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Chapter 1

Introduction

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Human activities create waste, and the disposal of these wastes has been an important issue for human society. The methods of handling, storing, collecting and disposing of these wastes can pose risk to the environment and to public health. In urban areas, especially in rapid urbanizing cities of the developing world, problem and issues of Municipal Solid Waste Management (MSWM) are of immediate importance. Thus the solid waste management practice require reduction of waste at source, recycling them, reuse them and disposal of waste. Landfilling is one of the most common methods used for disposal of waste.

In modern day society collection and disposal of waste to solid waste landfills are essential in order to minimize the risk to public health and safety. Solid waste landfills are regulated differently than hazardous waste landfills, may include a variety of solid, semi-solid, and small quantities of liquid wastes. In general landfills, remain open for years before undergoing closure and post closure phases. A municipal solid waste is a biochemically active unit where toxic substances are leached or created from combinations of non-toxic precursors and gradually released into the surrounding environment over a period of decade's Biological, chemical and physical processes within the landfill promote the degradation of wastes and result in the production of leachate and gases.

. The research and development in this field is to be at low priority in India and also in most of the Asian countries. The landfilling method followed in India is not in keeping with the modern practice of engineered sanitary landfill and waste is largely dumped at site. This dumping is normally carried out in low lying area that is prone to flooding and is often vulnerable to contamination of groundwater.

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1.2 Impacts of Landfill

Landfills are an essential part of everyday living but they may contaminate groundwater as well as surface water. In the United States, plastic liners were used to protect groundwater quality. The quantity and quality of municipal solid waste depends upon various parameters such as population, life style, standard of living, food habit the extent of industrial and commercial activities in the area, cultural tradition of inhabitants and climate.

Landfills cause numerous environmental problems, the main concern related to landfills is contamination of groundwater, or aquifer by leakage or soil contamination. The largest sources of water on our planet is groundwater, over 90% of readily available freshwater is extracted from groundwater. This resources has two differenr funcion function firstly it is definate source of both urban and rural water supply and secondaly it sustains many wetland ecosystem. Landfills also pollutes local roads and water cources from wheels or vechicles when they leave the landfills.

