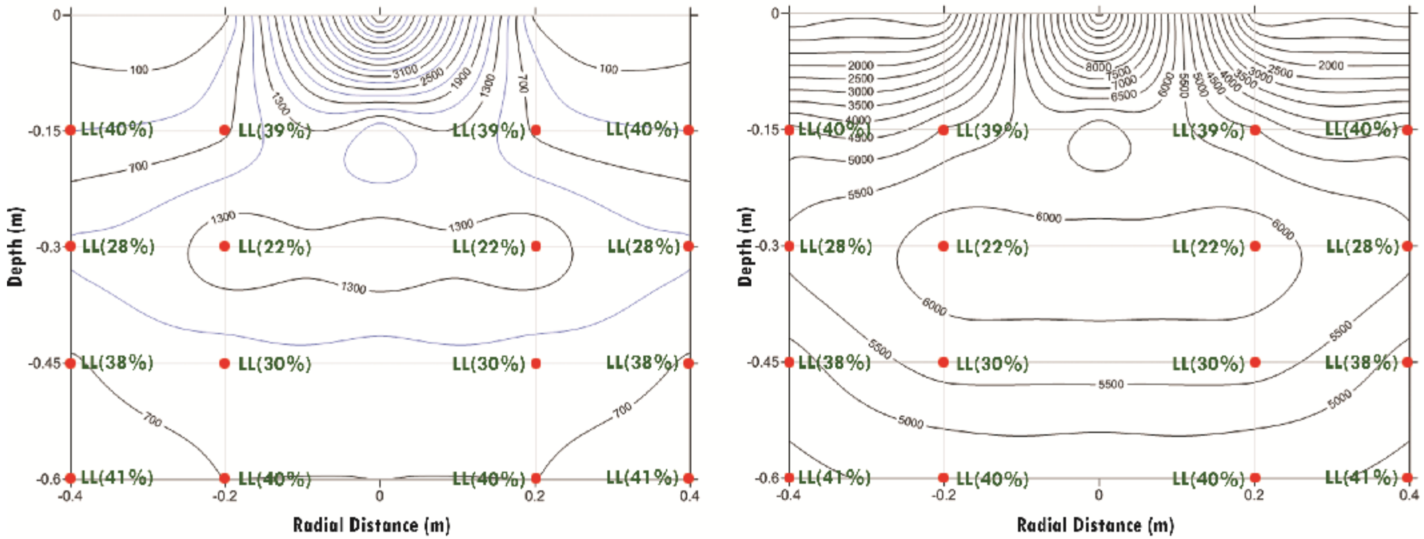
Thus it can lead to a conclusion that, due the gravitational force and diffusion mechanism, the Test soils at depth 0.3 m will be highly influenced by the chemicals in leachate than other depths.

It can be observed from the Figs. 4.34 and 4.35 that a slight increase in chemical concentration (both cation and anion) causes an increase in liquid limit of both soils. Further increase in chemical concentration leads to a gradual decrease in liquid limit even less than the control soil.

Considering the Test soil-I, an increase in liquid limit from 31% to 40% was observed when the cation - anion concentration is 4500 mg/kg - 400 mg/kg of soil. As cation - anion concentration increases beyond 5500 mg/kg - 1000 mg/kg of soil, the liquid limit decreases below the control value.

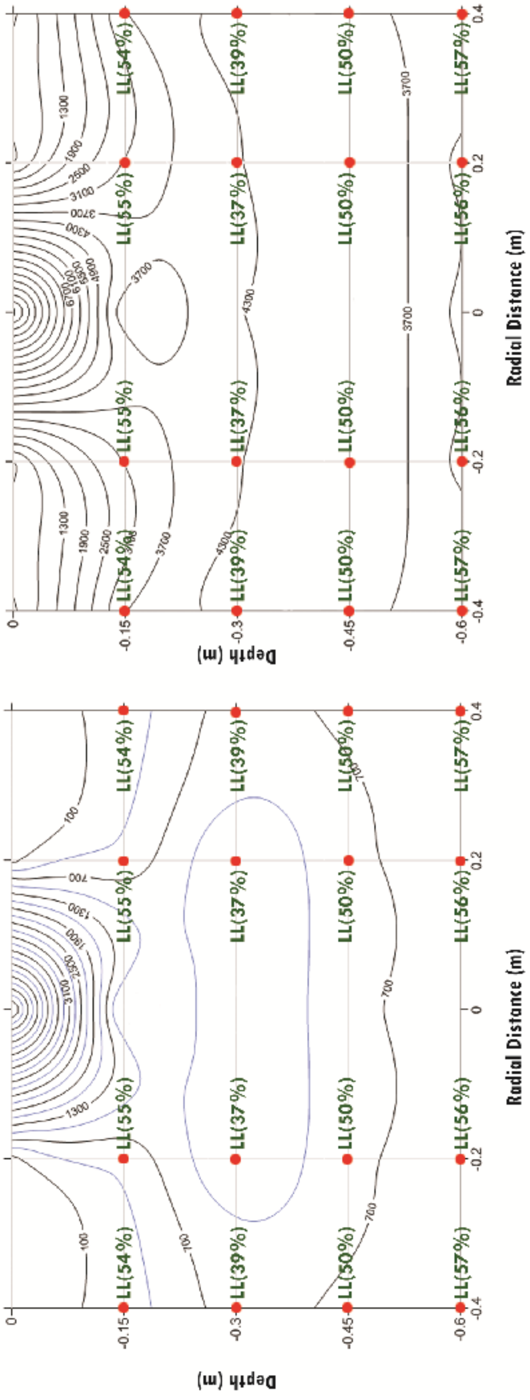
Test soil-II shows increase in liquid limit from 50% to 55%, when the cation is 3100 mg/kg - 550 mg/kg of soil. As cation and anion concentration increases beyond 3900 mg/kg - 550 mg/kg of soil, liquid limit of Test soil-II is less than the control value.

From the Figs. 4.34 and 4.35, we can see that where the concentrations of ions are similar, we are getting similar values of liquid limit. At the positions where the concentration is very high, we are observing a reduction in liquid limit.



(a) Anion Concentration **(b) Cation Concentration**

Fig. 4.34 *Spatial Contours of Ion Concentrations Superimposed with Liquid Limit (Test Soil-I)*



(a) Anion Concentration

(b) Cation Concentration

Fig. 4.35 *Spatial Contours of Ion Concentrations Superimposed with Liquid Limit (Test Soil-II)*

4.3.3.3 Plastic limit

Figs. 4.36 and 4.37 give the variation of plastic limit of Test soil-I and II respectively with respect to the cation and anion concentrations.

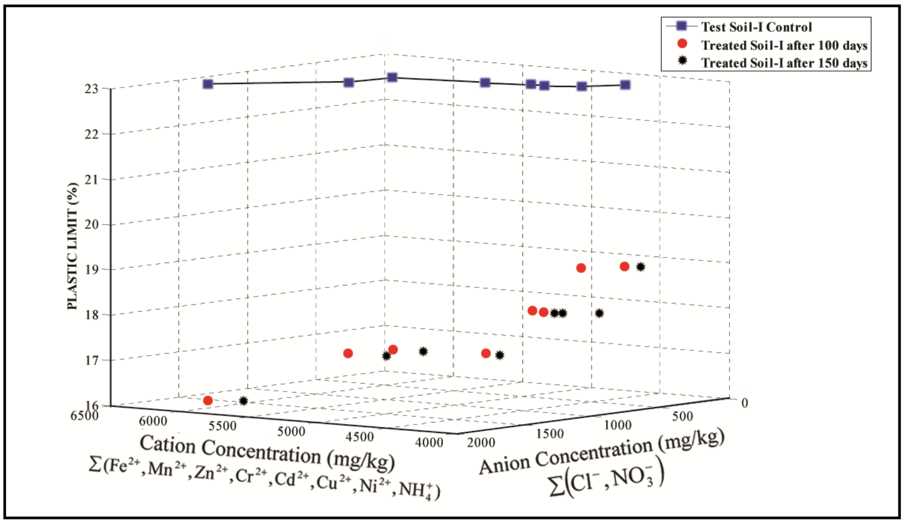


Fig. 4.36 *Plastic Limit Vs. Ion Concentrations of Test Soil-I*

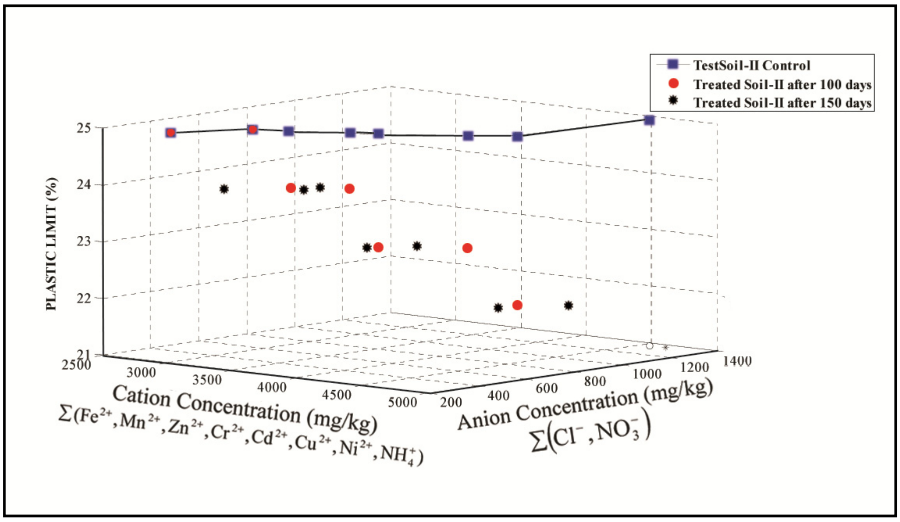


Fig. 4.37 *Plastic Limit Vs. Ion Concentrations of Test Soil-II*

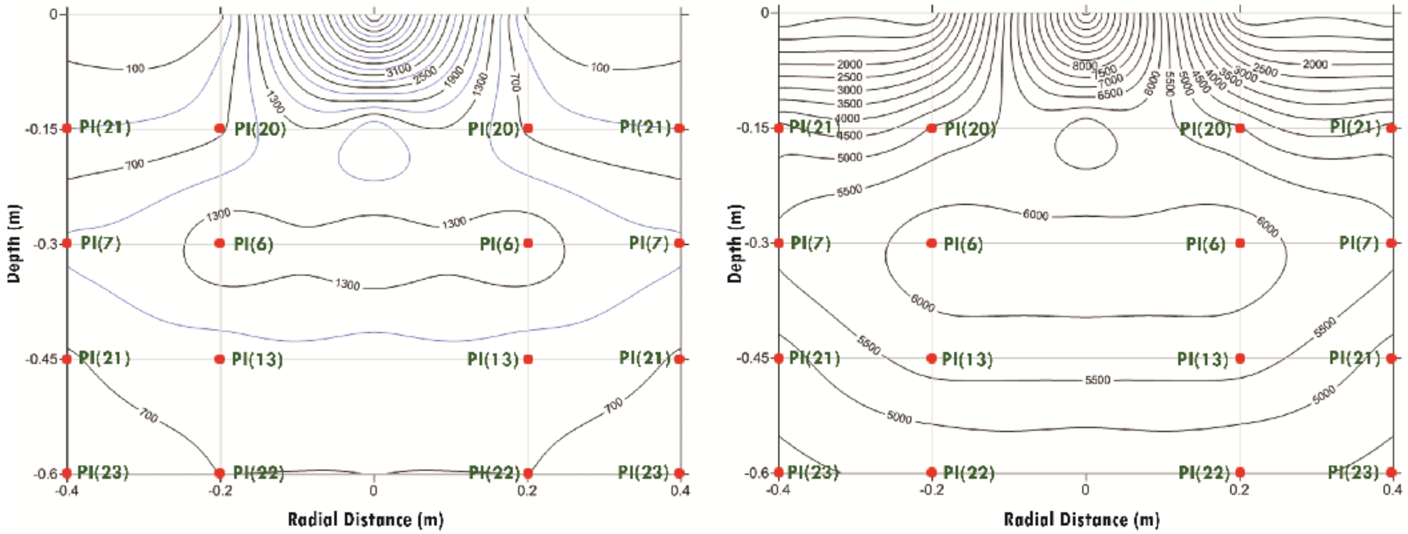
It is observed that, as ion concentration increases, plastic limit of test soils decreases. It decreases from 23% to 16% in Test soil-I and from 25% to 21% in Test soil-II at approximately 6100 mg of cations and 1525 mg of anions per kg of Test soil-I and approximately 4685 mg of cations and 1350 mg of anions per kg of Test soil-II. It can be observed that there is not much change in plastic limit value due to ageing.

4.3.3.4 Plasticity index

As in the case of liquid limit, plasticity index also increases initially as chemical concentration increases and further increase in chemical concentration causes gradual reduction in plasticity index of Test soils.

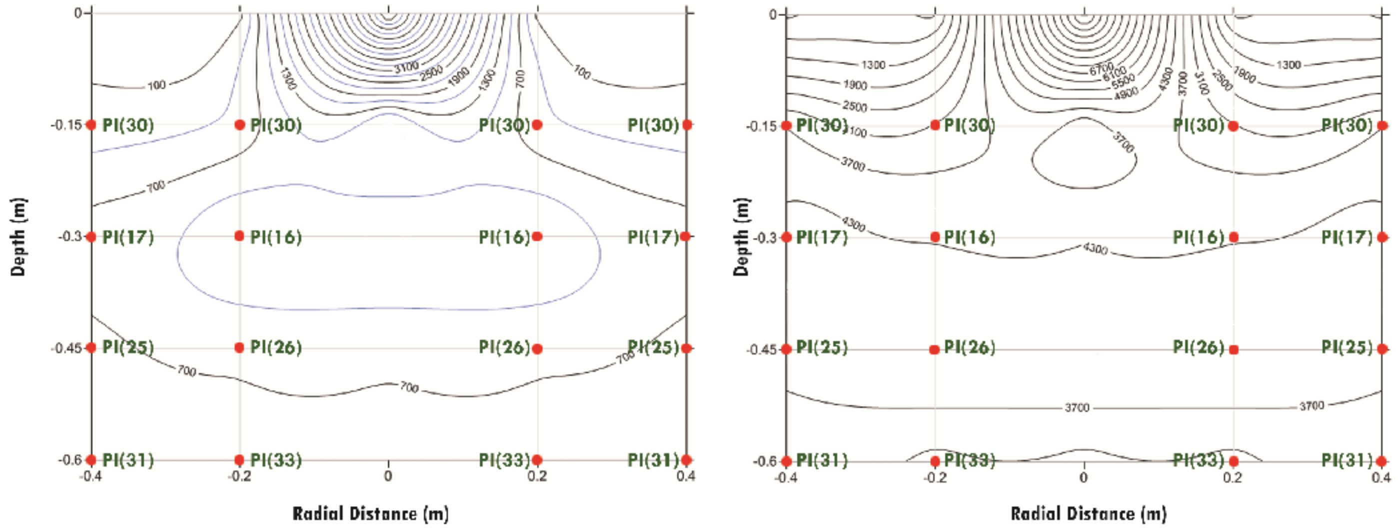
Plasticity index of Test soil-I increases from 8 to 21 at cation - anion concentrations of 4500 mg/kg - 400 mg/kg of soil. Increase in cation - anion concentrations beyond 6000 mg/kg - 1300 mg/kg of soil decreases the plasticity index to 6 (Fig. 4.38).

For Test soil-II, plasticity index increases from 25 to 30 for cation - anion concentrations of 3700 mg/kg - 400 mg/kg of soil. Beyond approximately 4200 mg/kg - 1000 mg/kg of soil the concentration, the plasticity index decreases upto 16 (Fig. 4.39). Thus small chemical concentration may improve the plasticity character of soil but beyond a range, the plastic behavior decreases.



(a) Anion Concentration **(b) Cation Concentration**

Fig .4.38 *Spatial Contours of Ion Concentrations Superimposed with Plasticity Index (Test Soil-I)*



(a) Anion Concentration

(b) Cation Concentration

Fig. 4.39 *Spatial Contours of Ion Concentrations Superimposed with Plasticity Index (Test Soil-II)*

4.3.3.5 Shrinkage limit

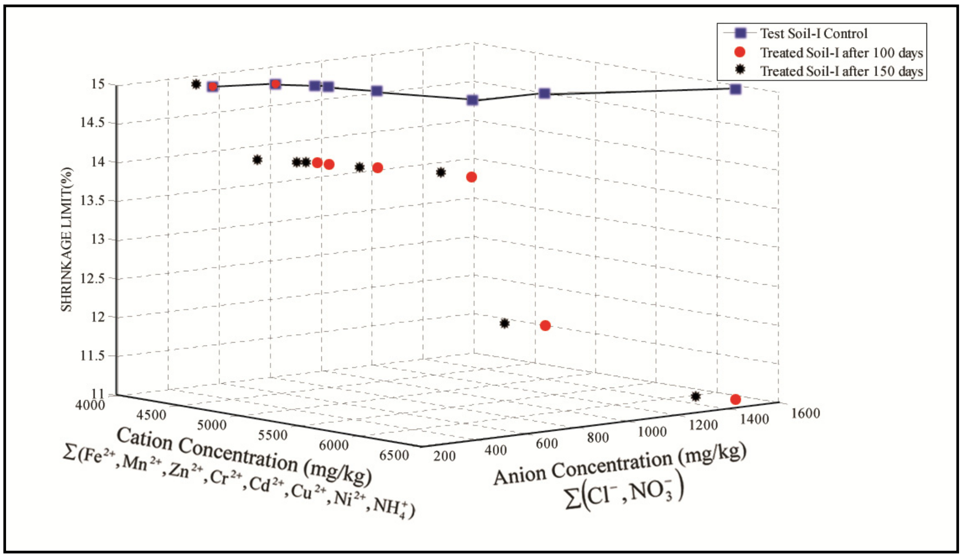


Fig. 4.40 *Shrinkage Limit Vs. Ion Concentrations of Test Soil-I*

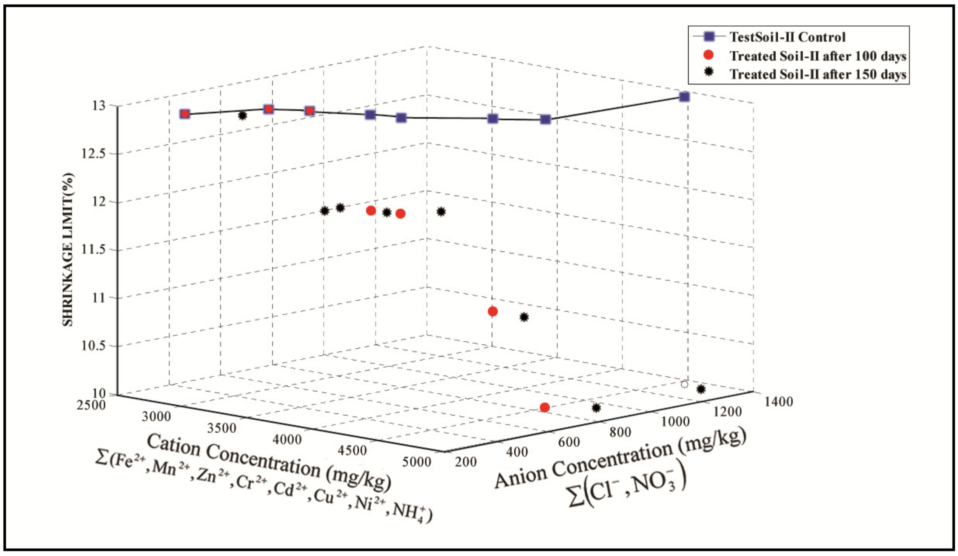


Fig. 4.41 *Shrinkage Limit Vs. Ion Concentrations of Test Soil-II*

Figs. 4.40 and 4.41 show the variation of shrinkage limit of Test soil-I and II respectively with respect to the cation and anion concentrations. Shrinkage limit of both test soils are observed to be decreased due to the chemical addition. Shrinkage limit of Test soil-I decreases from 15% to 11% at approximately 6100 mg of cations and 1525 mg of anions per kg of test soil. Corresponding decrease in Test soil-II is from 13% to 10% for an approximate 4685 mg of cations and 1350 mg of anions per kg of test soil.

4.3.3.6 Unconfined compressive strength

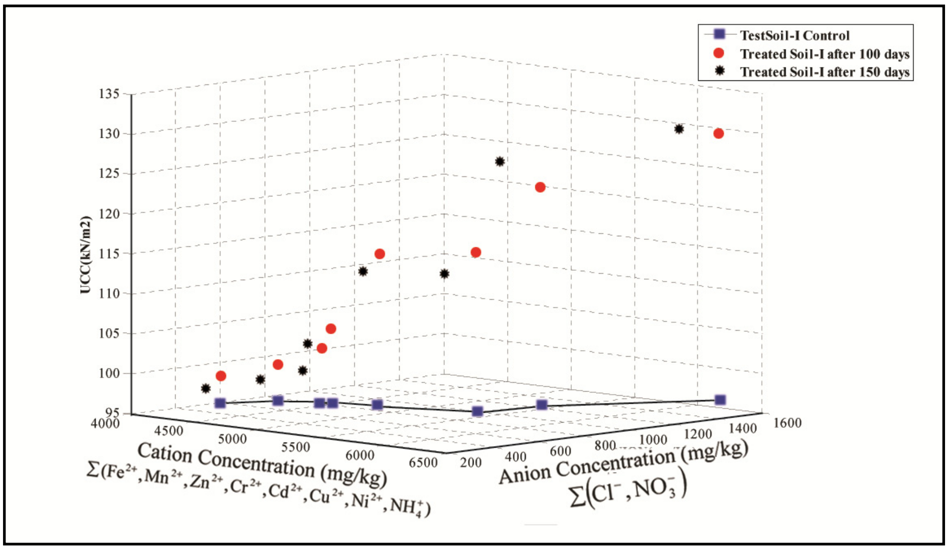


Fig. 4.42 *Unconfined Compressive Strength Vs. Ion Concentrations of Test Soil-I*

Figs. 4.42 and 4.43 show the effect of chemicals on the unconfined compressive strength of Test soil-I and II respectively. From the figures it can be observed that presence of chemicals can improve the strength of soil. At cation concentration of 6100 mg/kg and anion concentration of

1525 mg/kg of Test soil-I, UCC value increases upto 130 kN/m^2 from 96.3 kN/m^2.

In Test soil-II, the increase in UCC is upto 125 kN/m^2 from a value of 78.3 kN/m^2 at an average 4685 mg of cations and 1350 mg of anions per kg of soil.

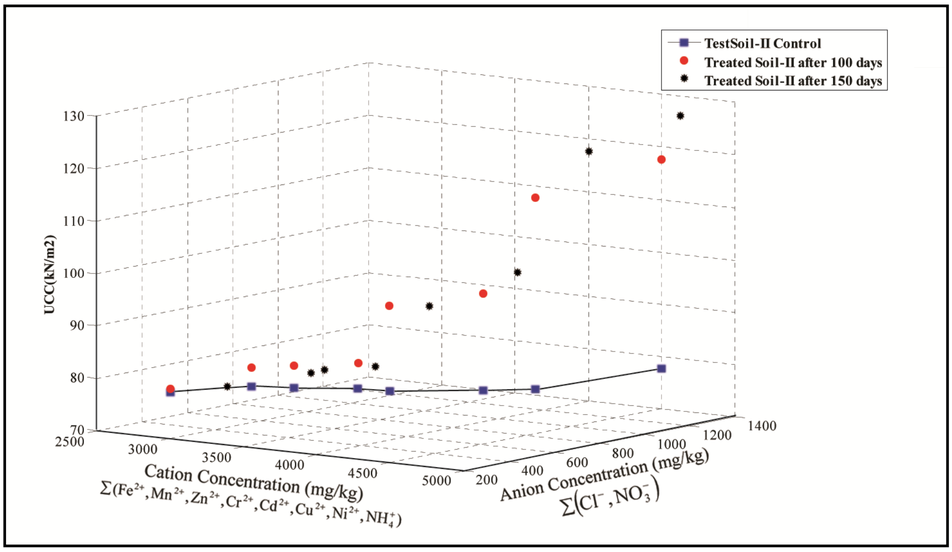
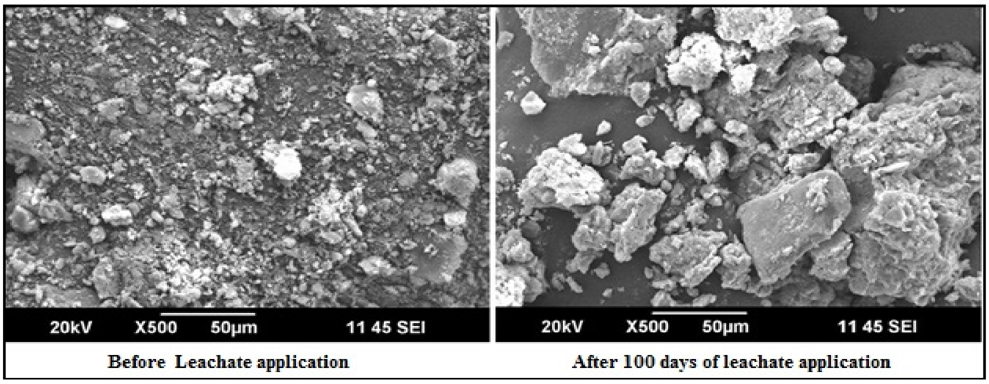


Fig. 4.43 *Unconfined Compressive Strength Vs. Ion Concentrations of Test Soil-II*

4.3.3.7 SEM analysis

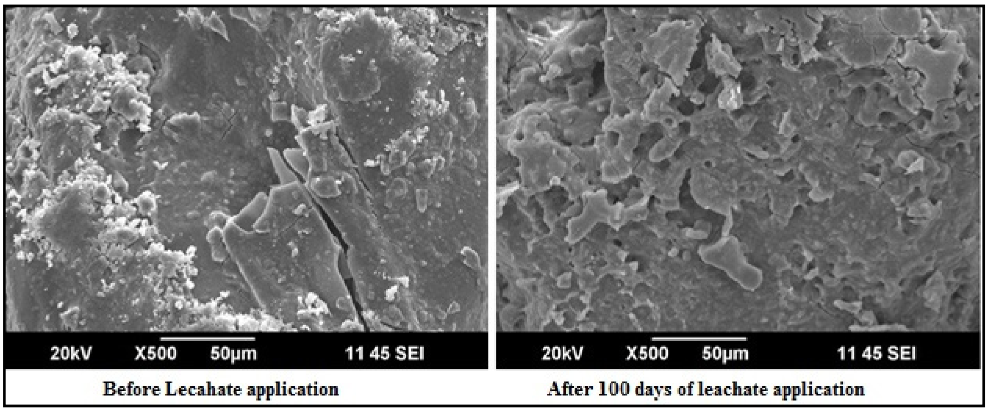
From the previous sections we can conclude that, the chemicals in the leachate of municipal solid waste landfill have a major influence on the soil properties. This may be due to the changes in microstructural behaviour of soils due to the leachate application. According to Romero and Simms (2008), microstructural behaviour of unsaturated soils has particular relevance to the geotechnical properties of the soils. To observe changes on microstructures of the contaminated soil, Scanning Electron Microscope test was performed on test soils before and after application of leachate. As the test soils with maximum chemical concentration is showing significant change in properties, both the test soil samples with maximum chemical concentration obtained after 100 days from the start of application of synthetic leachate is analysed with Scanning Electron Microscope. Investigation was using a JEOL JSM-6390 Scanning Electron Microscope operated at a voltage of 20 kV. Fig. 4.44 and Fig. 4.45 give SEM results of Test Soil-I and II.



Before Leachate application

After 100 days of leachate application

Fig. 4.44 *Scanning Electron Micrographs of Test Soil-I*



Before Lecahate application

After 100 days of leachate application

Fig. 4.45 *Scanning Electron Micrographs of Test Soil-II*

Fig. 4.44 illustrates the SEM-micrograph of Test soil-I. The micrograph of Test soil-I before leachate application shows an occurrence of grains of silt and fine sand fractions and little amount of clay as a matrix between the loose grains. The specimen has silt-fine like structure and relatively large voids distributed in the specimen. The micrograph of Test soil-I after 100 days of leachate application shows crumbs of flocs with a porous nature. The reaction of chemicals in the leachate with soil lead to the flocculation of soil grains with large pore space between each flocs and is responsible for the increase in porosity of the soil system. SEM-micrograph of Test soil-II before leachate application (Fig. 4.45) indicates that it is with sheet-like structure and flaky arrangement of the clay particles. The SEM-micrograph of leachate applied Test soil-II after 100 days (Fig. 4.45) illustrates cementitious compounds (as reaction products) joining together and filling the pore spaces. This led to join the soil particles together and to gain strength.

4.4 Summary

In this chapter a laboratory set-up was developed to simulate the action of leachate in an unlined municipal solid waste landfill and studied the flow of synthetic leachate and its effect on soil. Based on the study following conclusions are made.

- The leachate is following a slopping downward pattern of flow through a uniform dense, single soil layer. But it is understood from the literature that, variation in density, soil type, number of layers, presence of cracks and fissures, direction of ground water flow etc., will have major role in the flow direction and pattern of leachate through soil. Since the site conditions of each landfill are different, the flow pattern of leachate through landfill cannot be generalized.

- The concentration of various chemicals at a position is different. The adsorption property of soil, mobility and solubility of chemicals etc., will influence the retention of the chemicals in soil.
- It is also proved that the chemicals in leachate has a major influence on the engineering properties of soil. The chemical addition may cause disintegration of soil grains and this may cause reduction in specific gravity and changes in Atterberg limits, as well as flocculation of soil grains. Further studies have conducted to explore more on these aspects in chapter 5.

Percolation of leachate was the only source of water in the test soil during the test period. After stopping the leachate application, considerable change in chemical concentration is not observed. This proves that the chance for the mobility of chemicals through soil without pore water flow is less. Thus we can simulate the contaminant transport through soil by simulating contaminant transport through ground water flow with reasonable accuracy.

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Chapter 5

EFFECT OF LEACHATE ON SOIL CHARACTERISTICS

Contents

5.1 Introduction

A large volume of leachate is produced in the process of decomposition of solid waste. Interaction of moisture with municipal solid waste (MSW) will lead to the production of leachate. As the composition of municipal solid waste landfill leachate depends on several factors it varies from time to time and site to site and it consists of organic matter, inorganic pollutants and hazardous substances (Slack et al., 2005; Umar et al., 2010). Major elements like calcium, magnesium, potassium, nitrogen and ammonia, trace metals like iron, copper, manganese, chromium, nickel, lead and organic compounds like phenols, poly-aromatic hydrocarbons, acetone, benzene, toluene, chloroform are generally found in leachate from a solid waste disposal site. The concentration of these in the leachate depends on the composition of waste. Such leachate generated from landfill sites pose serious environmental risks to the surrounding soil (Freeze and Cherry, 1979; Alker et al., 1995; Nayak et al., 2007). The chemicals contained in leachate from the landfill may undergo a variety of conversion and destruction reactions as they pass through the soil and into the underlying formations. The effectiveness of each soil to attenuate leachate is different, and not all elements or compounds are equally removed or reduced in concentration. Some of the pollutants may be adsorbed on to the soil media during the flow of leachate through the soil (Suad and Mustafa, 2013). Literature on the previous works has shown that the index and engineering properties of soil contaminated with landfill leachate, changes due to chemical reactions between the soil mineral particles and the contaminant (Foreman and Daniel, 1986; Gidigasu, 1976; Gnanapragasam et al.; 1996, Nayak et al., 2009). Knowledge of the effect of chemicals on the geotechnical properties of contaminated soil is essential to reduce the problems that geotechnical engineers faces while placing new structures on sites with contaminated soils. This will facilitate the invention and introduction of site specific technologies.

5.2 Experimental Study

Previous chapters strengthen the fact that, the chemical composition of the leachate has great influence on the physical and chemical properties of soil. Here it is intended to study the effect of chemical concentration on the engineering properties of soil. As the leachate from the MSW landfill leach through the soil, the concentrations of chemicals in the leachate also vary. To study that effect, here two types of test soils, i.e., low compressible Test soil-I and high compressible Test soil-II, is treated with synthetic chemicals at different concentrations and discussed its effect on the engineering properties after a maturing period of 7 days, 50 days, 100 days and 150 days in this chapter. Representative soil samples used for this experimental study are the same as that which was used in the previous study explained in Chapter 4.

Based on the composition of synthetic leachate as mentioned in Table 4.4, different concentrations are selected as 25%, 50%, 75% and 100% concentration that of the original synthetic leachate and different solutions were prepared in the laboratory accordingly. These synthetic leachate, prepared at 25% variations in chemical concentrations, were named as A1, A2, A3 and A4 and the chemical composition is tabulated in Table 5.1. The pH of the synthetic leachate was in the range of 5.8 to 6.0. Composition of synthetic leachate shows that divalent cations has predominant role among other inorganic chemicals in the synthetic leachate. Table 5.2 shows the concentration of chemical ions (cations and anions) in the synthetic leachate.

Table 5.1 *Composition of Synthetic Leachate*

Chemical Parameters	Concentration (mg/l)			
	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)
Chloride	1625	3250	4875	6500
Ammonia	75	150	225	300
Nitrate	14.25	28.5	42.75	57
Iron	2825	5650	8475	11300
Manganese	29.75	59.5	89.25	119
Zinc	9.5	19	28.5	38
Chromium	7.5	15	22.5	30
Cadmium	1.2	2.4	3.6	4.8
Copper	2.75	5.5	8.25	11
Nickel	7	14	21	28
TOC	2790	5580	8370	11160

Table 5.2 *Ionic Concentration in the Synthetic Leachate.*

Parameters	**Concentration (mg/l)**			
	A1	**A2**	**A3**	**A4**
Cations	2957.7	5915.4	8873.1	11830.8
Anions	1639.25	3278.5	4917.75	6557

Synthetic leachate was prepared with the same chemical compounds and method used in the laboratory modelling of leachate transport. The quantity of water used for the preparation of synthetic leachate is equivalent to the optimum moisture content of the test soils. After addition of this synthetic leachate to the two soils, the samples were kept in air tight packets for 7 days, 50 days, 100 days and 150 days for maturing. After maturing period, each packets were opened and tests were conducted in accordance with the current Bureau of Indian Specifications (IS: SP: 36 (Part 1) 1987) for the determination of particle size distribution, Atterberg limits, hydraulic conductivity and unconfined compressive strength.

5.3 Results and Discussions

Results of the tests carried out after maturing periods of 7 days, 50 days, 100 days and 150 days for analyzing the effect of chemicals on particle size distribution, shear strength, Atterberg limits and hydraulic conductivity of test soils are as discussed below.

5.3.1 Particle Size Distribution

The results of the particle size distribution of test soil-I and II treated with leachate at different concentrations namely A1, A2, A3 and A4 along with the control soil are presented in Figs. 5.1 to 5.8.

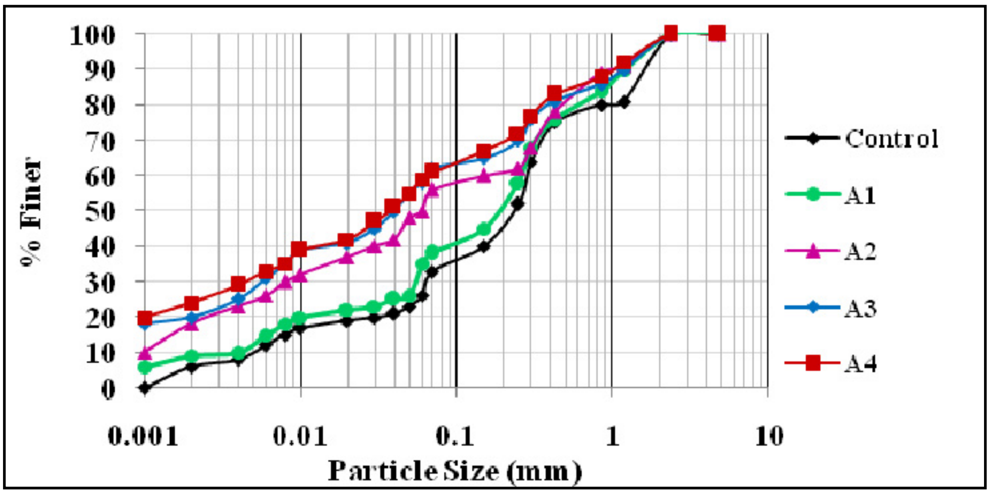


Fig. 5.1 *Particle Size Distribution of Test Soil-I after 7 Days*

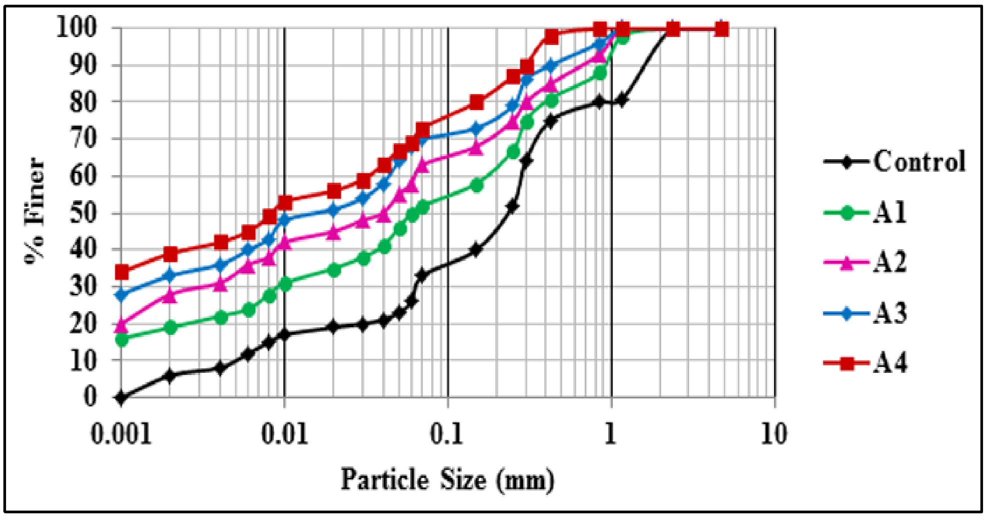


Fig. 5.2 *Particle Size Distribution of Test Soil-I after 50 Days*

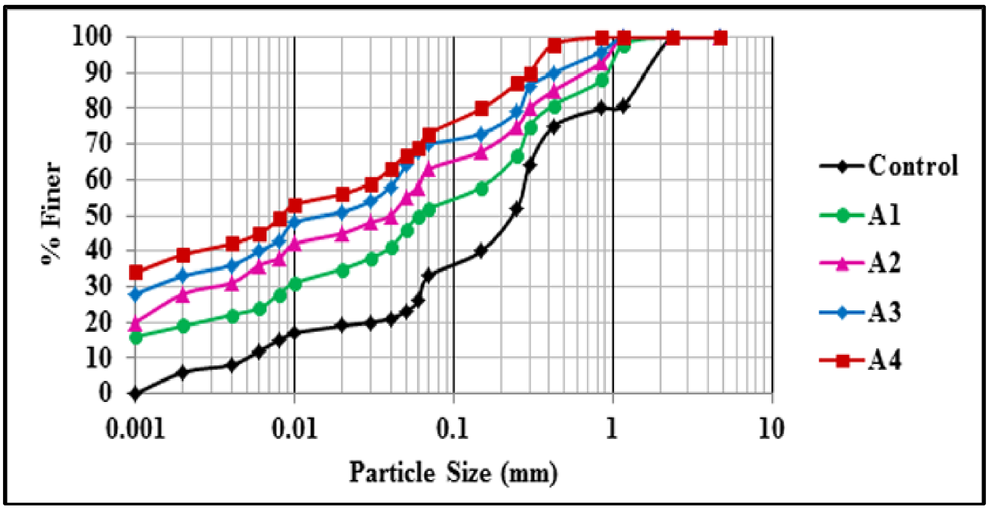


Fig. 5.3 *Particle Size Distribution of Test Soil-I after 100 Days*

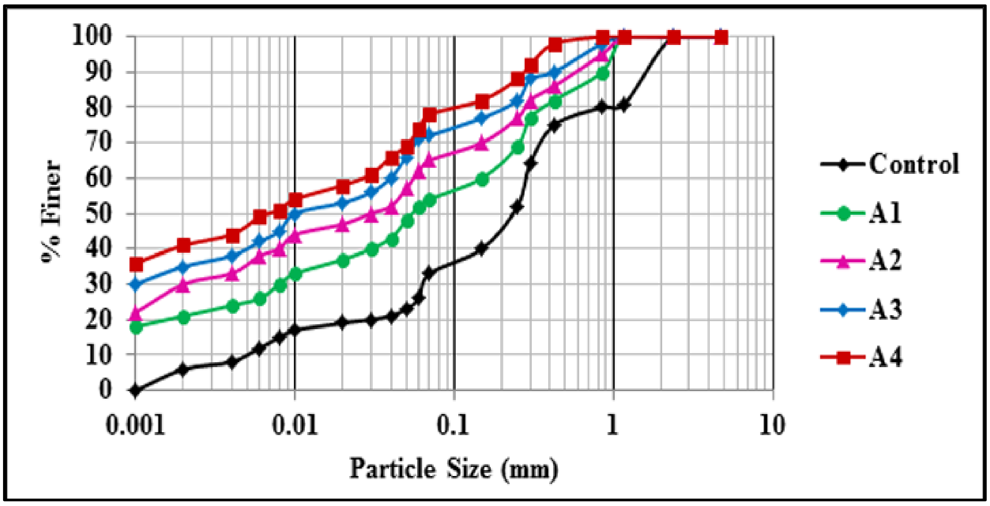


Fig. 5.4 *Particle Size Distribution of Test Soil-I after 150 Days*

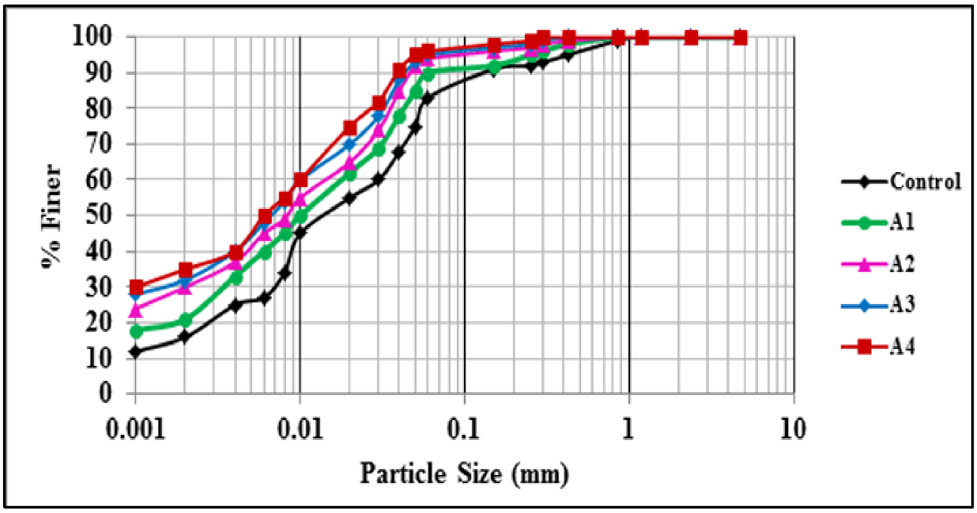


Fig. 5.5 *Particle Size Distribution of Test Soil-II after 7 Days*

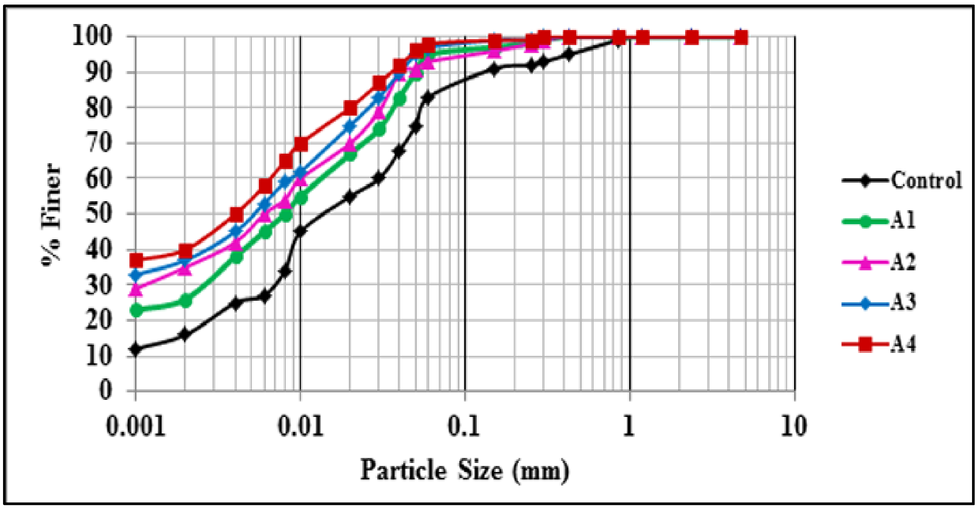


Fig. 5.6 *Particle Size Distribution of Test Soil-II after 50 Days*

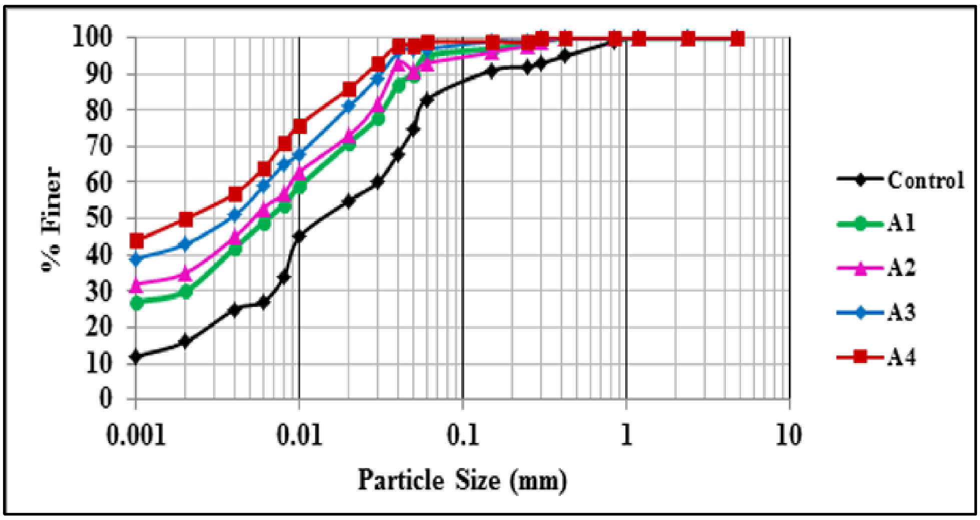


Fig. 5.7 *Particle Size Distribution of Test Soil-II after 100 Days*

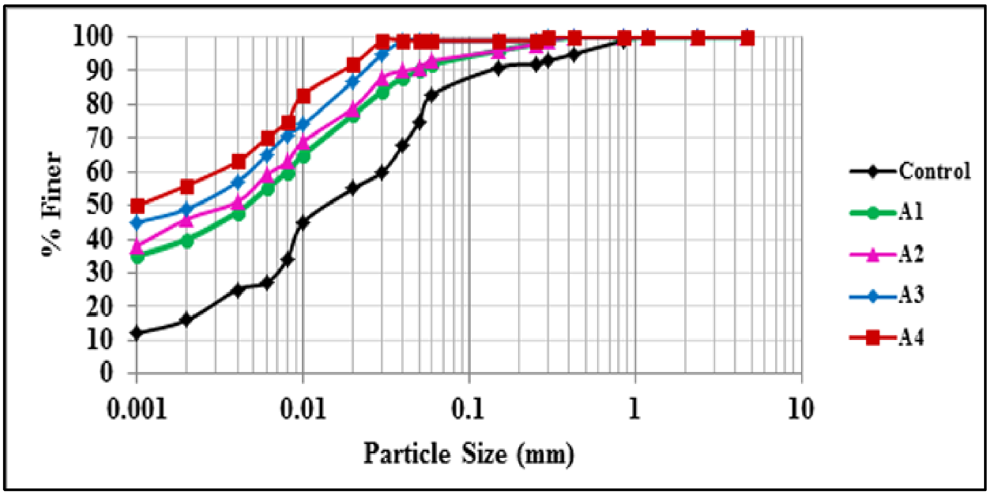


Fig. 5.8 *Particle Size Distribution of Test Soil-II after 150 Days*

The Figs. 5.1 to 5.8 shows that the chemical treated Test soil-I and Test soil-II has more fines than the untreated control soil. The percentage of fines increases as the concentration of leachate increases.