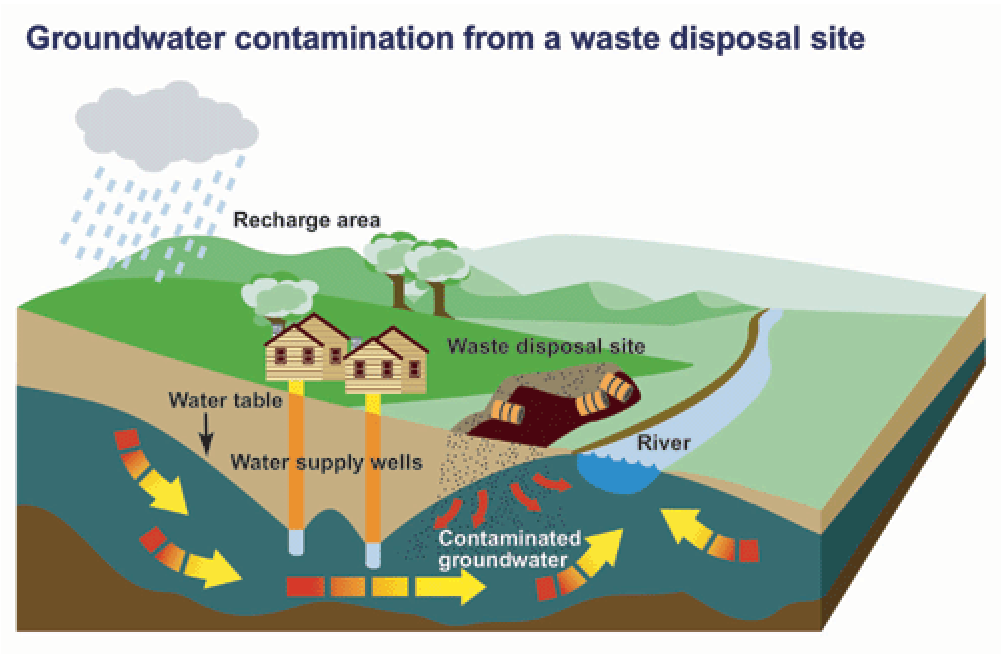

Figure 1.1: Sources of Groundwater Contamination

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The decomposition of organic matter release methane gas into the atmosphere. Methane into the atmosphere methane being a greenhouse gas having more affinity then carbon-di-oxide gas is harmful to environment as well as can be a danger to inhabitants because of its flammable and exposure behaviour. In developing countries landfills are improperly operated resulting to infiltration of pesticides and fertilizers from agricultural waste and leakage of wide range of organic pollutants from industrial waste, pipelines, petrol stations etc. leading to saviour pollution to groundwater.

Other issues due to landfills include injuries to wildlife, find nuisance problems such as vermin, odour, dust, noise pollution, and local property values.

1.3 Controlled landfill design

A sanitary landfill is defined as a system in which municipal solid waste are disposed off, compacted, and covered with a layer of soil at the end of each day's operation. The planning, analysis, and design of modern land disposal system involve the application of a variety of scientific, engineering, and economic principles. Engineering principles are used to circumscribe the wastes to the smallest area, to reduce them to the smallest particle volume, and to cover them after each day's operation and to reduce exposure to vermin. The essential components of a MSW landfill are a liner system at the base and sides of the landfill, a leachate collection and control facility, a gas collection and control facility, a final cover system at the top, a surface water drainage system an environmental monitoring and a closure and post-closure plan for long-term monitoring, operation and maintenance of the complete landfill.

The concepts of contaminant systems for modern sanitary landfills involve the use of barrier layers at the bottom of landfill to prevent leachate from leaving the landfill and contaminating the underlying soil and groundwater, and to prevent water from entering the landfill to create leachate. Barrier layers are constructed of materials that possess a low permeability to water. The most common material includes compacted soil. Natural clay deposits are sometimes used as landfill barrier layers. In most sanitary landfills however, clay liners are constructed by modifying the structure of the clay soil brought to the site by the addition of water and mechanical compaction to achieve optimum engineering characteristics. A number of properties make compacted soil amenable to use as a component

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in a landfill contaminant system. These include mechanical properties such as shear strength but most importantly the permeability of the clay to landfill leachate. Most engineered clay liners must meet requirements for hydraulic conductivity of less than 10^{-7}cm/sec.

1.4 Objectives of Study

Looking to the current practice of municipal solid waste disposal practice being followed in India and the extent of likely impact on groundwater contamination, a study was taken with the focus on identification of groundwater contamination potential of landfill and control measure for the prevention of such contamination. Following were the objective of present study.

1. To develop and validate mathematical model that would address the problem of migration of contaminants from the bottom of landfill.

2. To apply the model developed in this study for the determination of likely impact of Okhla landfill sites at Delhi on the contamination of groundwater in its vicinity.

3. To monitor groundwater in terms of quality of observation wells and utilization of data so obtained in groundwater modelling to study transport of contaminant in landfill.

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Chapter 2

Literature Review

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A landfill site is defined as a tip, dump, rubbish or dumping ground and it is a site for the disposal of waste material by burial. It is one of the oldest methods to treat waste. Previously, landfills were the most common method for the disposal of wastes and may use in many places of the world. Landfills are also used for waste management purposes, such as consolidation and transfer, the temporary storage, or processing of waste material such as sorting, treatment, or recycling.

According to Abu-Rukah and Al-Kofahi, 2001 large quantities of wastes are generated from urban, municipal, and industrial sectors. Landfills served from many decades as ultimate disposal sites for all different types of the wastes. In developing countries these find their way into the environment with little or no treatment. Physical, chemical, and biological processes interact simultaneously to bring about the overall decomposition of the wastes. One of the most common by-product of these mechanisms is chemically laden leachates. As said by Jagloo the most serious environmental problem at landfills is the migration of leachates from the site and the subsequent contamination of groundwater.