As the maturing period increases percentage finer increases corresponding to clay size particles. For the Test soil-I treated with 25% concentration of leachate (A1), the percentage of soil finer than 0.002 mm size increases from 6% to 9% in 7 days of maturing period. Further it increases to 14%, 19% and 21% corresponding to 50 days, 100 days and 150 days of maturity period. The corresponding values for Test soil-I treated with 50% concentration of leachate (A2), 75% concentration of leachate (A3) and 100% concentration of leachate (A4) are (18%, 24%, 28%, 30%), (20%, 28%, 33%, 35%) and (24%, 33%, 39%, 41%) respectively.

In Test soil-II treated with 25% concentration of leachate (A1), the percentage finer than 0.002 mm size increases from 16% to 21%, 26%, 30% and 40% corresponding to 7 days, 50 days, 100 days and 150 days of maturing period. The corresponding values for Test soil-II treated with 50% concentration of leachate (A2), 75% concentration of leachate (A3) and 100% concentration of leachate (A4) are (30%, 35%, 36%, 46%), (32%, 37%, 43%, 49%) and (35%, 40%, 50% , 56%) respectively.

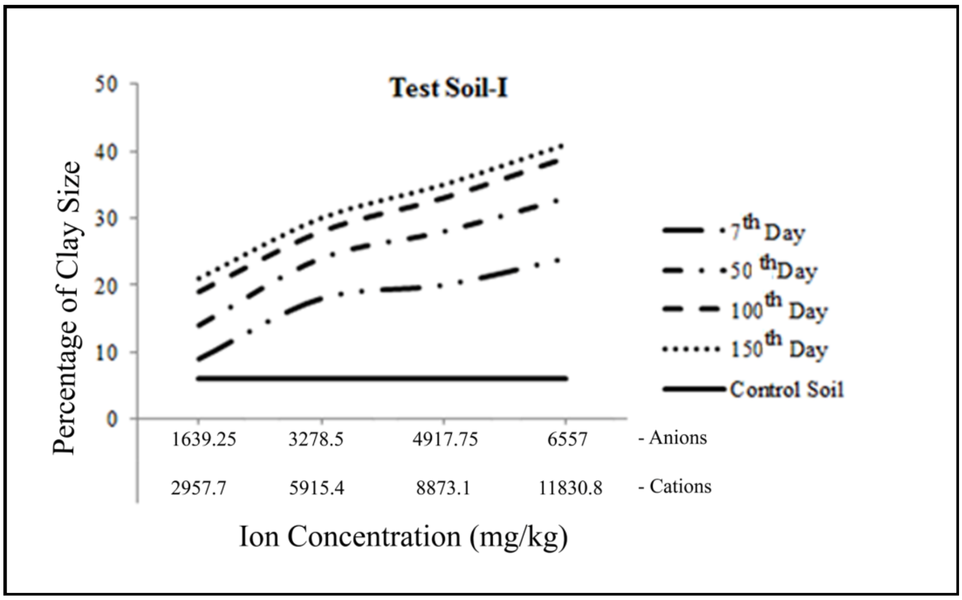


Fig. 5.9 *Ion Concentration Vs. Clay Size Particles of Test Soil-I*

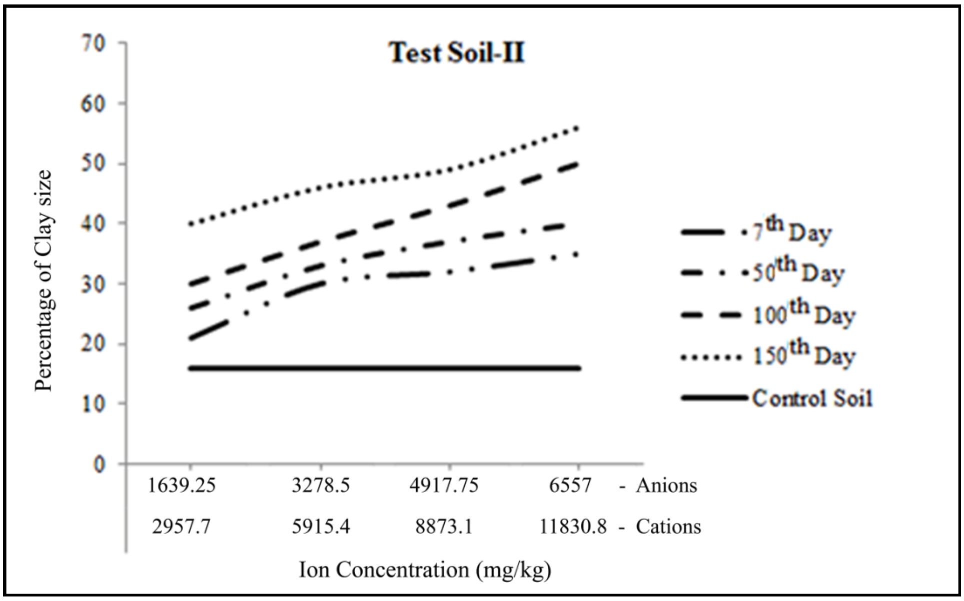


Fig. 5.10 *Ion Concentration Vs. Clay Size Particles of Test Soil-II*

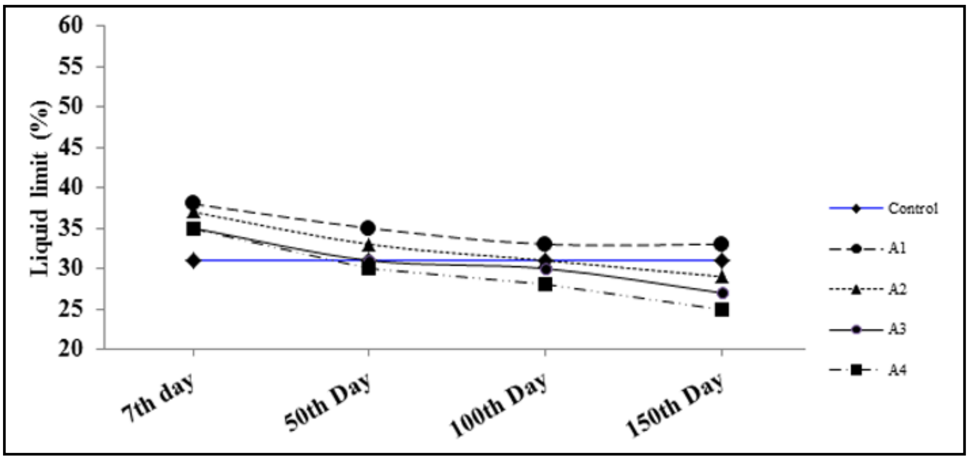
It is found that the chemical concentration has a major influence on the degradation of soil. To understand this, the percentage of clay size particles is plotted against the ion concentration. Fig. 5.9 and 5.10 shows an increase in the clay size particles in Test soil-I and Test soil-II as the ion concentration increases.

The results of the study show that the clay size particles are increased due to the influence of chemicals in the landfill leachate. The change in the particle size of the soil can be explained by chemical weathering. Chemical weathering involves the transformation of primary minerals into secondary minerals. Secondary minerals serve as the basic building blocks of the small particles with the soil. As a result, new materials may be synthesized.

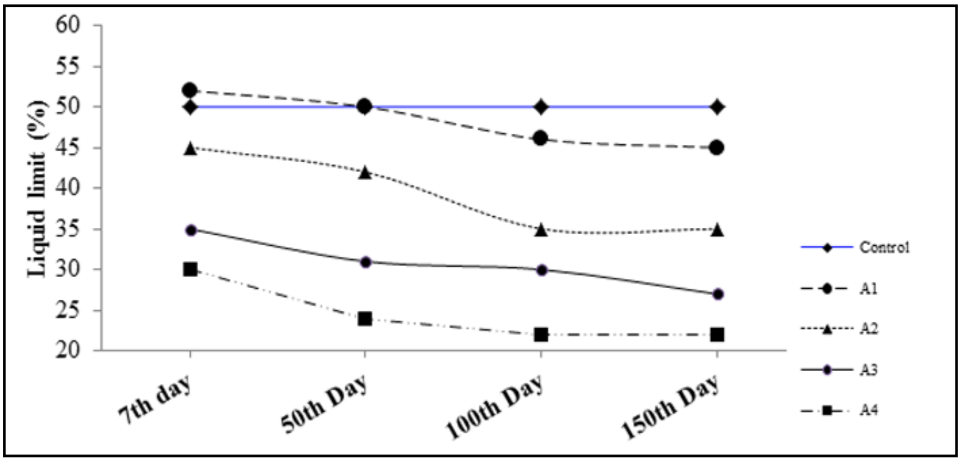
According to Mitchell, 2005, the clay grain content in heavily polluted soil samples is higher than that of light polluted soil. When a soil mass is influenced by pollutants, the colloids in the soil, such as organic and inorganic composite colloids and soluble salts, gets dissolved and it results in the weakening of strong link between soil grains. Thus most of the soil grains will disperse easily and clay grain content will get increased in heavily polluted soil (Jia et al., 2009).

5.3.2 Atterberg Limits

Chemicals have a major role in change in the plasticity characteristics of soils. Figs. 5.11, 5.12, 5.13 and 5.14 show the variation in Atterberg limits and plasticity index of Test soil-I and II as chemical concentration and contact period changes.



(a) Test Soil-I

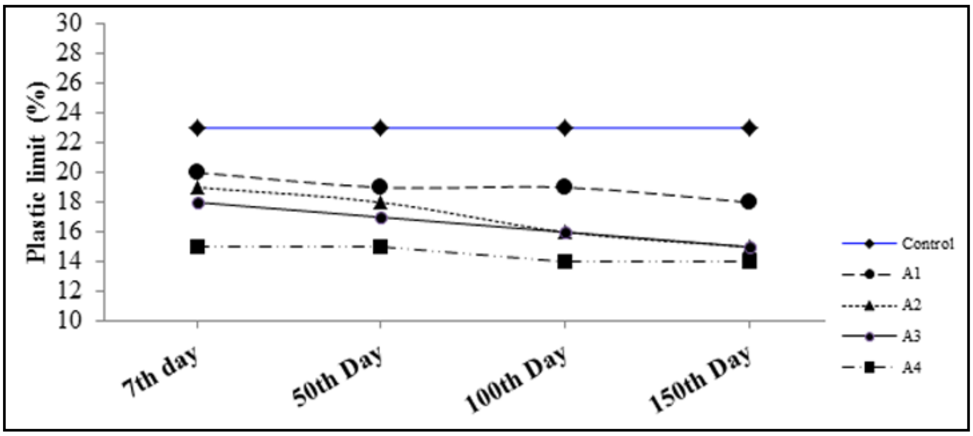


(b) Test Soil-II

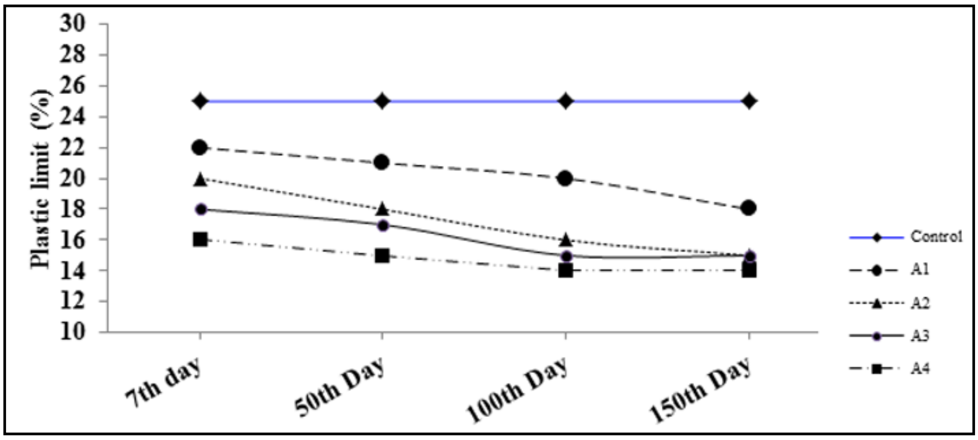
Fig. 5.11 *Liquid Limit Vs. Maturing Period*

The chemicals in the synthetic leachate causes an increase in liquid limit of 22% on Test soil-I treated with 25% leachate chemical concentration (A1) on 7th day. As maturing period increases percentage of increase in liquid limit decreases. Percentage increase in liquid limit of Test soil-I corresponding to maturing period of 50 days, 100 days and 150 days are 13%, 7% and 6%. Also as chemical concentration increases percentage of increase in liquid limit decreases. Test soil-I treated with 50% leachate chemical concentration (A2), on 7th day shows 19% increase of liquid limit. On 50th day, the increase in liquid limit is only 6.5%. The same soil shows 0% increase in liquid limit on 100th day and the liquid limit gets reduced by 6% on 150th day. Increase in liquid limit of Test soil-I treated with 75 % (A3) and 100% of leachate chemical concentration (A4) is 13% and 12% respectively. On 50th day both reflect 1% and 3% reduction in liquid limit respectively. After 100 days the corresponding reduced percentages are observed as 3% and 10%. Maximum reduction is observed on 150th day. It is 13% and 19% for Test soil-I treated with 75 % (A3) and 100% (A4) of leachate chemical concentration.

Test soil-II treated with 25% leachate chemical concentration (A1) on 7th day shows 4% increase in liquid limit. After 50 days 0% increase is observed. After 100 days and 150 days the liquid limit is reduced by 8% and 10% respectively. Test soil-II treated with 50% (A2), 75% (A3) and 100% (A4) of leachate chemical concentration show 10%, 30% and 40% reduction in liquid limit respectively on 7th day. The corresponding reduction after 50 days is 16%, 38% and 52% and after 100 days it is 30%, 40% and 56% respectively. After 150 days, Test soil-II treated with 50% (A2), 75% (A3) and 100% (A4) of leachate chemical concentration is showing 30%, 46%, and 56% reduction in liquid limit respectively. Thus it is proved that chemical concentration as well as ageing has major influence on the liquid limit of soil, showing a slight increase with low concentration and ageing, and then gradually reduces even below that of virgin soil.



(a) Test Soil-I

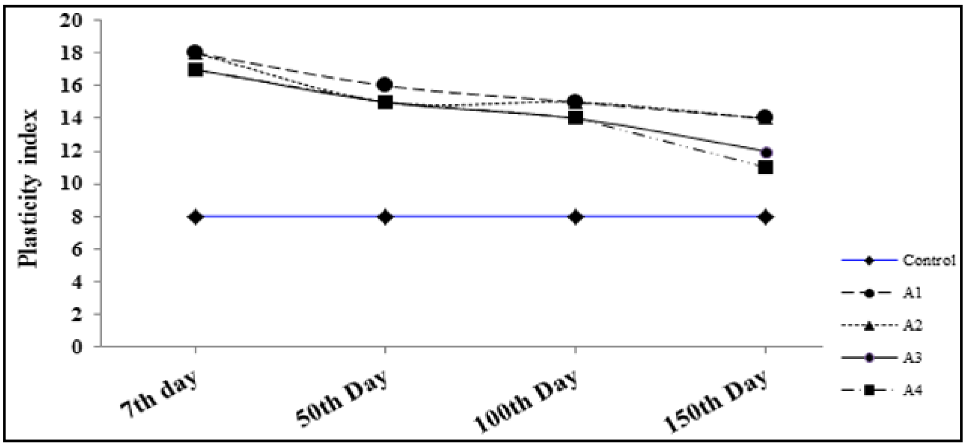


(b) Test Soil-II

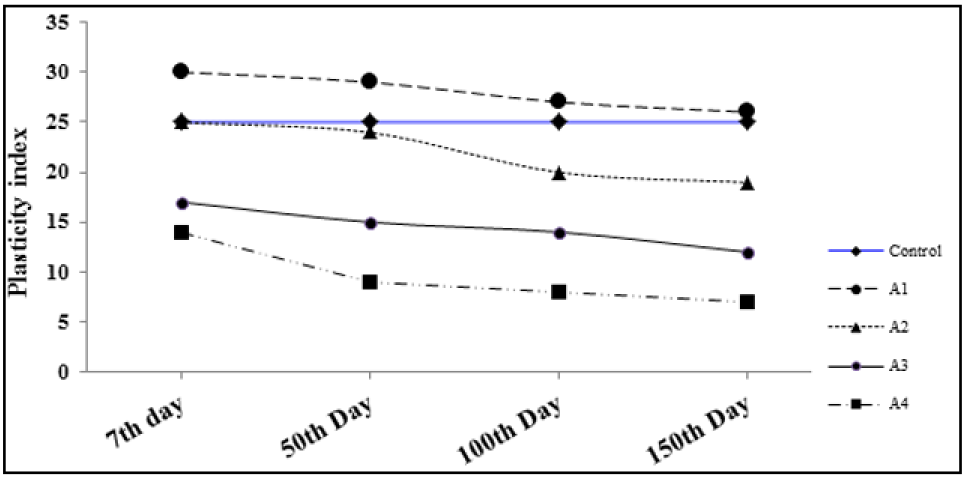
Fig. 5.12 *Plastic Limit Vs. Maturing Period*

Reduction in plastic limit of Test soil-I is observed to be 13%, 17%, 18% and 22% after 7 days, 50 days, 100 days and 150 days, when it is treated with 25% leachate chemical concentration (A1). The corresponding reduced values are 17%, 22%, 30%, and 35% when it is treated with 50% (A2) of leachate chemical concentration and 22%, 26%, 30%, 35% on treatment with 75% (A3) of leachate chemical concentration.

Test soil-I treated with 100% (A4) leachate chemical concentration on 7th day and 50th day is showing 35% reduction in plastic limit. The maximum reduction in plastic limit of Test soil-I is observed after 100 days and it is 39%. Even after 150 days, this maximum value did not changed.



(a) Test Soil-I



(b) Test Soil-II

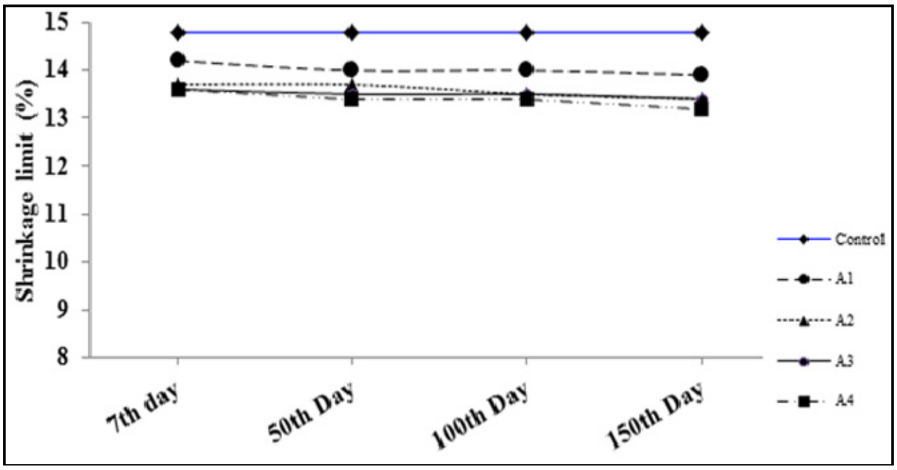
Fig. 5.13 *Plasticity Index Vs. Maturing Period*

Plastic limit of Test soil-II is observed to be reduced by 12%, 16%, 20% and 28% after 7 days, 50 days, 100 days and 150 days when it is treated with 25% of leachate chemical concentration (A1). On treatment with 50% of leachate chemical concentration (A2) the corresponding reduction are 20%, 28%, 36% and 40%. The corresponding values for Test soil-II treated with 75% concentration of leachate (A3) and 100% concentration of leachate (A4) are (28%, 32%, 39%, 40%) and (36%, 40%, 43%, 44%) respectively.

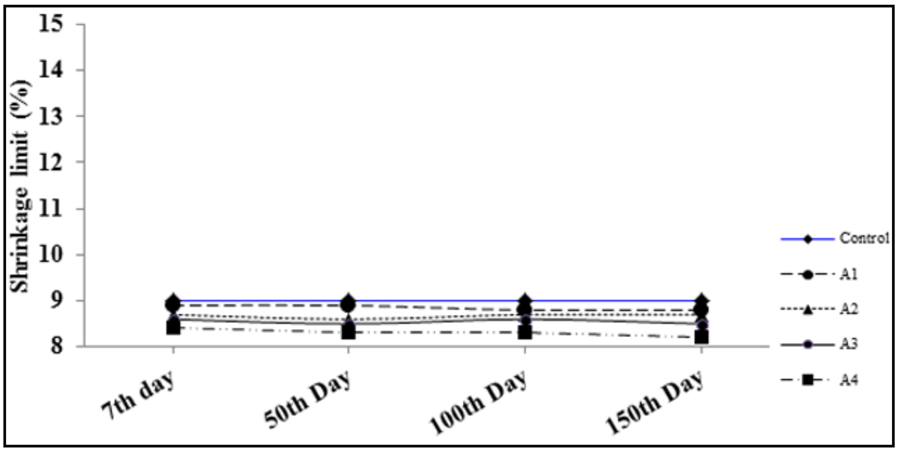
Test soil-I is a low plasticity soil and as it is added with chemical, its plasticity index increases from 8 to a range of 17 to 20 in 7 days on addition of 25% (A1) to 100% (A4) of leachate chemical concentration. As contact period increases, slight decrease in the increased value is observed. It is observed to reduce in the range of 14% to 11% with in 150 days.

For Test soil-II which is of high plasticity, the plasticity index increased from 25 to 30 on addition of 25% (A1) of leachate chemical concentration in 7 days. As maturing period increases to 50 days, 100 days and 150 days, plasiticity index gets reduced to 29, 27 and 26 respectively. On addition of 50% (A2) of leachate chemical concentration to Test soil-II, no change in plasticity index is observed as time passes. After 50 days, 100 days and 150 days, the reduction in plasticity index is observed to be upto 24, 20 and 19 respectively. The reduced values for Test soil-II treated with 75% (A3) of leachate chemical concentration after 7 days, 50 days, 100 days and 150 days are 17, 15, 14 and 12 respectively. The corresponding values on treatment with 100% (A4) of leachate chemical concentration are 14, 9, 8 and 7 respectively.

Fig 5.14 shows that, addition of chemicals to the soil reduces the shrinkage limit. On addition of 25% of leachate chemical concentration to Test soil-I, a reduction of 4% to 6% is observed during the test programme. As percentage of leachate concentration increases, the shrinkage limit is reduced further. No significant change is shown as ageing increases.



(a) Test Soil-I



(b) Test Soil-II

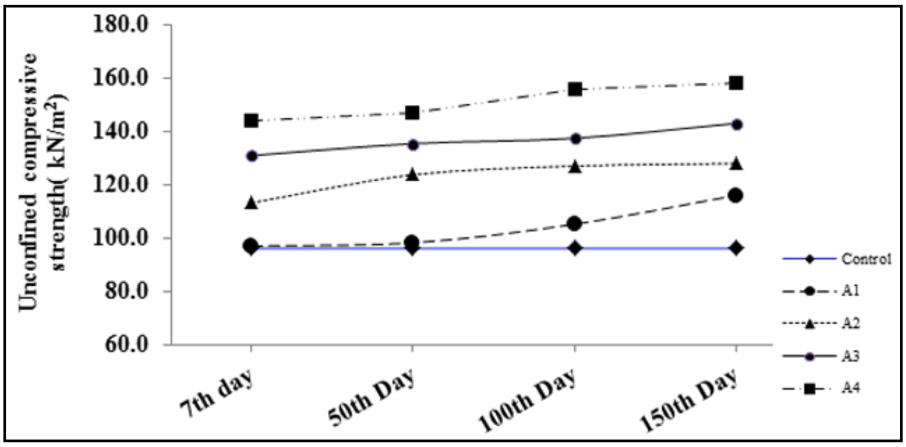
Fig. 5.14 *Shrinkage Limit Vs. Maturing Period*

Decrease in Atterberg limits may be attributed due to the change in nature of pore water fluid. The acidic nature of leachate in the pores media tends to disintegrate the soil particles and causes increase in specific area of soil. Increasing the salt concentration decreases the inter-particle repulsion which results in particles moving more freely in lower water contents, thus the Atterberg limits of the soil may decrease.

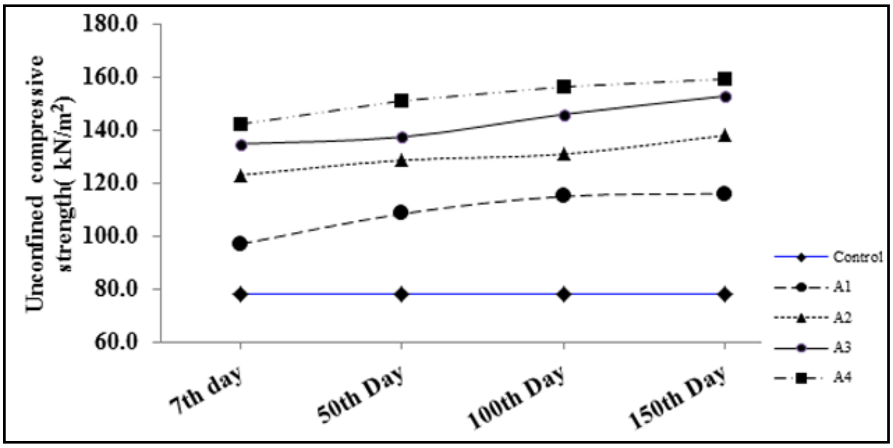
5.3.3 Soil Strength

Effect of chemicals on the strength parameters is assessed by conducting unconfined compressive strength on soils with varying concentration of chemicals and maturing period. The result is illustrated in Figs. 5.15 (a and b).

Unconfined compressive strength of test soils was observed to be increased due to the addition of chemicals. It shows a slight increasing trend towards maturing period also. Addition of 25% of leachate chemicals (A1) in Test soil-I leads to an increase in UCC strength from 1% to 20% within 7 days to 150 days of maturing period. The corresponding increase is from 18% to 33% and 36% to 48% on addition of 50% (A2) and 75% (A3) of leachate chemicals. 49% to 64% of gain in UCC strength is attained by Test soil-I when it is treated with 100% (A4) of leachate chemical concentration in 7 days to 150 days.



(a) Test Soil-I



(b) Test Soil-II

Fig. 5.15 *Unconfined Compressive Strength Vs. Maturing Period*

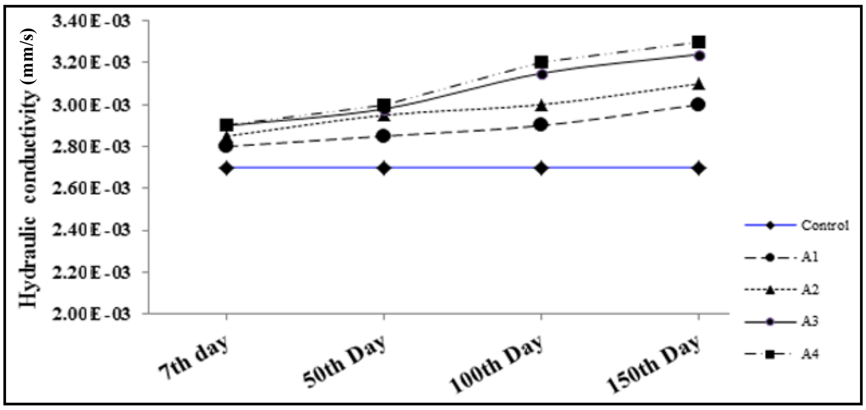
Percentage of increase in UCC strength of Test soil-II is more, compared to Test soil-I on treatment with same quantity of chemicals for same maturing period. 24% to 48% of gain in strength of Test soil-II is obtained on addition of 25% concentration of leachate chemicals and matured for 7 days to 150 days. When the leachate A4, with 100% concentration, is added to the soil, the highest increase in strength is observed upto 103%.

According to Kenney et al., 1992 and Tuncan et al., 1998, the liner material should be strong enough to sustain the static load exerted by the overlying body of waste. Limited information is currently available on the strength of soil interacted with chemicals. However, some of the researchers were focused on the investigation of the shear strength of lower activity clays such as kaolinite, sub soil or red earth. According to them, the large increase in inter-particle attraction made possible by the reduction of the diffuse double layer and was responsible for the flocculation of the clay mixture. This effect resulted in increased strength of clay mixtures. Thus it may be stated that, the increase in UCC strength when the concentration of the solutions was increased is attributed to the change in the thickness of Diffuse Double Layer (DDL).

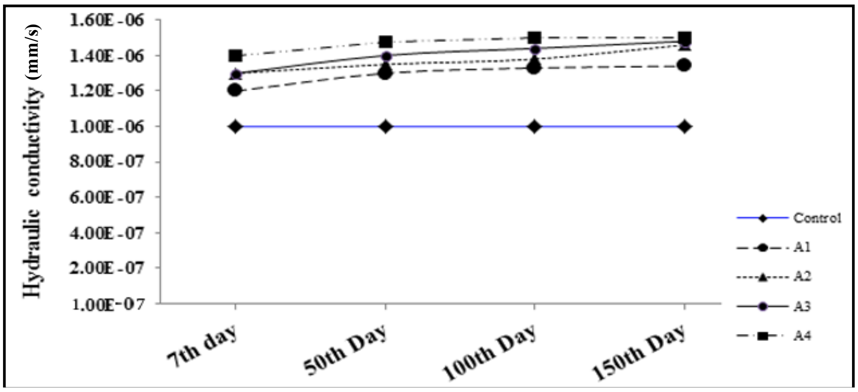
5.3.4 Hydraulic Conductivity

Because of the disintegration of the soil particles and reduction of the pore spaces, there can be some effect on hydraulic conductivity as there is chemical content with soil. Fig. 5.16 illustrates the effect of chemicals on the hydraulic conductivity of test soils.

Figs. 5.16 (a and b) show that the hydraulic conductivity of test soils increases as the concentration of chemicals and maturing period increases. 11% increase in hydraulic conductivity is observed in Test soil-I treated with 25% (A1) of leachate chemical concentration and matured for 150 days. Presence of 50% (A2) and 75% (A3) of leachate chemical concentration leads to an increase of 15% and 20% in hydraulic conductivity in 150 days. The corresponding increase is 22% on addition of 100% (A4) of leachate chemical concentration to Test soil-I.



(a) Test Soil-I



(b) Test Soil-II

Fig. 5.16 *Hydraulic Conductivity Vs. Maturing Period*

In Test soil-II, 20% to 34% of increase in hydraulic conductivity is found on addition of 25% (A1) of leachate chemical concentration in 7 days to 150 days of maturing. 50% (A2) and 75% (A3) of leachate chemical concentration leads to 46% and 48% increase in hydraulic conductivity respectively in 150 days of maturing. 40% to 50% of increase in hydraulic conductivity is observed in Test soil-II treated with 100% (A4) of leachate chemical concentration. Comparing with that of lateritic soil (Test soil-I), it is observed that the maturing period is having more influence in lateritic soil.

According to Robrecht (2006), landfill leachate containing high ionic concentration should increase the hydraulic conductivity as the increased ionic concentration decreases the double layer thickness. Thus the increase in hydraulic conductivity may be due to the physicochemical interactions including changes in the double layer thickness and results the flocculation of the clay particles.

5.4 DDL Theory Approach

The effects of pollutants on soils are complex, and may different for different types of soils. In the literature the effect of chemicals on the geotechnical properties are explained by Diffuse Double Layer (DDL) theories. Clay particles are negatively charged due to isomorphous substitution, and ionization of hydroxyl groups on the surface of other soil colloids and organic matter. As a consequence of the negative charge at the surface of clay particles, electrostatic forces exist between the negative surface and exchangeable cations. The strength of these forces is a function of the charge, the position of the charge and the valence of the exchangeable cations. If clay particles come into contact with a solution, cations from the solution are attracted to the clay surfaces to maintain electrical neutrality and a cation concentration gradient is formed. Because of this cation concentration gradient, the cations will tend to diffuse away from the clay surface to the solution. Thus the concentration of the cations decreases further from the surface of the clay minerals. This produces an electrostatic surface property known as the diffused double layer of the clay particle. The nature and properties of such layers are highly dependent on the type of mineral and the chemistry of the pore water. The thickness of the double layer decreases with decreasing values of the dielectric constant or increasing concentration of cations contained in the fluid which contacts the clay. DDLs bound to each clay mineral cause assemblages of clays to exhibit plasticity, cohesion and swelling. A second consequence of the presence of these double layers is a reduction of the frictional properties of the clay through the separation of minerals and particles contacts by double layers or through swelling (Moore, 1991, Sridharan and Jayadeva, 1982). All processes that change the electric properties of the double layer can change the macroscopic structure and the physical properties of clays.

The effect of pore fluid on the liquid limit has been studied by Sridharan and Rao (1975). Liquid limit is primarily, controlled by the shearing resistance to a limit and the thickness of the diffuse double layer. The shear strength of soil is affected by changes in attractive and repulsive pressures. Many factors are responsible for the net attractive and repulsive forces between soil particles. From several investigations, it has been concluded that the primary force responsible for repulsion between two soil particles is the interaction of diffuse double layers.

The hydraulic conductivity is supposed to change if the thickness of double layer changes. A smaller DDL results in a larger effective pore space, which leads to an increased hydraulic conductivity and larger DDL leads to clay particles being more peptized and thus the susceptibility to erosion is increased, resulting in an increased risk of pore clogging, which leads to a decreased hydraulic conductivity (Robrecht, 2006). Thus at low and relatively low chemical concentrations, the permeability increases with increase in the concentration. At high chemical concentrations, the type of cation or anion of the solution plays less important role. The long-term effects of acidic solutions increase the permeability (Sivapullaiah, 2009).

5.5 Summary

The present investigation results show reasonable agreement with DDL theories. In the synthetic leachate used for the experiments, cation concentration is high. The high cation concentration will tend to reduce the DDL thickness, resulting in increase in shear strength. It is widely accepted that the liquid limit is a measure of shearing resistance and thus liquid limit gets decreased. Also the small DDL thickness leads to increase in hydraulic conductivity. The long term effects of the cation concentration may lead to further reduction of DDL thickness. At greater ionic concentration, there is a lesser tendency of cations to diffuse away from the soil particles and tendency in reduction of DDL thickness may be reduced.

Thus we can conclude that the chemical solutions tended to reduce the thickness of the DDL, resulting in modification of Atterberg limits, hydraulic conductivity and shear strength of soils. Even though we have not analysed/ measured the effect of the synthetic leachate on the DDL thickness of the test soils, increase in the percentage of clay sized particles and obtained results of Atterberg limits, hydraulic conductivity and shear strength of test soils treated with the synthetic leachate, leads to the conclusion that the modification in the soil property can be due the modifications in the DDL thickness of the test soils.

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Chapter 6

CONTAMINANT TRANSPORT MODELLING

Contents

6.1 General

Contaminant transport models are generally used to identify the pattern of disperse of contaminants and to see whether contamination exists above a prescribed level at a particular spot. These models range from simple mathematical equations to complex computer generated models. A mathematical equation or computer generated model does not provide a unique solution to an environmental problem. It provides a scenario based on specific assumptions and specific input values. Varying certain input parameters, can have a dramatic effect on the results of a model. Selecting proper boundary conditions and other parameters can be quite case specific. Use of a computer model does not always minimize the need for sample data, borings, wells, etc.. In fact, more data may be required to adequately calibrate the model to fit the existing site conditions. The calibrated model can be used to run in predictive mode to generate results for a range of sensitive parameters and the results can be evaluated and summarized (DEQ, 2001).

In chapter 4, analysing the results, it leads to the conclusion that the contaminant transport through soil can be simulated with reasonable accuracy by simulating that of ground water flow. Here in this chapter, the contaminant transport is studied using a numerical model of ground water pollution transport and has been discussed in detail.

6.1.1 Principle and Concepts used in Ground Water Contaminant Modelling

The analytical as well as numerical ground water models are built upon a number of principles and concepts, which describe the best estimation of probable physical, chemical and biological events. The ability to access these events by mathematical relationships provides the basis for both analytical and numerical development. The main processes that control the transport of contaminants are physical processes such as advection and dispersion, and geo-chemical and bio-chemical reactions. Advection involves the dissolved contaminant flow from the contaminant source through ground water towards down gradient. The spreading of contaminants is the result of dispersion. (Bear and Cheng, 2010). In the case of a conservative contaminants, reactions that alter the contaminant concentration do not occur between the contaminant and the soil matrix in the aquifer system. As a result, the total mass of contaminant in the flow regime does not change. In addition to the described effect of advection and dispersion, the total mass of contaminants in transport is reduced by chemical and biochemical activity. Principles and important concepts of ground water contaminant modelling include Darcy's law, Hubert's force potential, Conservation of mass, Hydrodynamic dispersion, and Chemical and biological activity (Bear, 1972).

6.1.2 Classification of Ground Water Contaminant Models

Ground water contaminant models which are used to predict contaminant transport can be classified into three categories (Bear and Verruijt, 1979): (a) advection models (b) advection-dispersion models and (c) advection-dispersion-chemical/biological reaction models.

Advection models

Advection models define the movement of contaminants as a result of ground water flow only.

A slug of water carrying contaminants moves through the soil system along with the ground water flow. Contaminants are transported with no changes in concentration with distance.

Advection-Dispersion models

When the concept of dispersion is introduced into the model, a term is included which provides for dispersion related mixing and spreading and leads to time-related changes in contaminant concentration. The dispersion term takes into consideration molecular diffusion, microscopic dispersion and macroscopic dispersion. Generally, because of scale of applications in terms of land area involved and relatively high flow velocities, molecular dispersion is of small consequence compared to micro-and macro-dispersion.

Advection-Dispersion-Chemical/Biological reaction models

Another step in model sophistication is the inclusion of effects of reactions, which change the concentration of transported contaminants. The reactions may be chemical or biological and can be incorporated into advection models or advection-dispersion models.

6.1.3 Details of Visual MODFLOW

Visual MODFLOW, a computer program based on FDM, has been developed for U.S. Geological Survey in the form of modular three dimensional ground water flow model. Visual MODFLOW is able to simulate a wide range of flow in porous media with wide varieties of systems and standards, including ground water flow and contaminant transport (Harbaugh et al., 2005).

The process of building the input data file for a ground water flow or transport model is often the most time-intensive and tedious task associated with ground water modelling projects. The logical structure and layout of the Visual MODFLOW interface eliminates these difficulties by guiding the user through the sequence of steps necessary to build a ground water flow and contaminant transport model. In addition, the many powerful and easy-to-use graphical tools give all the flexibility that one can need to assign complex property distributions, multiple pumping wells and steady-state or transient boundary conditions (Sathyanarayana, 2004)

6.1.3.1 Ground water flow equation

The governing flow equation for three dimensional saturated flow in saturated porous media is:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z\frac{\partial h}{\partial z}\right)\pm Q=S_s\frac{\partial h}{\partial t}\text{................}(6.1)$$

where,

kx, ky, kz	Hydraulic conductivity along the assumed x, y, z axis
h	Piezometric head
Q	Volumetric flux per unit volume representing source / sink terms
Ss	Specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material
t	Time

6.1.3.2 Solute transport equation

The flux of solute mass through a control volume is governed by equation 6.2

$$\frac{\partial C}{\partial t}=\left[\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial C}{\partial z}\right)\right]-$$
$$\left[\frac{\partial}{\partial x}(V_xC)+\frac{\partial}{\partial y}(V_yC)+\frac{\partial}{\partial z}(V_zC)\right]\text{................................}(6.2)$$

where,

Vx, Vy, Vz	Seepage velocities in x, y, z directions
Dx, Dy, Dz	Dispersion coefficients
C	Solute concentration
t	Time

The equation states that the sum of all mass, which consumes or creates solute with the control volume, must be equal to a change in the concentration of the solute with the control volume (Rao et al., 2011).

6.2 Ground Water and Pollutant Transport Conceptualisation

Here the ‘Visual MODFLOW’ program is used to model the case study area described in Chapter 3 and the results obtained are compared with that of actual observed values to validate the modelling.

6.2.1 Study Area

Location of study area lies between latitude of 10° 3′ 30″ N and 10° 4′ 20″ N and, longitude of 76° 19′ 10″ E and 76° 20′ 10″ E. The landscape with elevations that range from 12.5 m to 2 m above mean sea level (AMSl). Fig 6.1 shows the surface contour map of the study area.

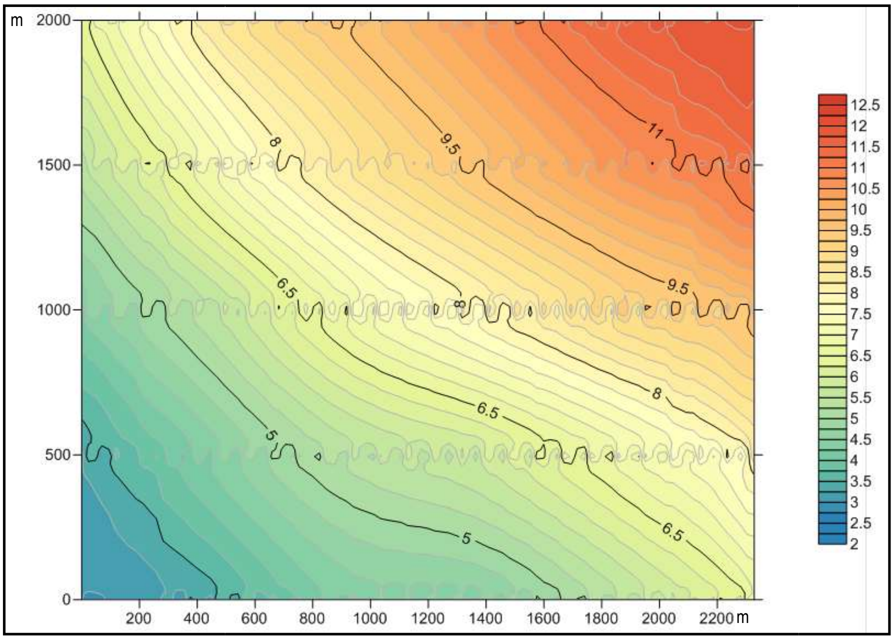

Fig. 6.1 *Surface Contour Map of Study Area*

6.2.2 Aquifer Parameters

Aquifer parameters were estimated from the data available in the local bodies. Precipitation is the main source of ground water recharge and takes place mostly during June to October. The ground water recharge varies from 290 mm to 350 mm per year for an annual rainfall of 3228 mm. The approximate hydraulic conductivity of field soil is varying from 0.002 m to 7 m per day as per the details available. Fig. 6.2 shows the average soil profile adopted for the study area approximated based on that obtained from three bore hole details randomly spaced in the study area. The top layer mostly consists of 5.6 m thick clayey silt and is underlain by 2.3 m sandy clayey silt. Bottom layer is a very hard strata like rock.

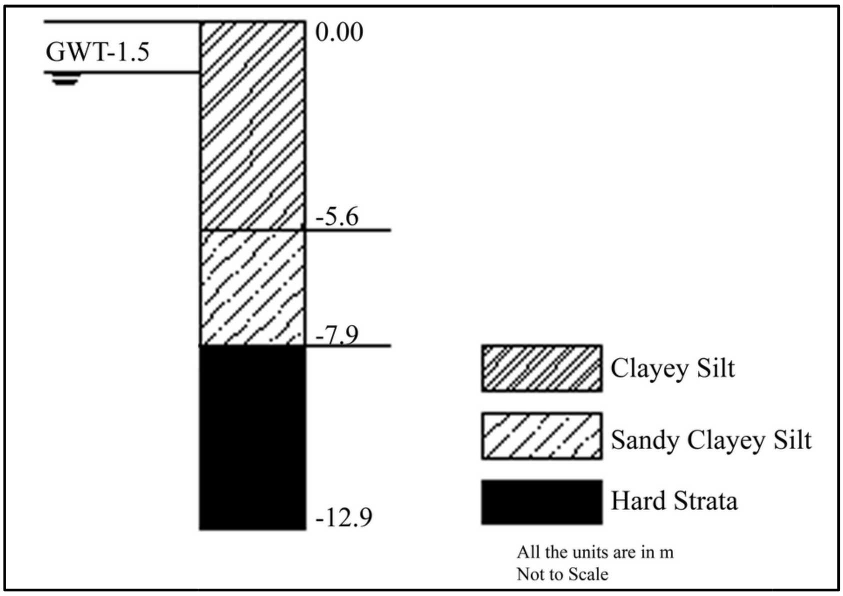

Fig. 6.2 *Soil Profile adopted for the Study Area*

6.2.3 Model Conceptualization

The following information and inferences are used for the conceptualization of ground water flow.

- The ground water recharge is due to rainfall from top of the aquifer.
- According to the geology of the study area, 9 to 11 % of annual rainfall is considered as recharge.
- Periyar River contributes and also receives the ground water from the aquifer system.
- The area is functioning as a landfill from 1992 and closed from the year 2012.

The study area (approximately of 2300 m x 2000 m) is simulated using a mesh of 80 rows and 80 columns (Fig. 6.3) and the soil stratum is simulated in three layers with varying permeability in accordance with the adopted soil profile.

The vertical section along the column no: 38 (which is the column passing through the municipal solid waste dumping place) in the simulated model is as shown in Fig. 6.4.

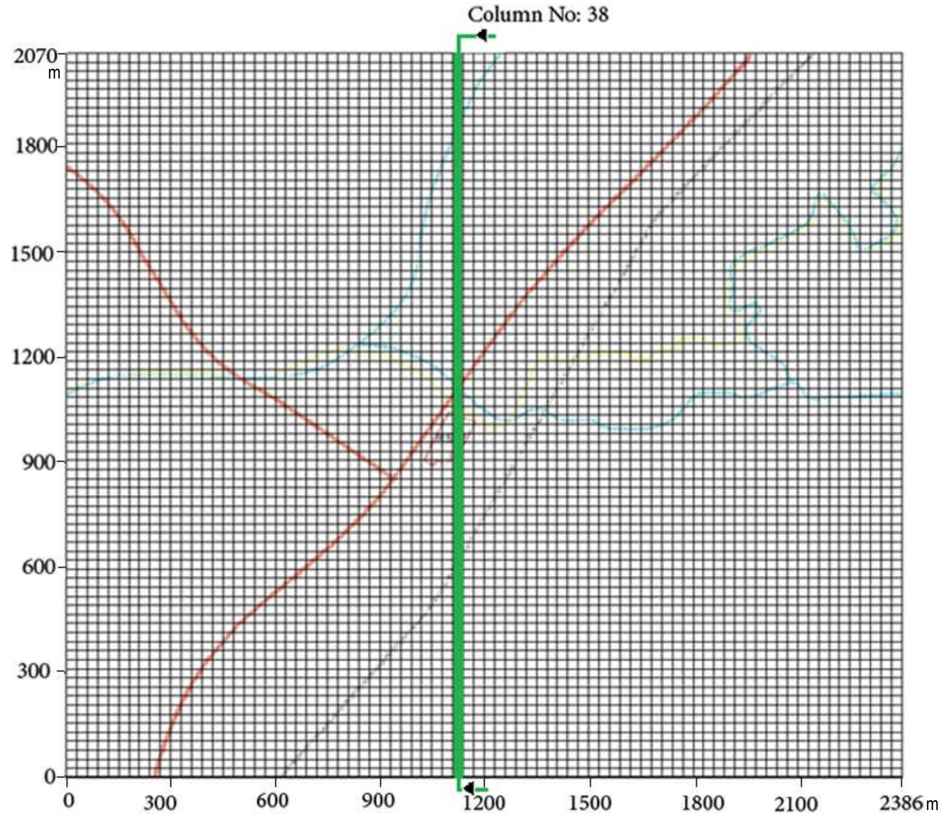

Fig.6.3 *Model Grid for the Study Area*

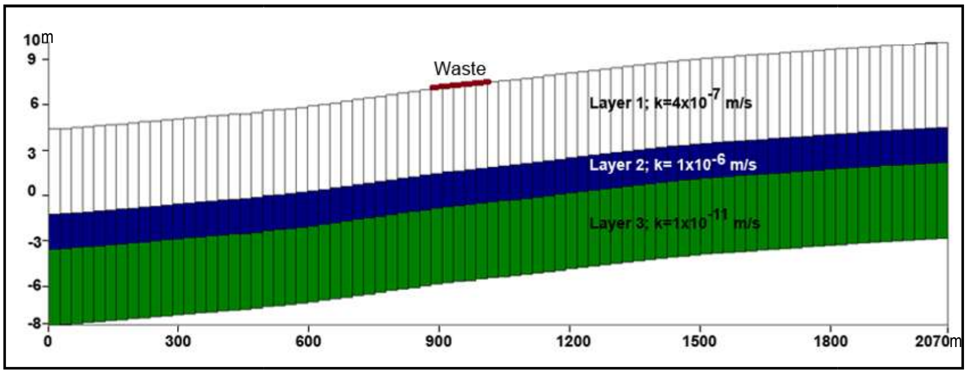

Fig.6.4 *Vertical Discretisation of the Aquifer*

The first stage of the modelling is flow simulation for computation of hydraulic head distribution. Since, the density and viscosity of the contaminated ground water is assumed to be the same as uncontaminated water, the distribution of hydraulic head and the velocity field is not affected by the migration of the plume and the flow is assumed to be steady state (Sathyanarayana, 2004). Considering 10% infiltration rate, the recharge 320 mm/year has been fed in to the model to simulate aerially distributed recharge to the aquifer system from the first layer. Hydraulic conductivity of first layer is assumed as $4 x 10^{-7}$ m/s as per the available details of the site. The values assigned second and third layers are $1 x 10^{-6}$ m/s and $1 x 10^{-11}$ m/s respectively. Fig. 6.5 shows the simulated ground water contours in m (AMSL) and flow direction.