In the previous time landfill has the most common tradition for the disposal of municipal solid waste. As the population increase the problem of disposal of waste also increase simultaneously. The design and operation of landfill facilities are essential with respect to aesthetic, safety, and health problems. To minimize the environmental impacts the design, construction and operation of the **Modern landfill sites** or **Engineered landfill sites** are necessary. Production of leachate from landfill sites cause groundwater and surface water pollution. Also the generation of the landfill gas cause adverse health effects, explosive conditions, and global warming. Landfills affect the solid waste disposals and the generated leachate which affect the ground water and pollute the nearby surface water bodies. Some

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Scholar like Poland reported that enhanced degradation of land fill wastes, degrade or immobilize harmful compounds within the waste mass and store excesses leachates.

As said by Lee in 1996, Modern landfills or Engineered sites have liners at the base, these liner act as barriers to leachate migration. However, after the period of time such liners deteriorate and ultimately fail to prevent the movement of leachates into an aquifer and contaminate the groundwater. However, it can take many years before groundwater pollution reveals itself, and chemicals in the leachates often react synergistically and often in unanticipated ways to affect the ecosystem.

2.2 Landfill Leachate

2.2.1 Leachate Generation

The precipitation falling on an active landfill surface causes leachate generation, although other contributors to leachate generation include groundwater inflow, surface water runoff, moisture from emplaced waste, and biological decomposition. The quantity of leachate produced is impacted by the following factors precipitation, type of site, groundwater infiltration, surface water infiltration, waste composition and moisture content, pre-processing of waste (baling or shredding), cover design depth of waste, climate, evaporation, evapotranspiration, gas production, and density of waste. Continuous production of leachate will occur once the absorptive capacity of waste has been satisfied. Leachate quantity is site specific and ranges from zero in arid states to nearly 100 percent of precipitation in wet climates during active landfill operation. Leachate production from new landfills occurs at relatively low rates, and then increases as more waste is placed and larger areas are exposed to precipitation. Leachate production reaches a peak just before closure and then declines significantly with the provision of surface grading and interim or final cover.

According to Jagloo, 2002, there are three important attributes that distinguish any source of groundwater contamination: the degree of localization, the loading history, and the kinds of contaminants released from them. A MSW landfill is a point source of groundwater contamination and produces a well defined plume in many instances. The loading of the landfills site depend upon the concentration of a contaminant or its rate of production with time. The rate of contamination are also controlled by seasonal factors such as climate,

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temperature, humidity, rainfall and by reducing in source strength as components of the waste such as organics, biodegrade.

2.2.2 Leachate Quality

Initial compositions of solid waste, degree of compaction, particles size, hydrology of the site and the age of the tip, all these chemical compositions affect the quality of leachate. The quality of leachate is further affected by several pre-treatment methods or management practices such as the shredding of waste, the separation of recoverable material such as paper, aluminium and glass. The recycling of leachate was back to the landfill, or the co-disposal of municipal wastewater sludge. The estimation of the volume of the leachate and the concentration profile of the main contaminants present is of particular importance for the proper design and operation of sanitary landfills. This knowledge permits the planning of facilities required for the collection and treatment of leachate, including recirculation of leachate back to the landfill. Moreover it would provide an estimate as to the duration of the process of decomposition and the possible life span of the landfill.

Two methods are used to model and predict municipal solid waste leachate composition and volume. The first and simplest method has been to fit empirical equations to contaminant concentration curve given by Raveh and Avnimeleh 1979. The contaminant curve is generally developed as either contamination concentration versus time or cumulative leachate volume per unit mass of refuse. Although these models capture the general decrease from high intial concentrations, they tend to be site-specific, to the particular landfill or lysimeter.