6.2.3.1 Calibration of the ground water flow model

The model is calibrated between the observed data and the simulated result. The water table configuration corresponding to September, 2008 was adopted for this purpose. For the steady state simulation, three observation wells (as marked in Fig. 6.5) were considered for calibration and the predicted Vs. observed values of head are plotted as shown in Fig. 6.6.

Here the predicted values obtained from the modelling are compared with that of the field observed values. The abscissa of a point is the observed head in the field and the ordinate is the predicted value corresponding to an observation well. If both the co-ordinates are equal, the point will lie on the diagonal and the scatter of points from the diagonal represents the divergence between the predicted and observed values. From the above discussions and from the Fig. 6.6, it can be observed that the ground water flow has been modelled with reasonable accuracy.

Mean error is the summation of differences between calculated values and observed values for each observation well divided by total number of observation wells and it is obtained as 0.242.

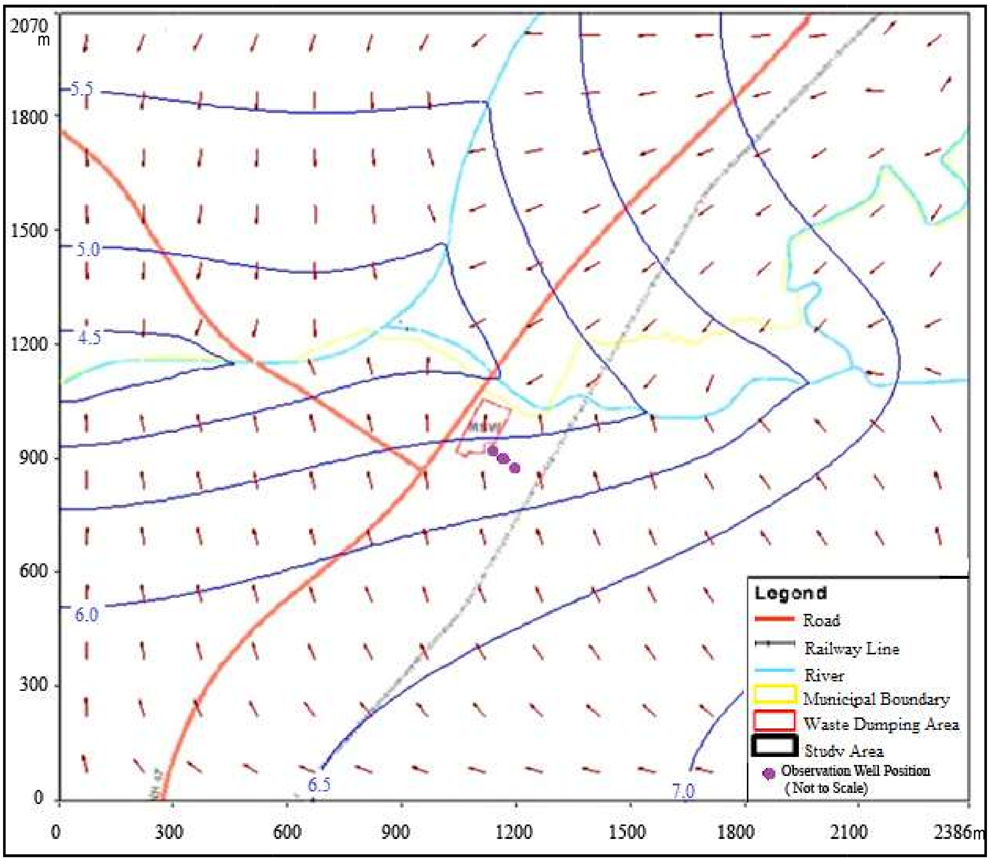

Fig 6.5 *Simulated Ground Water Contours in m (AMSL) and Flow Direction*

Mean absolute error is same as mean error except the absolute value differences between the calculated and observed values are determined and it is same as that of mean error in this case.

Root mean square error is the square root of the sum of the square of the difference between the calculated and observed values divide by number of observation wells and it is found to be 0.083.

All these errors can be directly obtained from the 'Visual MODFLOW' windows.

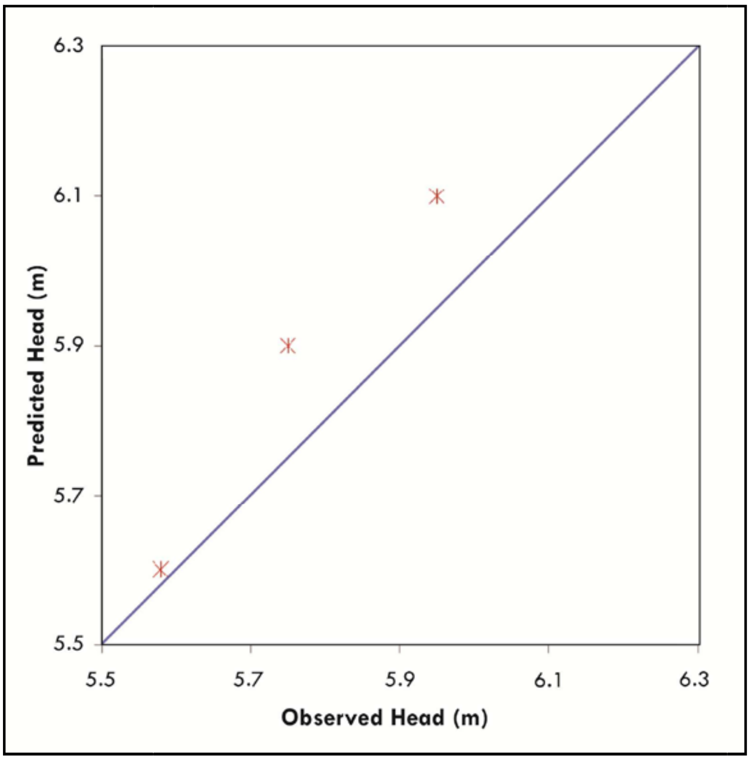

Fig. 6.6 *Computed and Observed Heads of Study Area for the Steady State Condition*

6.2.4 Solute Transport Modelling

In order to model the leachate transport, the flow of chloride concentration was simulated for the present study on the assumption that it will fairly represent the contaminant transport. According to Rowe, 1995, chloride represents 0.07% to 0.21% of in-situ wet waste. Considering that the area has functioned as a landfill for 20 years and based on the approximate waste load (as per the information from the local bodies) the chloride concentrations in leachate are calculated as shown in Table 6.1 and are assigned accordingly as input parameters. Here the landfill is modelled for 30 years and the leachate transport is predicted.

Table 6.1 *Input Chloride Concentrations in Leachate*

Age of Landfill (No. of Days)	Chloride Concentration (Input Parameter) mg/l
0-365	1500
366-1825	2500
1826-2920	3500
2921-7300 (Closing day)	4500
7301-10950	0

6.2.4.1 Calibration of the solute transport model

The chloride concentration at the three observation wells on September 2008 was used for the calibration of the solute transport. The predicted and observed chloride concentration in these three observation wells of study area for the steady state condition are plotted and shown in Fig. 6.7 similar to Fig. 6.6.

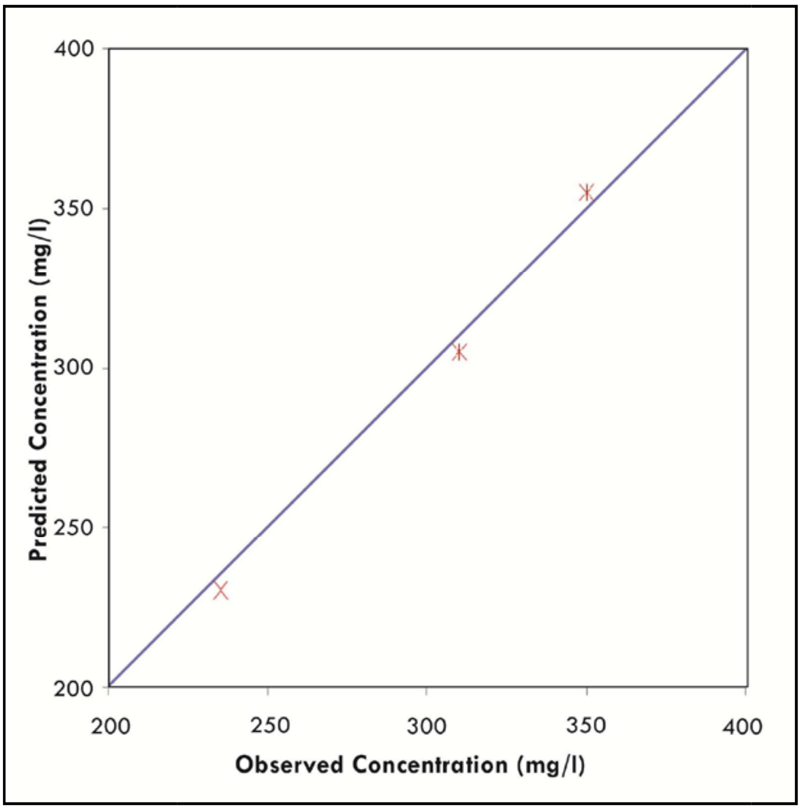

Fig. 6.7 *Computed and Observed Chloride Concentration of Study Area for the Steady State Condition*

From the figure it can be observed that the predicted and measured Chloride concentrations are almost same, since the points are more or less lying on the diagonal.

6.3 Results and Discussions

Having established the validity of the modelling, it is intended to explore the prediction of pollutant transport (in terms of Chloride concentration) for different years starting from the beginning. Fig. 6.8 shows the lateral spread of the pollutant after one year (i.e., year 1993) and it can be observed that the leachate spread through the soil for a distance of about 150 m to 200 m. The transport of leachate is in accordance with the ground water flow. Considering the vertical section (Fig. 6.9), it can be seen that as depth increases, the leachate concentration decreases as expected.

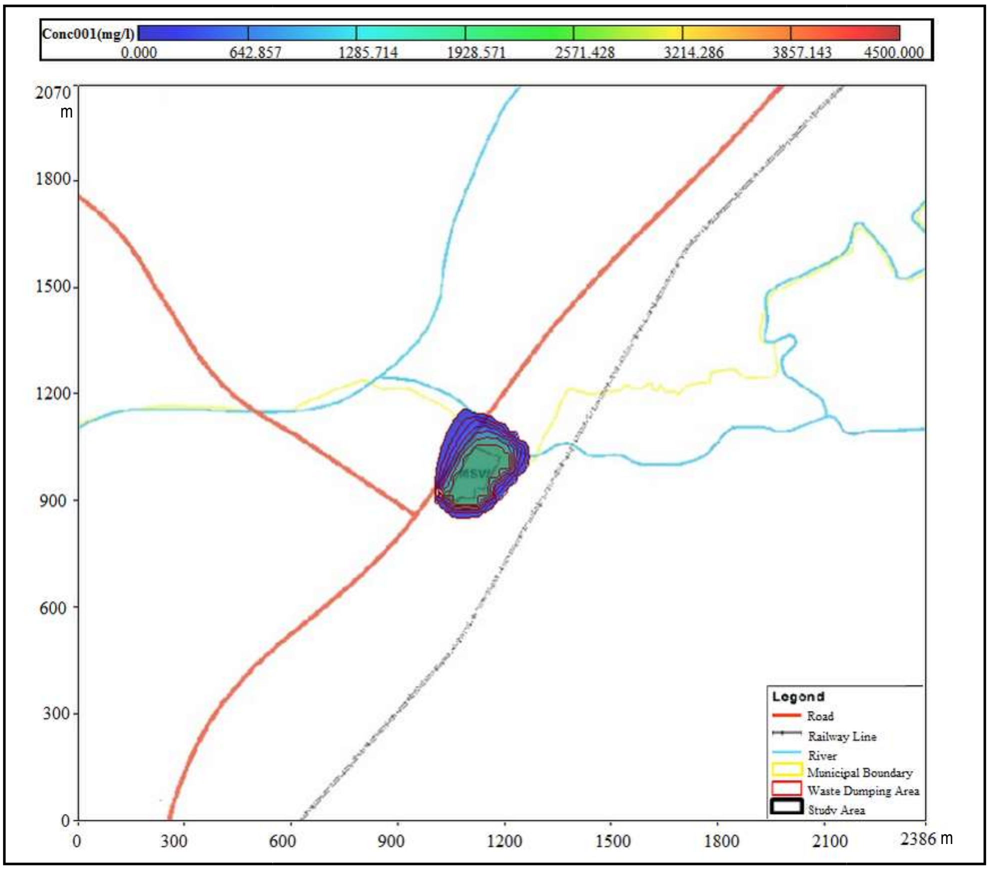

Fig. 6.8 *Observed Leachate Concentration during 1993*

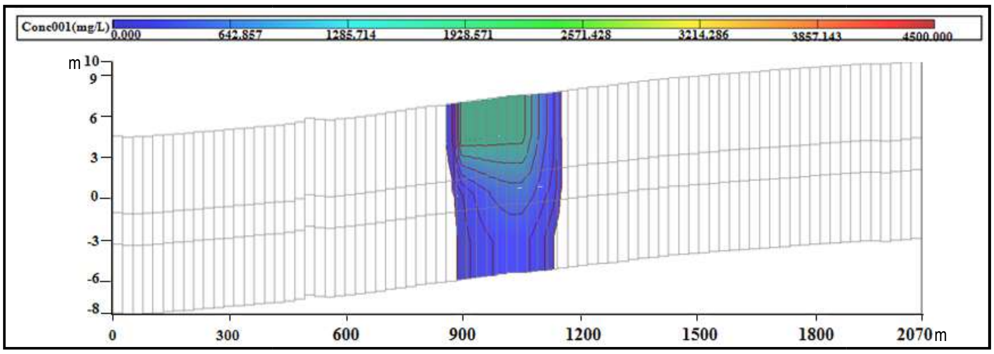

Fig. 6.9 *Vertical Dispersion of Leachate (along Column 38) during 1993*

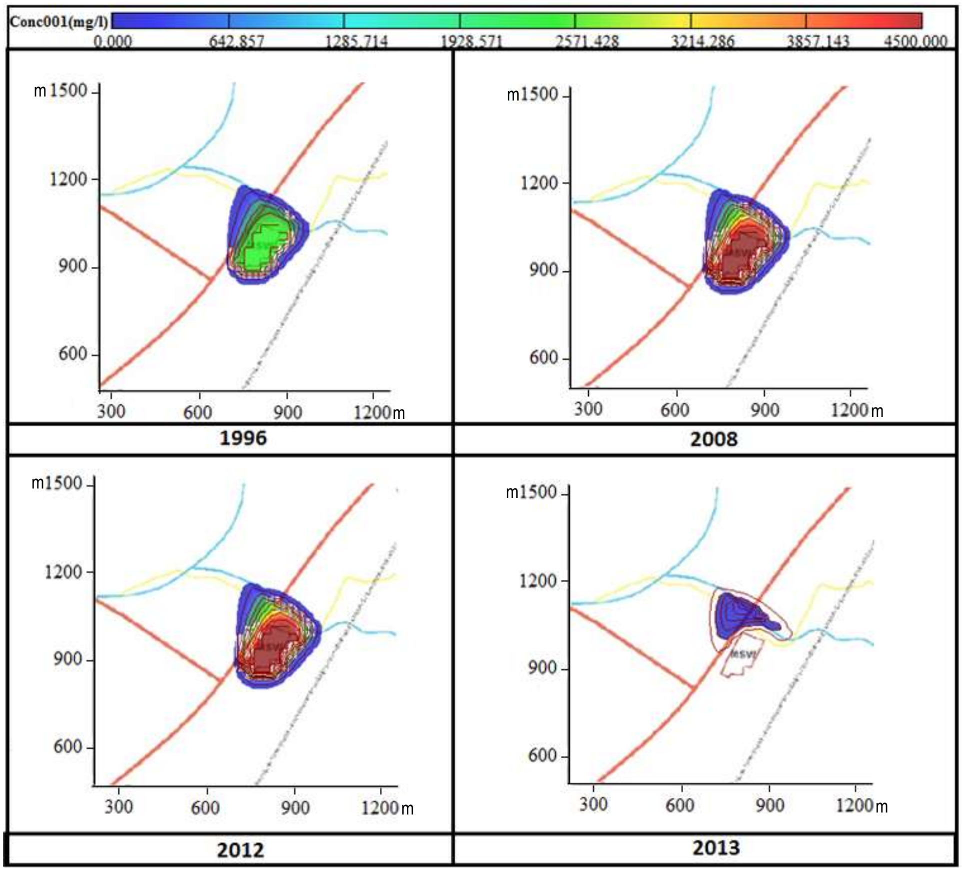

Fig. 6.10 *Observed Leachate Concentration during 1996, 2008, 2012 and 2013*

The Fig. 6.10 shows the lateral spread of leachate during the years 1996, 2008, 2012 and 2013 and the respective vertical flow is shown in Fig 6.11. It can be observed that, the concentration of the leachate around the landfill increases as time passes due to the addition of waste in the landfill, till it closes in 2012. One year after closing (in 2013), it can be observed from Figs. 6.10 and 6.11 that, the leachate plume is gradually shifted from the centre of the landfill area and also considering the vertical transport, the higher concentration points are shifted towards the river. This may be due to the influence of ground water flow.

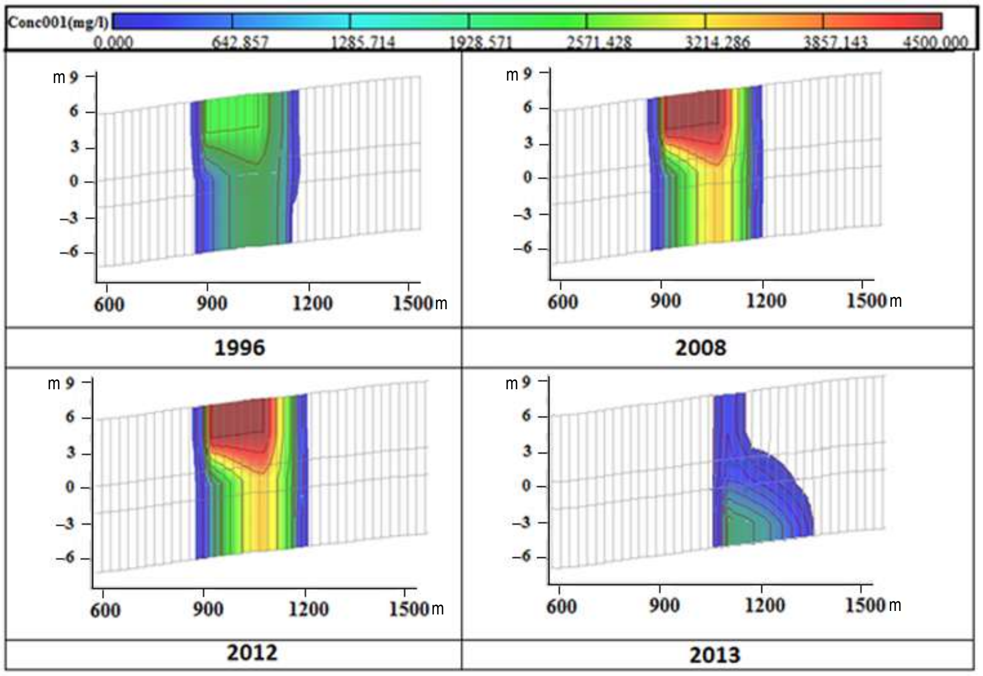

Fig 6.11 *Vertical Dispersion of Leachate (along Column 38) during 1996, 2008, 2012 and 2013*

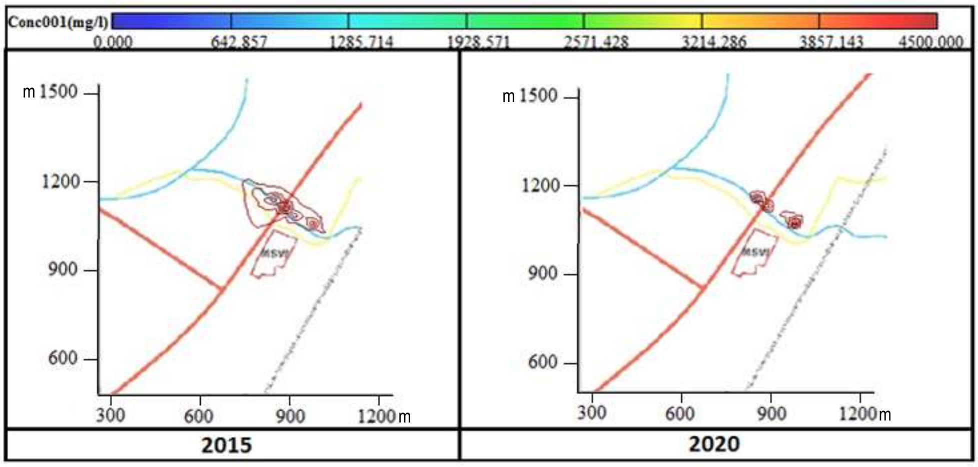

Fig 6.12 *Predicted Leachate Concentrations in 2015 and 2020*

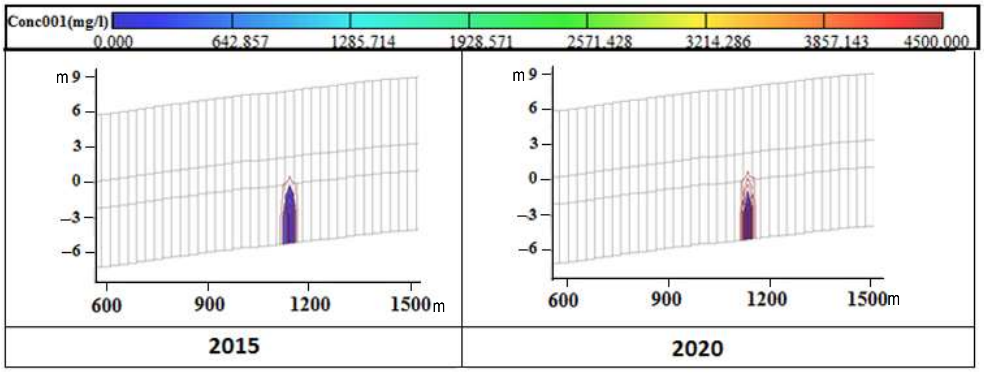

Fig 6.13 *Predicted Vertical Dispersion of Leachate (along Column 38) in 2015 and 2020*

For predicting the future transport of the leachate, the analyses have been done for the years corresponding to 2015 and 2020. The respective results are given in Figs. 6.12 and 6.13. The figures clearly show the shifting of leachate plume away from the source and also the concentration decreases as can be observed from the colour code of the figures. The shifting of leachate is due to stream aquifer interaction. Due to this phenomenon, the flow of leachate is towards direction of ground water flow.

It may be noted that, after the closure of a landfill, even though the input volume of pollutants from the waste gets stopped, trace of pollutants in the soil will continue for some more period. But it will get diluted as time passes. This is due to the infiltration of surface water through the soil.

It also can be observed that the concentration at the disposal place get lowered to a very small value of 0.2 mg/l in 2020. Thus we can conclude that in a period of 8 years after closing, the effect of leachate on the dumping place will get nullified for this study area.

6.4 Summary

For the analysis of contaminant transport, numerical models are very essential as other methodologies are not effective. The numerical models are very helpful to assess the future prediction and management and remediation in the polluted area. In the present study, finite difference method based model ‘Visual MODFLOW’ is used for flow and transport modelling in the study area. For the study area the above said software and the model is found to be very effective in the future prediction of flow and contaminant transport in the study area.

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Chapter 7

SOIL POLLUTION CONTROL MANAGEMENT

Contents

7.1 Introduction

The leachate migration which results in ground water and other lithospheric pollution is a major concern. In the case of an unlined landfill or a landfill with damaged liner causing leakage of leachate, the removal of chemical contaminants from leachate is a desirable prerequisite before it mixes with surrounding water body. Introduction of a permeable reactive barrier in the plume of leachate is an effective solution for this. Permeable reactive barrier (PRB) is a technology developed right from the 90s and is an engineered treatment zone of reactive material or materials that is placed in the subsurface in order to remediate contaminated fluids as they flow through it (Carey et al., 2002). Permeable reactive barriers (PRBs) consist of a water permeable material with specific chemical reactivity towards one or more chemical constituents via mechanisms such as adsorption, exchange, oxidation-reduction, or precipitation. Fig. 7.1 shows the schematic representation of PRB. Materials used in the field must be effective, inexpensive and readily available in multiple-ton quantities to be able to treat large volumes of water, or soil. Zero-valent iron, zeolites, apatites, periclase, carbonates, pecan shells, compost, peat moss, cottonseed meal, lime etc., are some of the reactive materials included in the past researches of PRB. Suitable cost-effective materials are to be developed and to be produced in multiple ton quantities (Judith et al., 2003), which can adsorb chemicals and thus purify the leachate.

Production of large quantity of agricultural wastes all over the world faces serious problems of handling and disposal. Therefore, few adsorption studies have been conducted herein on locally available raw agricultural wastes like coir pith, rice husk and sugar cane bagasse, to assess its feasibility as a reactive media in permeable reactive barriers.

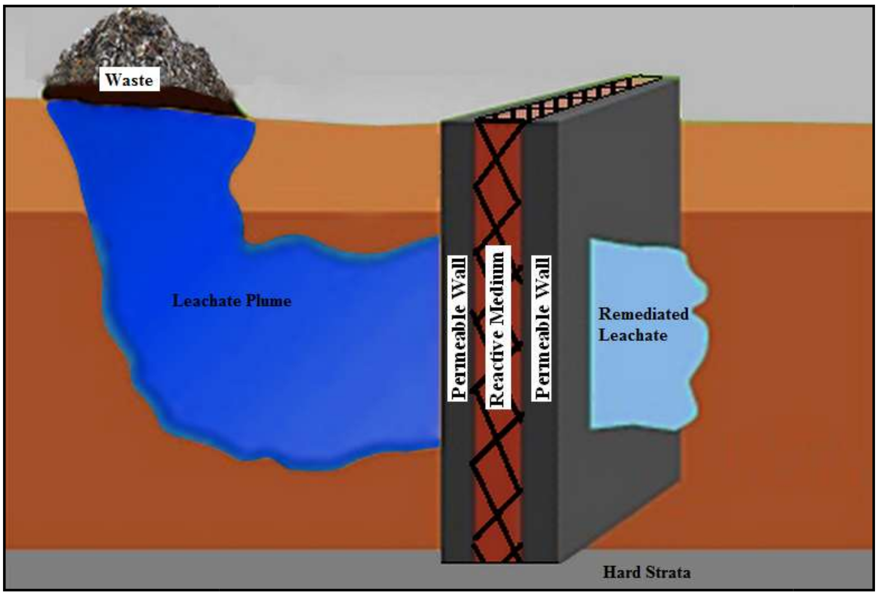


Fig. 7.1 *Schematic Representation of Permeable Reactive Barriers*

7.2 Materials

7.2.1 Coir Pith

India is the third largest country in terms of area and production of coconut, with Kerala having the highest concentration of coconut cultivation (Kerala development report, 2008). Coir pith is a soft biomass separated from coconut husk during the extraction of coir fibre (Ash et al., 2006). During the process of production of one ton of coir approximately two tons of coir pith is produced (Abesh and Anitha, 2012).Coir pith is of porous structure with organic nature. As it is available in large scale in India, it would be an ideal choice as a reactive material, if possible. Coir pith used for this study was collected from a local coir manufacturing unit near Alapuzha, Kerala (Fig. 7.2).

Fig. 7.2 *Coir Pith used for Present Study*

7.2.2 Rice Husk

India is the second largest producer and consumer of rice in the world. Rice husk is a major by-product of the rice milling industry. It is highly porous and lightweight, with a very high external surface area. Rice husk used for this study was obtained from a rice mill at Kalady, Kerala (Fig. 7.3).

Fig. 7.3 *Rice Husk used for the Study*

7.2.3 Sugarcane Bagasse

Sugarcane bagasse is a by-product of the sugar industry. For each 10000kg of sugarcane crushed, a sugar factory produces nearly 3000 kg of wet bagasse. Sugarcane bagasse used for this study was collected from sugarcane juice shop at Cherthala, Kerala (Fig. 7.4).

Fig. 7.4 *Sugarcane Bagasse used for the Study*

7.3 Methods

7.3.1 Material Preparation

Coir pith, Rice husk and Sugarcane bagasse were collected and air dried and the Sugarcane bagasse was chopped into pieces. Acid treatment to the materials were carried out by mixing with 0.5 M citric acid in a ratio of 1000 mg material to 7 ml citric acid for 30 minutes in order to ensure that materials had completely imbedded the liquid as described by Marshall et al. (1999). These samples were dried in a hot air oven at 110^0C for 12 hours. These materials were washed with distilled water and were soaked in 2% sodium bicarbonate ($NaHCO_3$) solution and were allowed to stand overnight to remove the residual acid. Then the materials were washed with distilled water. Finally, these materials were dried in a hot air oven at 110^oC for 12 hours. The dried materials were ground and sieved to get the particle size of 0.450 mm to 2 mm for this study.

7.3.2 Experimental Leachate

For the experimental purpose, the synthetic leachate was prepared with the same concentration as in the previous experiments (Table 4.4) and allowed to flow through the adsorbent materials in the test moulds.

7.3.3 Characterization of Materials

The adsorbent obtained from different agriculture wastes have been characterized. The pH and water soluble matter in these materials were found by following the procedures:

pH: 1000 mg of adsorbent in 50 ml of distilled water was agitated for 1 hour. The supernatant was tested for pH using pH meter (Dhayabaran et al., 2012).

Matter soluble in water: 10000 mg (10 g) of the carbon material was weighed accurately and transferred into a one litre beaker. About 300 ml of distilled water was added and heated to boiling with continuous stirring. Stirring was continued for 5 minutes. The material was then allowed to settle and the supernatant liquid was filtered. Filtrate was transferred to a china dish, evaporated to almost dryness in a boiling water bath and finally dried in an electric oven, maintained at 110^0C, cooled and weighed (Dhayabaran et al., 2012).

$$\text{Water soluble matter (\%)} = \frac{\text{M1}}{M}100\text{…. (7.1)}$$

Where,

M1 = Mass of the residue in gram.

M = Mass of the material taken for test in gram.

Bulk Density: Bulk density of study materials were determined by gently filling in a cylindrical jar of known volume with the material and weighed.

The experimental results showing the characteristics of adsorbents are given in Table 7.1

Table 7.1 *Characteristics of Adsorbents*

Parameter	Coir Pith	Rice Husk	Sugarcane Bagasse
pH	4.7	4.6	4.9
Water soluble matter (%)	3.8	4.3	4.1
Bulk density (kN/m^3)	6.034	5.626	6.278

7.3.4 Experimental Set-up

A test cylinder made of PVC pipe of 400 mm height and 150 mm diameter is used. A strainer (made of perforated steel plate) overlaid by a geotextile is placed at bottom. The adsorbent materials are filled to a depth of 300 mm at their bulk density. Height of the test cylinder can be increased by connecting with another PVC pipe of same dimensions. Thus another set of experiments were conducted by increasing the depth of adsorbents to 600 mm. A reducer is provided at the bottom, through which leachate can be collected after passing through the waste layer, by keeping a beaker at the bottom (Fig. 7.5).

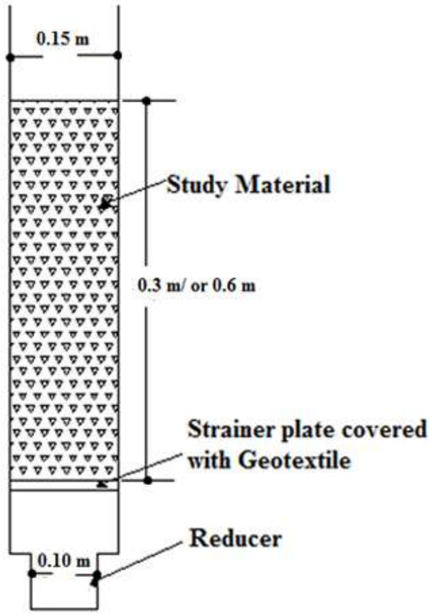


Fig. 7.5 *Cross Section of Test Cylinder*

The synthetic leachate is kept in an overhead tank. A floating valve arrangement is provided to maintain a constant head of 0.4 m throughout the experiment. The flow of leachate is controlled by a control valve (Fig.7.6). Leachate is passed through the test cylinder which was filled with adsorbent materials, at a constant rate of 0.05 ml/s for 6 weeks. Leachate was collected every week after passing through the test materials and tested for the chemical concentration. The collected leachate is recirculated and the tests are continued for 6 weeks.

Fig. 7.6 *Experiment Set-up*

7.4. Results and Discussions

Figs 7.7 to 7.8 show the variation of chemical contents of the leachate passing through the adsorbent layers of 300 mm and 600 mm thick with respect to time upto 6 weeks. The ordinate corresponds to percentage reduction in chemical concentration of the collected leachate from the test set up, with respect to concentration of original synthetic leachate.

7.4.1 Reduction in Chloride Concentration

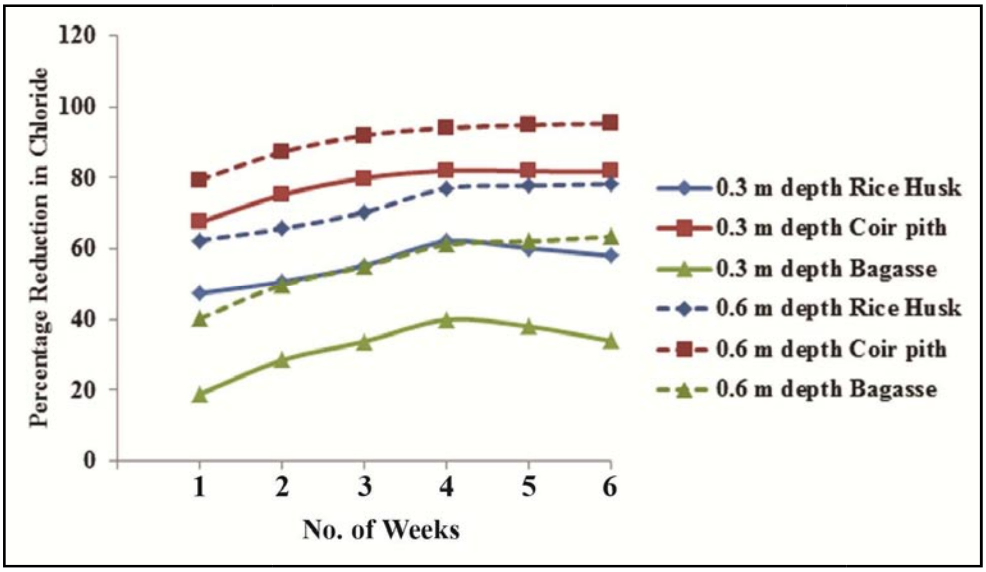


Fig. 7.7 *Reduction in Chloride Concentration of Leachate*

From the Fig. 7.7 the following observations are made. 19% of reduction in Chloride is observed in the filtrate of synthetic leachate from 300 mm thick sugarcane bagasse in 1 week and the corresponding reduction for 600 mm thick layer is 40%. After 4 weeks, though the 300 mm thick sugarcane bagasse layer reduces 40% of Chloride, its efficiency in reducing the Chloride decreases as time period increases to 6 weeks. But as thickness of layer increases to 600 mm, 61% and 63% reduction were observed in 4 weeks and 6 weeks respectively. Rice husk layer of 300 mm thick reduces 47% of Chloride and 600 mm thick layer reduces 62% of Chloride in

1 week. As can be observed from Fig 7.7, the efficiency of 300 mm thick rice husk reduces as time passes. In the case of coir pith the reduction of Chloride is 68% and 80% after 1 week in the filtrate of synthetic leachate from 300 mm and 600 mm thick layer respectively. The corresponding values after 4 weeks is 82% and 94% and that after 6 weeks it is 82% and 95% respectively. This shows almost a saturation level after a month's treatment.

7.4.2 Reduction in Ammonia Concentration

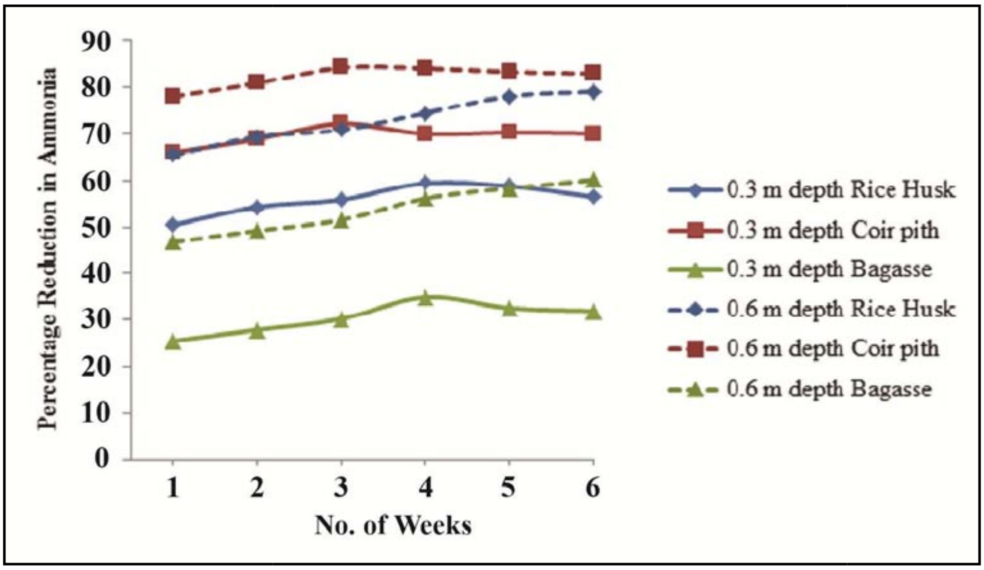


Fig. 7.8 *Reduction in Ammonia Concentration of Leachate*

Considering the Ammonia concentration of the leachate before and after the treatment, the sugar cane bagasse of 300 mm thickness reduces 26% of Ammonia and 600 mm thick layer reduces 47% of Ammonia in 1 week. The corresponding values after 4 weeks are 35% and 51%. After 4 weeks a 300 mm thick medium shows a decreasing trend in efficiency and reduction in Ammonia. But the increasing trend of reduction in Ammonia continues till 6 weeks in the case of 600 mm thick layer. A similar trend is also observed in the case of rice husk and coir pith. Here in the case of Ammonia also, the maximum reduction is shown by the coir pith medium. More than 80% reduction is observed when 600 mm thick column is used. Another point to be noted is that in the case of coir pith, the percentage reduction values remains more or less constant even after 5 to 6 weeks.

7.4.3 Reduction in Nitrate Concentration

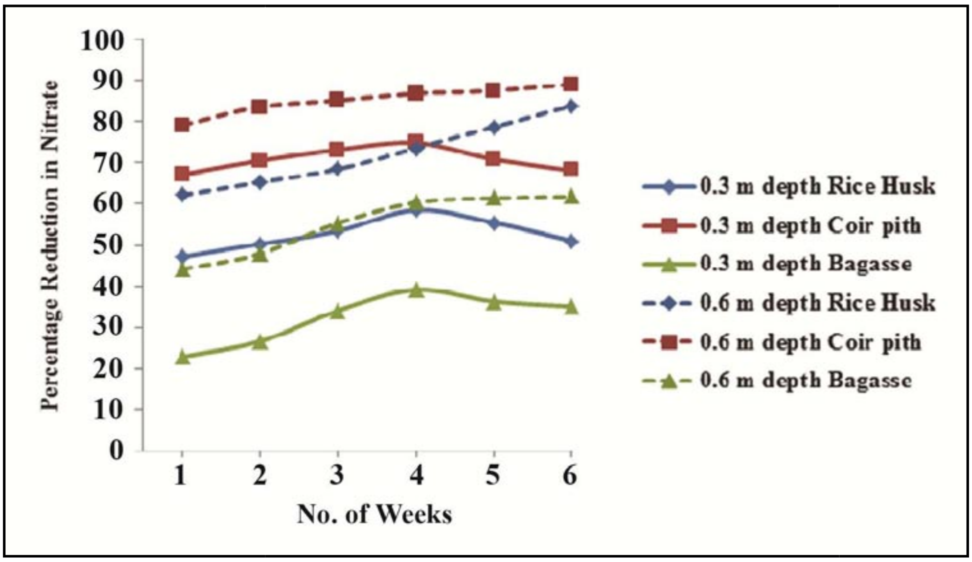


Fig. 7.9 *Reduction in Nitrate Concentration of Leachate*

From the Fig. 7.9, it can be observed that, as in the previous cases, maximum reduction of Nitrate in the filtrate from 300 mm adsorbent beds is obtained after 4 weeks. As the thickness of reactive medium increases to 600 mm, efficiency also increases.

7.4.4 Reduction in Concentration of Metals

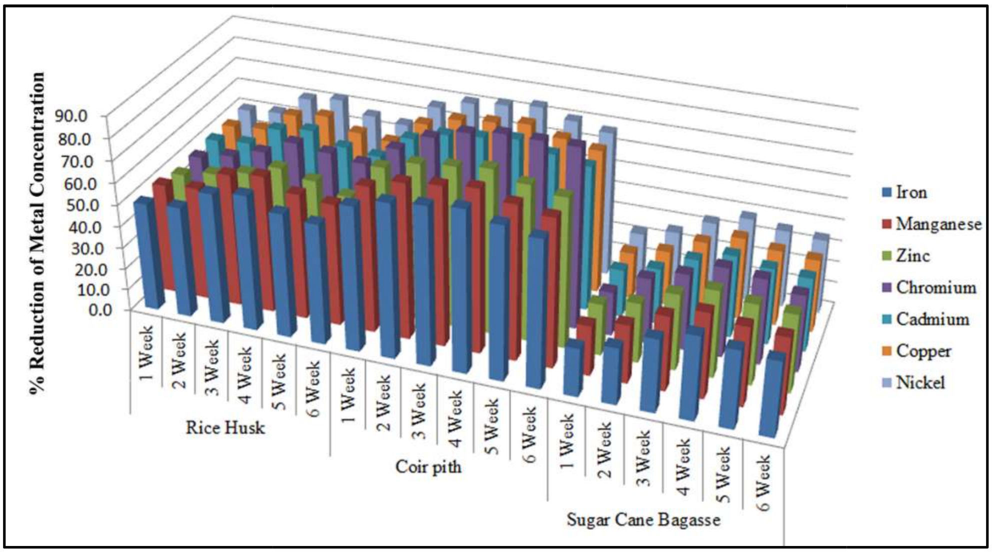


Fig. 7.10 *Reduction in Metal Concentration in the Filtrate from 300 mm thick Adsorbent Layers*

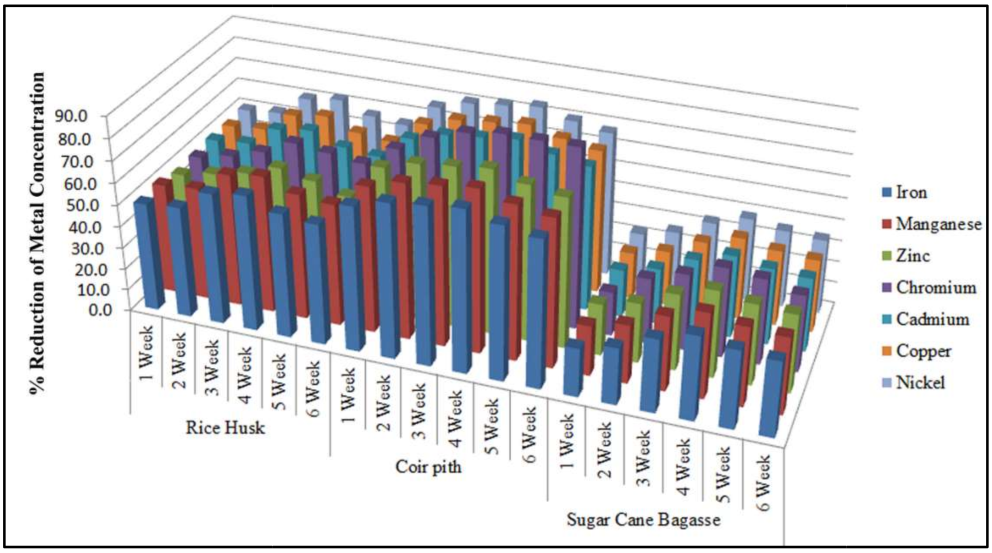


Fig. 7.11 *Reduction in Metal Concentration in the Filtrate from 600 mm thick Adsorbent Layers*

Figs. 7.10 and 7.11, compares the reduction in concentration of metals, viz., Iron, Manganese, Zinc, Chromium, Cadmium, Copper and Nickel, observed in the filtrate from 300 mm and 600 mm thick adsorbent layers respectively as time passes. Here also when 300 mm thick adsorbent layers are used, maximum reduction of these chemicals is obtained in 4 weeks. After that efficiency of the layers get lowered. Among the three adsorbent materials, coir pith is giving a better result compared to rice husk and sugar cane bagasse. A 600 mm thick coir pith bed reduces approximately, 88% of chemicals in 6 weeks. The corresponding values for a rice husk and sugar cane bagasse bed of same thickness are 77% and 60% respectively

The result of adsorption studies are tabulated in Tables 7.2 and 7.3.

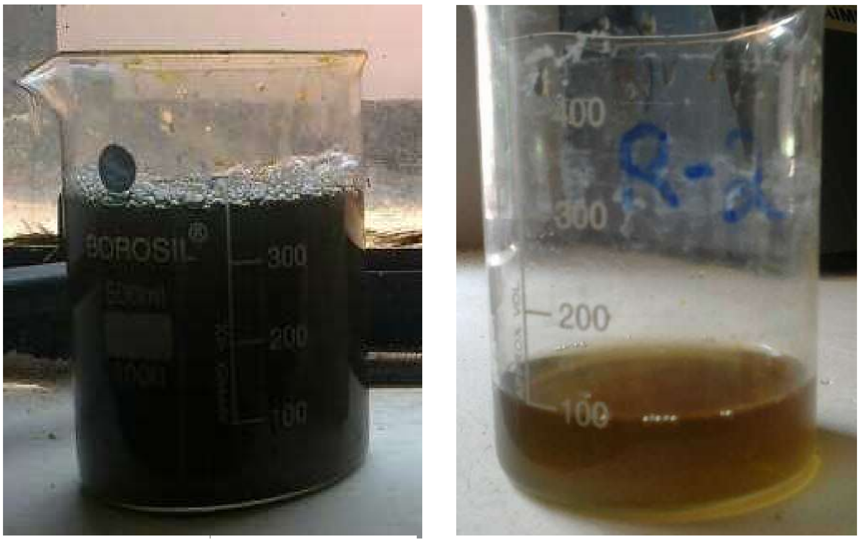
The synthetic leachate prepared for the test having a dark colour (may be because of high Iron content) as shown in Fig. 7.12(a). As this leachate passes through the reactive medium, there is a distinct colour change in the leachate and that is observed to be different for different media, where the impact of each adsorbent material are clearly observed as in Fig. 7.12. Variation in color confirms the efficiency of coir pith in reduction of chemical concentration of synthetic leachate, among the materials tested.