In the second methods, models were developed that quantitatively describe the biological processes occurring during leaching. The model used almost exclusively by several authors was developed originally by Straub and Lynch (1982a). These authors used four process equations to describe the solubilisation of organic matter, the degradation of soluable organic matter and the growth of acidogenic and methanogenic anaerobic biomass. The lysimeter was simulated as a series of fully mixed reactors. They used data from the literature to calibrate the models and derived values for the kinetic coefficients' satisfactory simulation was obtained when the reactor was depicted with four fully mixed compartments in series. In a second paper, Straub and Lynch (1982b) used the theory of unsaturated flow through

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porous media to describe the flow through the lysimeter. The flow equations were solved explicitly. Using the same kinetic parameters calculated previously, these authors found no significant differences between the two models. They concluded that the fully mixed reactor assumption offered a good simplification for the simulation of the decomposition processes in lysimeter.

2.2.3 Leachate Quantity

Determination of expected quantity of leachate generated is essential to the design of Leachate Collection and Removal (LCRS) System. The total quantity of leachate generated at the given waste contaminant system is primarily a function of the quantity of water infiltrated into the system and the quantity of fluids generated within the waste. The former is turn in dependent on a number and intensity of climatologic and hydrologic processes, primarily rainfall, runoff and evaporation. Thus, to estimate the quantity of leachate, one needs to conduct a water balance for the entire system. Leachate quantity is estimated by using a simple water balance method. Which used the amount of water enter into the landfill either by precipitation or by other ways like surface water sources. The amount of water infiltrated from the landfill by refuse, intermediate cover, or final cover. The water also evaporated from the surface of landfill and some may transpires through vegetative cover. Due to infiltration the some deficiency of water is obtained in soil storage. This deficiency is given by the difference between the field capacity and existing moisture content. The remaining infiltrated water moves downward and eventually leachate (L).

The water balance methods are based on procedures developed by Thornthwaite (Thornthwaite et al. 1964) in the soil and water conservation field. The work done by him to developed the water balance equation is very useful for many researches in last 50 years. In his study he consider the water balance models of landfills as a “black box,” which require a balance between inflow and outflow of water through the system. The basic water balance equation was given by:

$$L = P - ET - R - \Delta S$$

Where, L= The leakage volume produced

P = Precipitation falling on the surface

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ET = Lose of water due to evapotranspiration

R = Lose of water due to Runoff

ΔS = Change in storage volume

These models are very useful in predicting leachate quantity and aids to the design of landfills. The accuracy of water balance model depends upon the input parameters, such as rainfall, permeability, evapotranspiration, and refuse moisture storage this is estimated by Bagchi 1994. The second approach to predict the flow of landfill is using finite-difference/finite element solution techniques. Many researchers use this difficult approach to predict the flow of landfill leachate through porous media (Korfiatis 1984; Straub and Lynch 1982a, 1982b). The advecion-diffusion equation using finite difference method imply this concept of water balance for evaluation of concentration of landfill leachate. It is one the most widely used method.

2.3 Typical Anatomy of a Sanitary Landfill

The design of a landfill will significantly affect its safety, cost, and effectiveness over the lifetime of the facility. Key items requiring attention in the design are listed in the following sections.

2.3.1 Protective Cover

Protective cover as shown in figure 2.1 consists of cover vegetation (1), top soil (2) and protective cover soil (3). Cover vegetation consist of native grasses and shrubs which are planted and the areas are maintained as open spaces. The vegetation is visually pleasing and prevents erosion of the underlying soils. Top soil helps to support and maintain the growth of vegetation by retaining moisture and providing nutrients. Protective cover soil protects the landfill cap system and provides additional moisture retention to help support the cover vegetation.

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Figure 2.1 Protective Cover of landfill

2.3.2 Composite Cap System

Composite Cap System as shown in figure 2.2 consists of drainage layer (4), geo membrane (5) and compacted clay (6). Drainage layer is a layer of sand or gravel or a thick plastic mesh called geonet which drains excess precipitation from the protective cover soil to enhance stability and help prevent infiltration of water through the landfill cap system. A geotextile fabric, similar in appearance to felt, may be located on top of the drainage layer to provide separation of solid particles from liquid. This prevents clogging of the drainage layer. Geomembrane forms a liner of a thick plastic layer, which prevents excess precipitation from entering the landfill and forming leachate. This layer helps to prevent the escape of landfill gas, thereby reducing odors. Compacted clay is placed over the waste to form a cap when the landfill reaches the permitted height. This layer prevents excess precipitation from entering the landfill and forming leachate and helps to prevent the escape of landfill gas, thereby reducing odors.