Table 7.2 *Chemical Adsorption of 300 mm thick Agro Waste Materials*

Chemical Constituents (mg/l)	Synthetic Leachate	Rice Husk						Coir Pith						Sugarcane Bagasse					
		1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	1 Week	2 Week	3 Week	4 Week	5 Week	6 Week
Chloride	6500	3079.2	3290.9	3592.1	4032.3	3914.0	3773.5	4385.0	4891.0	5195.0	5334.0	5322.0	5315.0	1227.9	1848.4	2189.5	2590.1	2469.4	2202.5
Ammonia	300	151.3	162.9	167.5	178.3	176.3	169.3	197.9	206.5	216.5	209.9	210.8	210.1	76.5	83.7	90.6	104.5	97.5	95.7
Nitrate	57	26.9	28.7	30.5	33.4	31.7	29.2	38.3	40.8	41.7	42.7	40.4	38.8	13.1	15.2	19.5	22.3	20.7	20.0
Iron	11300	5650.6	5789.0	6825.3	7063.4	6467.1	6283.1	7518.8	8018.4	8200.7	8389.1	7941.0	7627.8	2521.0	2943.3	3787.8	4350.8	4034.1	3896.2
Manganese	119	60.5	62.0	72.9	75.4	69.1	67.2	80.2	85.4	87.4	89.3	84.6	81.3	27.5	32.0	40.9	46.8	43.5	42.0
Zinc	38	18.3	19.5	20.7	22.6	21.5	19.8	25.9	27.5	28.2	28.8	27.3	26.2	9.1	10.5	13.3	15.2	14.1	13.7
Chromium	30	14.7	15.6	17.0	19.1	18.5	17.9	20.7	23.0	24.4	25.1	25.0	25.0	6.1	9.0	10.6	12.4	11.9	10.6
Cadmium	4.8	2.4	2.4	2.9	3.0	2.7	2.7	3.2	3.4	3.5	3.5	3.4	3.2	1.1	1.2	1.6	1.8	1.7	1.6
Copper	11	5.4	5.6	6.6	6.8	6.2	6.0	7.2	7.7	7.9	8.1	7.7	7.4	2.4	2.8	3.6	4.2	3.9	3.7
Nickel	28	14.0	14.4	17.0	17.5	16.1	15.6	18.7	19.9	20.4	20.8	19.7	18.9	6.3	7.3	9.4	10.8	10.0	9.7

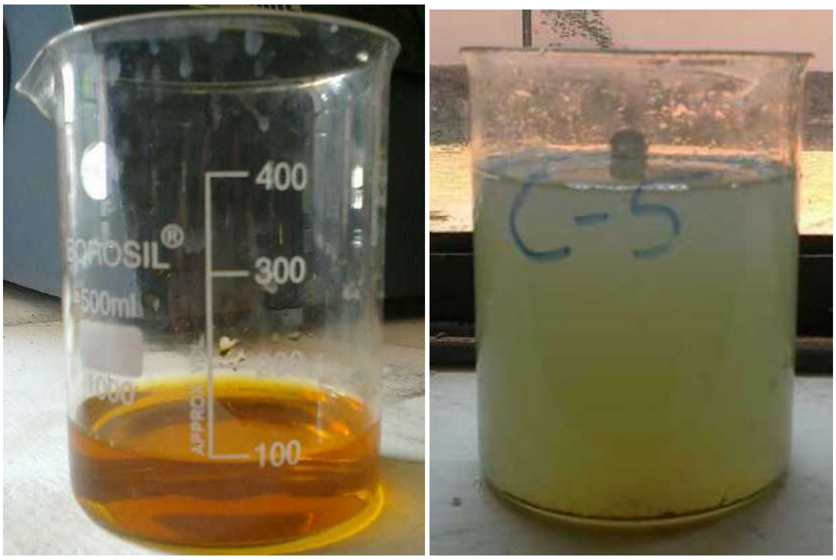
Table 7.3 *Chemical Adsorption of 600 mm thick Agro Waste Materials*

Chemical Constituents (mg/l)	Synthetic Leachate	Rice Husk						Coir Pith						Sugarcane Bagasse					
		1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	1 Week	2 Week	3 Week	4 Week	5 Week	6 Week
Chloride	6500	4054.2	4265.9	4567.1	5007.3	5057.0	5089.5	5165.0	5671.0	5975.0	6114.0	6168.5	6194.5	2612.4	3232.9	3574.0	3974.6	4036.5	4121.0
Ammonia	300	196.3	207.9	212.5	223.3	234.1	237.0	233.9	242.5	252.5	252.0	249.8	248.7	140.4	147.6	154.5	168.4	174.9	180.3
Nitrate	57	35.5	37.3	39.0	42.0	44.9	47.8	45.1	47.6	48.6	49.5	49.9	50.8	25.2	27.3	31.6	34.4	35.1	35.3
Iron	11300	7345.6	7484.0	8520.3	8758.4	8996.5	9234.6	8874.8	9374.4	9556.7	9745.1	9797.0	9983.8	4927.9	5350.2	6194.7	6757.7	6881.7	7017.3
Manganese	119	78.4	84.5	90.7	93.2	95.2	96.6	94.5	99.7	101.6	103.6	104.7	105.9	52.9	57.3	66.2	72.2	75.4	77.1
Zinc	38	24.0	25.2	27.7	28.8	29.3	29.8	30.4	32.1	33.6	33.8	34.2	34.6	17.2	18.6	21.4	23.3	23.8	24.4
Chromium	30	19.5	20.4	22.5	23.6	23.7	23.8	25.8	26.6	27.6	28.2	29.1	29.4	14.4	15.9	16.9	18.8	19.1	19.8
Cadmium	4.8	3.1	3.2	3.6	3.7	3.8	3.8	3.8	4.0	4.0	4.1	4.2	4.3	2.1	2.3	2.6	2.9	2.9	3.0
Copper	11	7.1	7.2	8.2	8.5	8.5	8.6	8.6	9.1	9.2	9.4	9.6	9.8	4.7	5.1	6.0	6.5	6.7	6.8
Nickel	28	19.9	20.4	21.2	21.7	21.9	22.1	23.0	23.8	24.1	24.6	25.2	25.5	12.6	14.0	15.4	16.8	17.2	17.7



(a)
Synthetic Leachate before Treatment

(b)
After Treatment with Sugar Cane Bagasse



(c)
After Treatment with Rice Husk

(d)
After Treatment with Coir Pith

Fig. 7.12. *Leachate Samples before and after Treatment with 600 mm thick Adsorbent Layers for 6 weeks.*

7.5 Summary

Adsorption process is a surface phenomenon where mixture of many components present in liquid or waste water is treated by forming an attachment bond by physical and chemical process (Motling et al., 2013). Among the three adsorbent materials used for adsorption studies with 300 mm thick layer, coir pith can reduce upto 60% to 80% of chemical concentration in the leachate, whereas rice husk and sugarcane bagasse can reduce upto 45% to 60% and 20% to 40% respectively. Also it can be observed that efficiency of each layers reduced after 4 weeks. When the layer thickness is increased to 600 mm, reduction in chemical concentration increases with the coir pith showing maximum reduction. As these materials are showing maximum reductions in chemical concentration within 4 weeks, these can be utilized at the temporary MSW holding areas even in the raw form after a simple acid wash. A layer of the material at the bottom of the waste holding area, itself improve the leachate properties.

The preliminary studies on coir pith, rice husk and sugar cane bagasse shows that these agricultural wastes can be effectively utilized as a reactive material in PRB for the reduction of the extent of soil pollution. Though the three selected materials are good in adsorption characteristics, the coir pith is showing a better result in the purification of leachate, due to the high adsorption capacity as reported by Violet et al. (2012).

The factors like surface area pore structure, thermo stability and low acid base reactivity etc. can also play important roles for obtaining efficiency of adsorption system (Motling et al., 2013). Further study is recommended in this area to modify these materials to improve the reactive properties, durability and efficiency.

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Chapter 8

SUMMARY AND CONCLUSION

Contents

8.1 Introduction

In landfills without liners between the waste and the underlying geology or with damaged liners, leachate is free to egress directly into the surroundings and will cause the pollution of soil and ground water. Here an attempt was made to generate knowledge on composition and concentration of pollutants in the soil near a municipal solid waste landfill area and also to study the effect of chemicals in the leachate on the engineering properties of soil. Then the study is extended to assess the feasibility of utilization of the locally available raw agricultural wastes as a reactive media in permeable reactive barriers.

This chapter presents summary and conclusion of this study based on the various objectives addressed.

8.2 Summary

The leachate generated from a municipal solid waste landfill is a mixture of several chemicals and to identify the effect of these chemicals on soil, a case study on an unlined municipal solid waste landfill at Kalamassery has been done. Soil samples as well as water samples were collected from the site and analysed to identify the pollutants and its effect on soil characteristics. Laboratory experiments were formulated to model the field around a municipal solid waste landfill and studied the pollutant transport pattern through the soil using synthetic leachate. Experiments were also conducted to study the effect of pollutants on engineering properties of soil. To visualize the flow of pollutants through soil in a broader sense, the transportation of pollutants through soil is modelled using a software 'Visual MODFLOW'. The field data collected initially was used to calibrate the modelling and thus simulated the flow pattern of the pollutants through soil around Kalamassery municipal solid waste landfill for an extent of 4 km^2. Flow is analysed for a time span of 30 years in which the landfill was closed after 20 years. As an environmental management measure to control the pollution through leachate, permeable reactive barriers are used as an emerging technology. Here the suitability of locally available materials like coir pith, rice husk and sugarcane bagasse were investigated as reactive media in permeable reactive barrier.

8.3 Conclusions

The major conclusions drawn from the above study, which can find applications in engineering practice, especially in the field of geo-environmental engineering, are presented below.

8.3.1 Identification of Chemicals in Soil near a Typical MSW Landfill

- From the case study on Kalamassery MSW landfill, which is in function as an unlined and untreated landfill from 1991, the major chemicals in the soil are identified as ammonia, chloride, nitrate, iron, nickel, cadmium, chromium, etc..

- Concentration of each chemical varies with respect to the distance and depth from the landfill. As per the bore hole samples collected, higher chemical concentration in soil is exhibited till 20 m from the landfill boundary and then decreases in the study region. Beyond 30 m, the soil is not affected by the leachate.
- Variations in the engineering properties of soil sample from the different distance and depth show that the chemicals in the soil near the landfill may have influence on the engineering properties of soil.

8.3.2 Laboratory Modelling of Synthetic Leachate Transport

The leachate transportation of an unlined MSW landfill is simulated by a test set-up in the laboratory using a test tank of 1 m diameter and 0.8 m height using two different soils (low compressible Test Soil-I and high compressible Test Soil-II) subjected to synthetic leachate. Soil samples were collected from 0.2 m and 0.4 m radial distance after 100 days and 150 days from the start of the experiment. The following qualitative conclusions are drawn from the study.

- Maturing period does not show any significant change in the chemical concentration. This can be due to the fact that as there is no flow through soil after the stoppage of leachate and the non-degradable metals remains as it is in the soil.

- The direction and pattern of leachate flow through soil depends upon the type of soil, density of soil, layers of soil, cracks and fissures in the soil, ground water flow etc.. As the conditions of each landfill site are different, the flow pattern of leachate through landfill cannot be generalized.
- Adsorption property of soil, mobility and solubility of chemicals etc. will influence the retention of the different chemicals in soil.
- Maximum changes in chemical concentration as well as the engineering properties are observed on soil samples at a radial distance of 0.2 m and at a depth of 0.3 m from the point of application of leachate. Thus it can be concluded that the chemical in leachate has a major influence on the engineering properties of soil.
- The pore water fluid and its flow has major role in the mobility of chemicals through soil.
- So the contaminant transport through soil is closely related to the contaminant transport through ground water flow.

8.3.2.1 Chemical concentration of soil

- Maximum concentration of Chloride adsorbed is found to be 23% of leachate concentration in Test soil-I and 19% of leachate concentration in Test soil-II. A maximum value of 25% and 21% of Ammonia in the leachate concentration is adsorbed by Test soil-I and II respectively. A maximum of 32% and 30% of Nitrate concentration in the leachate are found to be taken up by the soil as it passes through Test soil-I and II respectively.

- Approximately 45% of concentration of metals (such as Manganese, Iron, Chromium Cadmium, Zinc, Copper and Nickel) present in the synthetic leachate is observed to be adsorbed by low compressible Test Soil-I at the position where maximum chemical concentration is obtained, while in high compressible Test soil-II, the corresponding value is 43 %.

8.3.2.2 Engineering properties of soil

- The leachate is a combination of different chemicals, and the net change in the engineering properties of soil treated with leachate is due to the combined effect of these mixed contaminants. The variation of the engineering properties of soil can be explained with respect to the total cation and anion concentrations in mg/kg of the soil.
- Leachate applied test soils are showing a decrease in specific gravity, plastic limit and shrinkage limit. Maximum percentage of reduction is obtained at the position with maximum chemical concentration.
- Liquid limit of both the test soils are getting increased for small chemical concentrations. Higher chemical concentrations lead to decrease the liquid limit of test soils.
- Small chemical concentration may improve the plasticity characteristics. Plasticity index increases in the case of Test soil-I

for selected cation and anion concentrations upto 5600 mg/kg and 900 mg/kg of soil respectively. Further increase in chemical concentration, decreases the plasticity index. For Test soil-II, improvement of plasticity is observed till the concentration of selected cations is 4250 mg/kg of soil and that of selected anion concentrations is 750 mg/kg of soil.

- Presence of selected chemicals can improve the strength of soil. Unconfined compressive strength of test soils is observed to be maximum, when the concentration of selected cations ($\sum Mn^{2+}$, Zn^{2+}, Cd^{2+}, Ni^{2+}, Fe^{2+}, Cr^{2+}, Cu^{2+}, NH_4^+) and anions ($\sum Cl^-$, NO_3^-) in the soil is maximum.

8.3.3 Effect of Chemical Concentration on Soil Characteristics

- To establish the effect of chemical concentration on soil properties, two soils (Test soils-I and II) are treated with the synthetic chemicals at different concentrations. The chemical concentration of the synthetic leachate corresponding to the observed field leachate is taken as 100% and, with respect to that, the leachates are diluted to get 75%, 50% and 25% of the field values. The effect of maturing period in engineering properties was also studied by keeping the soil-leachate mixture for 7, 50, 100 and 150 days.
- For the Test soil-I treated with 100% concentration of leachate, the percentage of soil finer than 0.002 mm increases from 6% to 24% in 7 days of maturing period. Further it increases to 33%,

36% and 41% corresponding to 50 days, 100 days and 150 days of maturity period. In Test soil-II, percentage finer than 0.002 mm increases from 16% to 35%, 40%, 50% and 56% corresponding to 7 days, 50 days, 100 days and 150 days of maturing period. As the colloids in the soil gets dissolved due to the influence of pollutants, most of the soil grains will disperse easily and clay grain content will get increased.

- Both the test soils treated with 25% leachate chemical concentration on 7th day is showing increase in liquid limit and plasticity index. Further increase in concentration and ageing causes decrease in liquid limit and plasticity index in both the soils.
- Plastic limit and Shrinkage limit of test soils are observed to be reduced as the chemical concentration as well as ageing increases. The maximum reduction is obtained for test soils treated with 100% chemical concentration and matured for 150 days.
- Unconfined compressive strength of test soils were getting increased due to the addition of chemicals. It shows an increasing trend towards maturing period also. Increase in UCC strength is upto 64.4% in Test soil-I and 103.8% in Test soil-II for highest chemical concentration and maturing period.
- Hydraulic conductivity also shows an increasing trend towards concentration of chemicals and maturing period in both test soils.

8.3.4 Contaminant Transport Modelling

Using a software 'Visual MODFLOW', the transportation of pollutants through soil at Kalamassery, municipal solid waste landfill is modelled and the flow of pollutants through soil is visualized. Fate of chloride is observed in the model study for a time span of 30 years.

- From the output it is observed that the leachate plume was travelling a distance of 250 m to 300 m around the landfill area on a continuous disposal of waste for 20 years. In the 20th year, the maximum chloride concentration beneath the landfill is observed to be 4500 mg/l.
- Further, the concentration of chloride in leachate beneath the landfill is observed to be reduced to 700 mg/l within one year after the closure of landfill. After 8 years, the chloride concentration of leachate at the disposal place gets lowered to 0.2 mg/l.
- Thus in the study area, within in a period of 8 years after the closure of landfill, the concentration of leachate on the dumping place is found to be insignificant.

8.3.5 Soil Pollution Control Management

Introduction of permeable reactive barrier in the path of leachate plume is an emerging technology to control the soil and ground water pollution due to the leakage of leachate. Adsorption studies were conducted in a test set-up to investigate the suitability of locally available agro waste materials like coir pith, rice husk and sugar cane bagasse after a simple acid wash, as a reactive media in permeable reactive barrier. Synthetic leachate of known concentration is allowed to flow cyclically after every week through 300 mm thick and 600 mm thick reactive medium and analysed the chemical concentration of effluent.

- Maximum percentage reduction in leachate concentration of the filtrate from 300 mm thick layer of coir pith, rice husk and sugar cane bagasse are observed on 4th week and is 83%, 64% and 41% respectively. When the layer depth is increased to 600 mm, efficiency of each material increases till 6th week.
- Among the three agro waste materials, coir pith exhibits better performance.
- The preliminary adsorption studies show that these agricultural wastes can be effectively utilized as a reactive material in PRB.

The research throws light on how the pollutant from a typical unlined municipal landfill transports through the soil and pollutes it. The extent and time span of pollution of landfill surroundings can be accurately predicted using software models of the landfill area by knowing field parameters and leachate characteristics. The results of this research clearly establish the influence of chemicals from the leachate of MSW landfill on the engineering properties of soil and also possible control measures to reduce the extent of soil and ground water pollution.

8.3.6 Scope for the Further Study

As per the obtained results of the studies, it is proved that the chemicals in the landfill leachate have a major influence on the soil properties. In the present study, the role of mixed contaminants is examined. The effect of each chemicals at different concentrations and contact periods with different soil types can be studied in detail. It is observed that the strength of the soil is getting improved due to the chemical addition. But the effect of these chemicals on the building parts while using the landfill area for construction has to be investigated.

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REFERENCES

[1] 40 CFR, (2005), “Introduction to Hazardous Waste Identification”, *United States Environmental Protection Agency*.

[2] Abesh, R. and Anitha, D. R. (2012), “Biochemical Aspects and Formation of Phenolic Compounds by Coir Pith Degraded by Pleurotus Sajor Caju”, *Journal of Toxicology and Environmental Health Sciences*, Vol. 4 (1), pp.29-36.

[3] Abichou, T., Craig, H. B., and Tuncer, B. E. (2000). “Foundry Green Sands as Hydraulic Barriers: Laboratory Study”, *Journal of Geotechnical and Geoenvironmental Engineering*, 126(12), pp.1174-1183.

[4] Abraham, V. C. (2009), “Roping in Students for a Clean City”, *Express News Service*,www.forum.kochinow.com

[5] Alexander, M. (1999), “Biodegradation and Bioremediation”, *San Diego*, Academic Press.

[6] Alker, S. C., Sarsby, R. W. and Howell, R. (1995), “ Composition of Leachate From Waste Disposal Sites”, *Proc. of Symposium on Waste Disposal by Landfill- Green’93*, Balkena, Rotterdam, Netherlands, pp.215-221

[7] Aller, L., Bennett, T., Lehr, J. H., Petty, R. J. and Hackett, G. (1987), “DRASTIC: A Standardized System for Evaluation Ground Water Pollution Potential Using Hydrogeologic Settings” *EPA-600/2-87-035, Kerr Environmental Research Lab, United States Environmental Protection Agency*, Ada, Oklahoma.

[8] Amin, M. and Hamidi, A. A. (2012), "Impacts of Municipal Waste Leachate on Accumulation of Heavy Metals in Soil and Barley", *The 4th International Engineering Conference-Towards engineering of 21st century*, Japan.

[9] AP42 (1995), "Compilation of Air Pollutant Emission Factors", *Fifth edition, United States Environmental Protection Agency*.

[10] APHA (1995), "Standard methods for the Examination of Water and Waste Water", *19th edition, American Public Health Association*.

[11] Arasan, S. (2010), "Effect of Chemicals on Geotechnical Properties of Clay Liners: A Review", *Research Journal of Applied Sciences, Engineering and Technology,* Vol. 2(8), pp.765-775

[12] Arasan, S. and Temel, Y. (2008), "Effect of Inorganic Salt Solutions on the Consistency Limits of Two Clays", *Turkish Journal of Engineering and Environmental Sciences.*

[13] Armstrong, M. D. and Rowe, R. K. (1999), "Effect of Landfill Operations on the Quality of Municipal Solid Waste Leachate", Proc. of *Sardinia 99, Seventh International Waste Management and Landfill Symposium, Cagliari, Italy*, Vol.2, pp.81-88.

[14] Ash, B., Satapathy, D., Mukherjee, P. S., Nanda, B., Gumaste, J. L. and Mishra, B. K. (2006), "Characterization and Application of Activated Carbon Prepared from Waste Coir Pith", *Journal of Scientific & Industrial Research*, Vol.65(2), pp.1008-1012.

[15] Bear, J. (1972), "Dynamics of Fluid in Porous Media", *American Elsevier Publishing Company*, New York.

[16] Bear, J. and Cheng, A. H. D. (2010), "Modeling Groundwater Flow and Contaminant Transport", *Springer*, XXII.

[17] Bear, J. and Verruijt, A. (1979), "Modeling Groundwater Flow and Pollution", *Kluwer Academic Publishers Group*, Auckland, New Zealand.

[18] Bello, A. A. (2012), "Regression Analysis between Properties of Subgrade Lateritic Soi", *Leonardo Journal of Science*, Vol. 21, pp.99-108.

[19] Bhalla, B., Saini, M. S. and Jha, M. K., (2014), "Assessment of Industrial Byproducts as Permeable Reactive Barriers for Landfill Leachate Management", *International Journal of Research in Engineering and Technology*, Vol. 3(3), pp.637- 648.

[20] Bhalla, B., Saini, M. S. and Jha, M. K. (2013), "Effect of Age and Seasonal Variations on Leachate Characteristics of Municipal Solid Waste Landfill", *International Journal of Research in Engineering and Technology*, Vol. 2 (8), pp.223-232.

[21] Boulding, J. R. and Ginn, J. S. (1995), "Practical Handbook of Soil, Vadose Zone and Groundwater Contamination", *Lewis Publishers*, USA.

[22] Carey, M. A., Fretwell, B. A., Mosley, N. G. and Smith, J. W. N. (2002), "Guidance on the Use of Permeable Reactive Barriers for Remediating Contaminated Groundwater", *National Groundwater & Contaminated Land Centre Report*, NC/01/51.

[23] Cermak, O., Cermakova, M and IlaVs.ky, J. (2004), "Characterization of Landfill Condition", *Slovak Journal of Civil Engineering*, Vol.1, pp.29-32.

[24] Chattopadhyay, B. C. and Chakravarty, S. (2009), "Containment of Sulfate Pollution in Soil by Natural Geotextile from Jute", *Journal of Materials in Civil Engineering*, Vol. 21, No. 3.

[25] Cho, W. J., Jae, O. L. and Kang, C. H. (2002), “Hydraulic Conductivity of Compacted Soil-Bentonite Mixture for a Liner Material in Landfill Facilities”, *Journal of Environmental Engineering Research*, Vol. 7(3), pp.121-127.

[26] Daniel, D. E. (1984), “Predicting Hydraulic Conductivity of Clay Liners”, *Journal of Geotechnical Engineering*, Vol.110 (2), pp.285–300.

[27] Daniel, D. E. and Yung, K. W. (1993),”Compacted Clay Liners and Covers for Arid Sites”, *Journal of Geotechnical Engineering*, Vol.119 (2), pp.223-237.

[28] DEQ (2001), “The Challenge of Environmental Clean Up”, *Land Protection Report, Department of Environmental Quality*, Okalahoma.

[29] Dhanyasree, A. R., Ajitha, Y. and Sheela, E. (2011), "Study on the Shrinkage, Swelling and Strength Characteristics of Clay Soils under Different Environmental Conditions", *Proc. of Indian Geotechnical Conference,* Kochi, India.

[30] Dhayabaran, V. V., Lydia, I. S., Merlin, J. P. and Sathiyan, A. (2012), “Utilization of the Agricultural Wastes for Decolourisation of Congo Red”, *International Journal of Chemical and Environmental Engineering*, Vol.3 (1), pp.7-11.

[31] Dinesh, C. K. and Babu, .J. A. (2003), “Monitoring Leachate Composition at a Municipal Landfill Site in New Delhi, India”, *International Journal of Environment and Pollution*, Vol.19 (5), pp.454-465.

[32] Donigian, A. S. and Rao, P. S. C. (1990), “Selection, Application and Validation of Environmental Models”, *Proc. of International Symposium on Water Quality Modelling of Agricultural Non-Point Sourc*es, Logan, U.T., Part 2, pp.577-600.

[33] EAI (Energy Alternatives India), "India MSW to Energy-Status, Opportunities and Bottlenecks". http://www.eai.in.

[34] El-Fadel, M., Bou, Z. E., Chahine, W. and Alayli, B. (2002), "Temporal Variation of Leachate Quality from Pre-Sorted and Baled Municipal Solid Waste with High Organic and Moisture Content", *Waste Management*, Vol.22, pp.269-282.

[35] Fetter, C. W. (1993), "Contaminant Hydrogeology", *Macmillan Publishing Company*, New York.

[36] Foreman, D. E. & Daniel, D. E. (1986), "Permeation of Compacted Clay with Organic Chemicals", *Journal of Geotechnical Engineering*, Vol. 112, pp.669-681.

[37] Freeze, R. A. and Cherry, J. A. (1979), "Ground Water", *Prentice-Hall*, Englewood Cliffs, New Jersey.

[38] Freudenrich (2000), "How Landfills Work?",www.science.howstuffworks.com.

[39] Gidigasu, M. D (1976), "Laterite Soil Engineering Pedogenesis and Engineering Principles", *Elsevier Scientific Pub.*, Amsterdam.

[40] Gnanapragasam, N., Lewis, B. G and Finno, R. J (1995), "Microstructural Changes in Sand-Bentonite Soils when Exposed to Aniline", *Journal of Geotechnical Engineering*, Vol.121 (7), pp.119-125.

[41] Goswami, D. and Choudhury, B. N. (2013), "Atterberg Limit and Shear Strength Characteristics of Leachate Contaminated Lateritic Soil", *Indian Journal of Research*, Vol. 3(4), pp.91-93.

[42] Harbaugh, A.W. (2005), "MODFLOW-2005: The U.S. Geological Survey Modular Ground-Water Model-the Ground-Water Flow Process", *United States Geological Survey (USGS) Techniques and Methods 6-A16*, Reston, Virginia, U.S. Geological Survey.

[43] Harshini, S. (2010), http://theviewspaper.net/waste-disposal-in-india.

[44] Henderson, A. D. and Demond, A. H. (2007), "Long-Term Performance of Zero-Valent Iron Permeable Reactive Barriers: A Critical Review", *Environmental Engineering Science*, Vol.24 (4), pp.401-424.

[45] IEPA (2012), "Updated Requirements for Clean Construction or Demolition Debris (CCDD) & Uncontaminated Soil Fill Operations", *Illinois Environmental Protection Agency*.

[46] IS: 3025 (Part 1) (1987), "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater, Sampling", *Bureau of Indian Standards*, New Delhi, India.

[47] IS: SP: 36 - Part 1 (1987), "Compendium of Indian Standards on Soil Engineering- Part 1, Laboratory testing of soils for Civil Engineering purposes", *Bureau of Indian Standards*, New Delhi, India.

[48] James, J. C. (2001), "Nitrogen in Soil and Fertilisers", *SC Turfgrass Foundation News*, Vol. 8 (1), pp.6-10

[49] Jassam, M., Khattab, S., Bouasker, M., Dufour, A., Jozja, N., Defarge, C. and AL-Mukhtar, M. (2014), "Transport of Nitrate Through Saturated-Unsaturated Soils Considering Non Homogeneous Soil Profile", *International Journal of Geology, Earth & Environmental Sciences*, Vol.4 (1), pp.8-22.

[50] Jayasekera, S. and Mohajerani, A. (2001), "A study of Effects of Municipal Landfill Leachate on a Basaltic Clay Soil", *Australian Geomechanics*.

[51] Jia, J. C. and Yang, Q., (2010), "Influence of Pore Water Chemistry on the Swelling Behavior of Compacted Clays", *Electronic Journal of Geotechnical Engineering*, Vol.15.

[52] Jia, Y. G., Wu, Q, Meng, X. M., Yang, X. J., Yang, Z. N. and Zhang, G. C. (2009), "Case Study on Influences of Oil Contamination on Geotechnical Properties of Coastal Sediments in the Yellow River Delta", *Proc. of International Symposium on Geoenvironmental Engineering*, Hangzhou, China.

[53] Johnson, R. L., Thomas, R. B., Johnson, R. O., Nurmi, J. T. and Tratnyek, P. G. (2008), "Mineral Precipitation Upgradient from a Zero-Valent Iron Permeable Reactive Barrier",*Ground Water Monitoring & Remediation*, Vol. 28(3), pp.56-64

[54] Judith, W., Bryony, H. and James, C. (2003), "PIMS: an Apatite II Permeable Reactive Barrier to Remediate Groundwater Containing Zn, Pb and Cd", *Environmental Geosciences*.

[55] Kaur, P. (2008), "Total Solids Occurring in Various Industries Effluent Water Present in Durg District", *Current World Environment*,Vol. 3(1), pp.157-160.

[56] Keerthi, R. (2011), "Anaerobic Treatment of Municipal Solid Waste Landfill Leachate", *Dessertation Report, Master of Technology in Environmental Science and Technology*, Thapar University, Patiala.

[57] Kehew, A. E. (2001), "Applied Chemical Hydrogeology", *Prentice-Hall*, Inc.

[58] Kenney, T. C., Van Veen W. A., Swallow, M. A. and Sungaila, M. A. (1992), "Hydraulic Conductivity of Compacted Bentonites and Mixtures", *Canadian Geotechnical Journal*, Vol.29, pp.364-374.

[59] Kerala development report (2008), *Planning Commission, Government of India*, Delhi.

[60] Kincaid, C. T., Morrey, J. R. and Rogers, J. E., (1984), "Geohydrochemical Models for Solute Migration-Volume 1: Process Description and Computer Code Selection", *EA-3417, Electric Power Research Institute*, Palo Alto, California.

[61] Kristin, E. D., (2009), "Remediation of Materials with Mixed Contaminants-Treatability, Technology and Final Disposal", *Örebro University Publishers*.

[62] Lee, G. F. and Anne, J. L. (1994), "Impact of Municipal and Industrial Non-Hazardous Waste Landfills on Public Health and the Environment: An Overview", *California EPA Comparative Risk Project*, Sacramento.

[63] Maria, L. (2009), "Trash Planet: India", *Article on Earth 911*.

[64] Marshall, W. E., Wartelle, L. H., Boler, D. E., Johns, M. M. and Toles, C. A. (1999), "Enhanced Metal Adsorption by Soybean Hulls Modified with Citric Acid", *BioResource Technology*, Vol.69, pp.263-268.

[65] McBride, M. B. (1994), "Environmental Chemistry of Soils", *Oxford University Pres*s,New York.

[66] McDonald, M. G. and Harbaugh, A. W. (1988), "A Modular Three-Dimension Finite-Difference Groundwater Flow Model", *United States Geological Survey (USGS)*, Washington DC., http://pubs.usgs.gov.

[67] Mishra, A. K. (2013), "Effect of Salt on the Hydraulic Conductivity and Compressibility of the Two Soil-Bentonite Mixtures with Different Bentonite Contents", *Proc. of Annual International Conference on Architecture and Civil Engineering,* Singapore.

[68] Mishra, A. K., Ohtsubo, M., Li, L. and Higashi, T. (2005), "Effect of Salt Concentrations on the Permeability and Compressibility of Soil-Bentonite Mixtures", *International Journal of Geotechnical Engineering*, Vol. 4(3).

[69] Mitchell, J. K. (2005), "Fundamental of Soil Behavior", *John Wiley & Son*s, New Jersey, pp.288–290.

[70] Mohammed, Y. F., Falah, H. R. I. and Kawther, Y. H. A. (2013), "Improvement of Clayey Soil Characteristics Using Rice Husk Ash", *Journal of Civil Engineering and Urbanism*, Vol. 3(1).

[71] Mondal, N. C. and Singh, V. S. (2009), "Mass Transport Modeling of an Industrial Belt using Visual MODFLOW and MODPATH: A Case Study", *Journal of Geography and Regional Planning*, Vol.2 (1), pp.001-019.

[72] Moore, R. (1991), "The Chemical and Mineralogical Controls upon the Residual Strength of Pure and Natural Clays", *Geotechnique,* Vol.41 (1), pp.35-47.

[73] Moses, G. and Oriola, F.O.P. (2011), "Compacted Black Cotton Soil Treated with Cement Kiln Dust as Hydraulic Barrier Material", *American Journal of Scientific and Industrial Research*.

[74] Motling, S., Dutta, A. and Mukherjee, S. N. (2013), "Applications of Adsorption Process for Treatment of Landfill Leachate", *Journal of Environmental Research and Development*, Vol.8 (2), pp.365-370.

[75] Mufeed, S., Kafeel, A., Gauhar, M. and Trivedi, R. C. (2008), "Municipal Solid Waste Management in Indian Cities – A Review", *Waste Management*, Vol.28(2), pp.459–467

[76] Municipal Solid Waste (Management and Handling) Rules (2000), *Ministry of Environment and Forests*, Government of India.

[77] Musa, A. (2012), "Effect of Municipal Solid Waste on Geotechnical Properties of Soils", *International Journal of Environmental Science, Management and Engineering Research*, Vol.1(5).

[78] Nader, S., Marzieh, S. and Mehran, K. F. (2011), "Effect of Inorganic Salt Solutions on Some Geotechnical Properties of Soil-Bentonite Mixtures as Barriers", *International Journal of Civil Engineering*.

[79] Nanda, H. S., Shivaraju, R and Ramakrishnegowda, C. (2011), "Impact of Municipal Solid Waste Disposal on Geotechnical Properties of Soil", *Indian Geotechnical Conference*, Kochi, India.

[80] National Research Council (1990), "Ground Water Models: Scientific and Regulatory Applications", *National Academy Press*, Washington, DC.

[81] Nayak, S., Sunil, B. M., Shrihari, S. (2009), "Shear Strength Characteristics and Chemical Characteristics of Leachate Contaminated Lateritic Soils", *Journal of Engineering Geology*, Vol. 106, pp. 20-25.

[82] Nayak, S., Sunil, B. M., and Shrihari, S. (2007), "Hydraulic and Compaction Characteristics of Leachate-Contaminated Lateritic Soil", *Journal of Engineering Geology*, Vol. 94, pp.137-144.

[83] Njar, G.N., Iwara, A. I., Ekukinam, U. E, Deekor, T. N. and Amiolemen, S. O. (2011), "Organic Carbon and Total Nitrogen Status of Soils under Rubber Plantation of Various Ages, South-Southern Nigeria", J*ournal of Environmental Sciences and Resource Management*, Vol.3.

[84] Olgun, M. and Yildiz, M. (2012), "Influence of Acetic Acid on Structural Change and Shear Strength of Clays", *Iranian Journal of Science and Technology-Transactions of Civil Engineering*, Vol. 36.

[85] Osinubi, K. J. and Eberemu, A. O. (2010), "Unsaturated Hydraulic Conductivity of Compacted Lateritic Soil Treated with Bagasse Ash", *GeoFlorida- Advances in Analysis, Modeling, and Design*, pp.357-369.

[86] Osinubi, K. J. and Moses, G. (2011), "Compacted Foundry Sand Treated with Bagasse Ash as Hydraulic Barrier Material", *Geo-Frontiers- Advances in Geotechnical Engineering*, pp.915-925.

[87] Osinubi, K. J. and Charles, M. N. (2006), "Design of Compacted Lateritic Soil Liners and Covers" *Journal of Geotechnical and Geoenvironmental Engineering*, Vol.132(2), pp.203-213.

[88] Ozcoban, M. S., Tufekci, N., Tutus, S., Sahin, U. and Celik, S. O., (2006), "Leachate Removal Rate and the Effect of Leachate on the Hydraulic Conductivity of Natural (Undisturbed) Clay", *Journal of Scientific and Industrial Research*, Vol. 65.

[89] Park, S., Choi, K. S., Joe, K. S., Kim, W. H. and Kim, H. S. (2001), "Variations of landfill Leachate's Properties in Conjunction with the Treatment Process", *Environmental Technology*, Vol.22, pp. 639–645.

[90] Patil, M. R., Quadri, S. S. and Lakshmikantha, H., (2009), "Alternative Materials for Landfill Liners and Covers", *Indian Geotechnical Conference*, Guntur, India.

[91] Pillai, S., Anju, E. P., Sunil, B. M., and Shrihari, S. (2014), "Soil Pollution near a Municipal Solid Waste Disposal Site in India", *Proc. of International Conference on Biological, Civil and Environmental Engineering*, Istanbul, Turkey.

[92] Rajamanickam, R. and Nagan, S. (2010), "Groundwater Quality Modeling of Amaravathi River Basin of Karur District, Tamil Nadu, Using Visual Modflow", *International Journal of Environmental Sciences*, Vol.1(1), pp.91-108.

[93] Ramakrishnegowda, C., Ramakrishna, Y., Shivashankar, R. and Sivapullaiah, P. V., (2011), "Geotechnical Properties of Shedi Soil affected by Alkali Contamination", *International Journal of Environmental Protection*, Vol.1 (4), pp.45-52.

[94] Raman, N. and Sathiya, D. N. (2008), "Impact of Solid Waste Effect on Ground Water and Soil Quality Nearer to Pallavaram Solid Waste Landfill Site in Chennai," *Rasayan Journal of Chemistry*, Vol.1(4).

[95] Rao, T. A., Rao, V. V. S. G., Ranganathan, K., Surinaidu, L., Mahesh, J. and Ramesh, G. (2011), "Assessment of groundwater Contamination from a Hazardous Dump Site in Ranipet, Tamil Nadu, India", *Hydrogeology Journal*, Vol.19, pp.1587-1598.

[96] Renou, S., Givaudan, J. G., Poulain, S., Dirassouyan, F. and Moulin, P. (2008), "Landfill Leachate Treatment: Review and Opportunity", *Journal of Hazardous Materials*, Vol.150(3), pp.468-493.

[97] Robert, S., Robert, H., Marc, A. and Rainer, S. (1979), "Development of Synthetic Municipal Landfill Leachate", *Journal of Water Pollution Control Federation*, Vol.51(7), pp.1965-1975.

[98] Robinson, A. H. (2005), "Landfill Leachate Treatment", *Membrane Technology*, Vol.6 (12).

[99] Robrecht, M. S. (2006), "Can the Diffuse Double Layer Theory Describe Changes in Hydraulic Conductivity of Compacted Clays?", *Geotechnical and Geological Engineering*, Vol.24.

[100] Rodriguez, I. J., Castrillon, P. L., Maranon, M. E. and Sastre, A. H. (2000), "Biomethanisation of Municipal Solid Waste in a Pilot Plant", *Water Research*, Vol.34 (2), pp.447-454.

[101] Romero, E. and Simms, P. H. (2008), "Microstructure Investigation in Unsaturated Soils: A Review with Special Attention to Contribution of Mercury Intrusion Porosimetry and Environmental Scanning Electron Microscopy", *Geotechnical and Geological Engineering*, Vol. 26(6), pp.705-727.

[102] Rowe, R. K. (1995), "Leachate characteristics for MSW Landfill", *Geotechnical Research Centre Report, The University of Western Ontario*, London.

[103] Samhan, N. and Ghanem, M. (2012), "Groundwater Assessment for the NW of Auja Tamaseeh Basin in Tulkarem Area, West Bank", *Journal of Water Resource and Protection*, Vol. 4, pp.407-413.

[104] Sathyanarayana, S. (2004), "Groundwater Pollution Field Investigation and Contaminant Transport Modeling", *Dissertation for degree of master of technology,centre for Environmental Science and Engineering, Indian Institute of Technology*, Bombay.

[105] Satyanarayana, P. V. V., Harshitha, A. and Sowmya, P. D. (2013), "Utilization of Red Soil Bentonite Mixes as Clay Liner Material" *International Journal of Scientific & Engineering Research*, Vol. 4(5).

[106] Seyed, R. S and Mustapha, S. (2011), "Prediction of Contamination Migration in an Unconfined Aquifer with Visual MODFLOW: A Case Study", *World Applied Sciences Journal*, Vol. 14 (7), pp.1102-1106.

[107] Seyed, R. S., Mustapha, S., Shaharin, I., Mohd., A., Mohd., Z., and Elias, R., (2010), “Simulation of Phosphorus Movement in Unconfined Aquifer by Means of Visual MODFLOW”, *Journal of Computer Science*, Vol. 6(4), pp.446-449.

[108] Shackelford, C. D. and Daniel, D. E. (1991), “Diffusion in Saturated Soil I: Background”, *Journal of Geotechnical Engineering*, Vol.117(3), pp.467-484.

[109] Singh, S. and Prasad, A. (2007), “Effects of Chemicals on Compacted Clay Liner”, *Electronic Journal of Geotechnical Engineering*, Vol. 12.

[110] Sivapullaiah, P. V. (2009), “Effects of Soil Pollution on Geotechnical Behaviour of Soils”, *Indian Geotechnical Conference*, Guntur, India.

[111] Slack, R. J., Gronow, J. R., and Voulvoulis, N. (2005), “Household Hazardous Waste in Municipal Landfills: Contaminants in Leachate”, *Science of the Total Environment*, Vol. 337(1–3), pp.119-137.

[112] Sridharan, A. and Rao, G. V. (1975), “Mechanisms Controlling the Liquid Limit of Clays”, *Proc. of International Conference on SM & FE*, Istanbul, Vol.1, pp.65-74.

[113] Sridharan, A., and Jayadeva M. S., (1982), “Double Layer Theory and Compressibility of Clays”, *Geotechnique*, Vol.32, pp.133-144.

[114] Studds, P. G., Stewart, D. I. and Cousens, T. W. (1998), “The Effects of Salt Solutions on the Properties of Bentonite-Sand Mixtures”, *Clay Minerals*, Vol. 33, pp.651-660.

[115] Suad, M. G. and Mustafa, A. A. (2013), “Evaluation of the Effect of Solid Waste Leachate on Soil at Hilla City”, *Journal of Babylon University*, Vol.3(21).

[116] Tuncan, A., M. Tuncan, M. Yalcin and Y. Guney, (1998), "The Effects of Environmental Pollution on Cyclic Swell and Shrink Behaviour of Na-Bentonite Clay", *Proc. of Third International Congress on Environmental Geotechnic*s, Lisboa, Portugal.

[117] Umar, M., Aziz, H. A. and Yusoff, M. S. (2010), "Variability of Parameters Involved in Leachate Pollution Index and Determination of LPI from Four Landfills in Malaysia", *International Journal of Chemical Engineering*.

[118] USEPA (2011), "MSW Landfill Criteria Technical Manual", *Subpart-D, Design criteria, United States Environmental Protection Agency,* http://www.epa.gov.

[119] Vandana, S. and Sivapullaiah, P. V. (2011), "Clay Mineral Liner System for Leachates Containing Organic Contaminants", Indian Geotechnical Conference, Kochi, India.

[120] Versar, Inc. (1987), "Current and Suggested Practices in the Validation of Exposure Assessment Models", *Report Prepared for United States EPA Office of Health and Environmental Assessment, Exposure Assessment Grou*p, Washington, DC. EPA Contract No. 69-02-4254, Work Assignment No. 55.

[121] Violet, V. D., Sharmila, I. L, Princy, J. M. and Sathiyan, A. (2012), "Utilization of the Agricultural Wastes for Decolourisation of Congo Red", *International Journal of Chemical and Environmental Engineering*, Vol. 3(1).

[122] Weaver, J., Enfield, C. G., Yates, S., Kreamer, D. and White, D. (1989), "Predicting Subsurface Contaminant Transport and Transformation: Considerations for Model Selection and Field Validation", *United States Environmental Protection Agency*, Ada, Oklahoma.

[123] Wei, L., Zhou, Q. and Hua, T. (2010), "Removal of Organic Matter from Landfill Leachate by Advanced Oxidation Processes: A Review", *International Journal of Chemical Engineering*.

[124] Zheng, C. and Bennett, G. C., (1995), "Applied Contaminant Transport Modeling", *Van Nostrand Reinhold, A Division of International Thompson Publishing Inc*., New York, pp.440.

[125] Zheng, C., (2009), "Recent Development and Future Directions for MT3DMS and Related Transport Codes", *Groundwater,* Vol.7, pp.620-625.

……

Publications

[1] Beena, K. S. and Meril, G. (2014), "Study on Grain Size Analysis of Soils Treated with Synthetic Leachate", *Sixth International Geotechnical Symposium on Disaster Mitigation on Special Geoenvironmental Conditions" (6IGS-2015)*, IIT Madras, Chennai, India (Communicated).

[2] Beena, K.S. and Meril, G. (2014), "Study on the Treatment and Reuse of Agricultural Waste Fibres", *Proc. of International Conference on Energy, Environment, Materials and Safety (ICEEMS'14)*, CUSAT, Kochi, India.

[3] Meril, G. and Beena, K. S. (2011), "Analysis of Soil Contaminated with Municipal Solid Waste Leachate", *International Journal of Advances in Engineering Research*, Vol. No. 2(6).

[4] Meril, G. and Beena, K. S. (2011), "Geotechnical Characteristics of Leachate- Contaminated Lateritic soil", *Proc. of Indian Geotechnical Conference,* Cochin, India.

[5] Beena, K. S. and Meril, G., "Contaminant Transport from a Municipal Solid Waste Landfill", *Proc. of Indian Geotechnical Conference*, Bombay, India.

To be Communicated

[1] Beena, K. S. and Meril, G., "Laboratory Studies on effect of Multiple Contaminant Transport in Soil", *Journal of Geotechnical and Geoenvironmental Engineering* (ASCE Publication) (Communicated).

[2] Beena, K. S. and Meril, G. (2015), "Fate of Leachate in an Abandoned Municipal Solid Waste Landfill", *Environmental Geotechnics* (ICE Publication).

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Appendix

Geosynthetic Clay Liner

Robert and Rowe (1996) has studied the effect of distilled water , aqueous single salt solutions with concentrations between 0.01 and 2.0 M NaCl, and a synthetic municipal solid waste leachate on confined swell, consolidation and hydraulic conductivity tests on a needle- punched geosynthetic clay liner. Results have shown that tests performed using synthetic MSW leachate gave comparable result with aqueous salt solutions 0.2 and 0.8 M NaCl.

Brown and Shackelford (2007) have evaluated the potential use of a commercially available geosynthetic clay liner (GCL) as the primary hydraulic barrier for animal waste lagoons on the basis of hydraulic conductivity (k) testing. The GCL was permeated under both aerobic and anaerobic conditions with both deionized water (DIW) and a simulated animal waste solution to determine the effect of the simulated solution on k of the GCL relative to k based on DIW. The k of the GCL increased only slightly(8%) on average when permeated with the simulated solution under anaerobic conditions relative to the k of 1.3 × 10–9 cm/s based on permeation with DIW, but increased by a factor of 4.2 on average when permeated with the simulated solution under aerobic conditions.

Goharrizi et al. (2013) has studied the effect of geosynthetic clay liner (GCL) layer to decrease soil pollution in the bed of landfills. Two different kind of soil were used for the experiments in two steps. In the first step, the penetration experiments have been done by water and leachate on condensed soil samples without use of GCL layers. In the second step, the penetration experiments have been repeated by water and leachate on condensed soil samples with GCL layers located on the top of soil samples. The results show that, the rate of permeability in soil samples with GCL layers are decreased about 98%.

References

[1] Robert J. P and Rowe R.K (1996), “Geosynthetic Clay Liner (GCL)-Chemical Compatability by Hydraulic Conductivity Testing and Factors Impacting its Performance”, *Canadian Geotechnical Journal*, Vol. 34, pp. 863-885

[2] Brown L. C and Shackelford C. D (2007), “Hydraulic Conductivity of Geosynthetic Clay Liner to a Simulated Animal Waste Solution”, *American Society of Agricultural and Biological Engineers*, Vol. 50(3), pp.831-841.

[3] Goharrizi R. S, Soltani F and Abolpour B (2013), “Study of geosynthetic clay liner layers effect on decreasing soil pollution in the bed of sanitary land fills”, *International Journal of Water Resources and Environmental Engineering*, Vol. 5(8), pp. 452-457

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