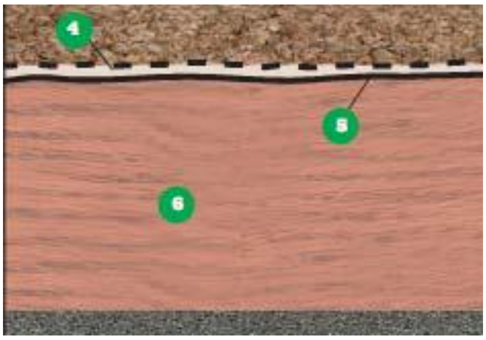

Figure 2.2 Composite Cap System of landfill

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2.3.3 Working Landfill

Working landfill consist of daily cover (7) and waste (8) as shown in figure 2.3. Daily cover is six to twelve inches of soil or other approved material which used to cover waste at the end of each working day. It reduces odors, keeps litter from scattering and helps deter scavengers. Waste is compacted in layers within a small area to reduce the volume consumed within the landfill. This practice also helps to reduce odors, keeps litter from scattering and deters scavengers.

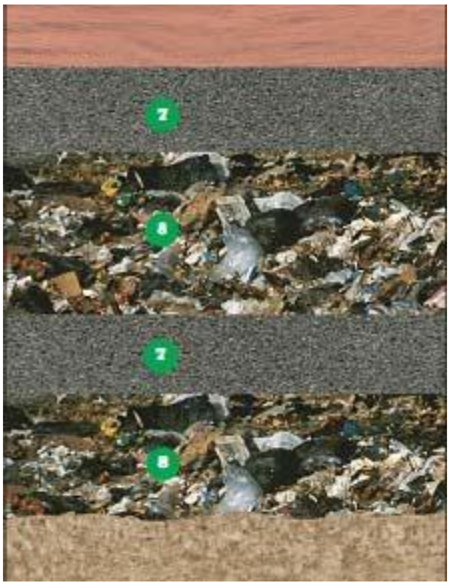

Figure 2.3 Working Landfill

2.3.4 Leachate collection System

Leachate is a liquid that has filtered through the landfill. It consists primarily of precipitation with a small amount coming from the natural decomposition of the waste. The leachate collection system collects the leachate so that it can be removed from the landfill and properly treated or disposed of. The leachate collection system as shown in figure 2.4 consist of leachate collection layer (9), filter geotextile (10) and leachate collection pipe system (11). leachate collection layer is a layer of sand or gravel or a thick plastic mesh called a geonet collects leachate and allows it to drain by gravity to the leachate collection pipe system. Filter geotextile is a fabric, similar in appearance to felt, may be located on top of the leachate collection pipe system to provide separation of solid particles from liquid. This prevents clogging of the pipe system. Leachate collection pipe system consist of perforated pipes,

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surrounded by a bed of gravel, transport collected leachate to specially designed low points called sumps. Pumps, located within the sumps, automatically remove the leachate from the landfill and transport it to the leachate management facilities for treatment or another proper method of disposal..

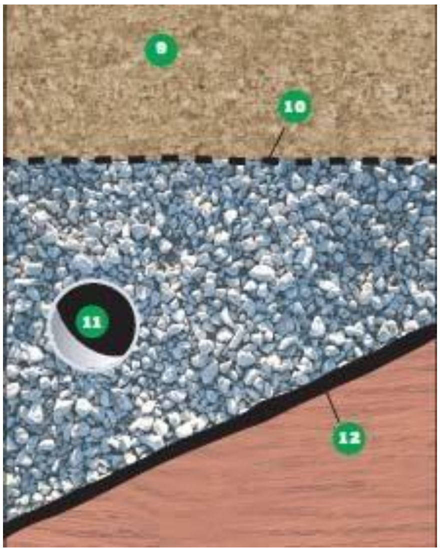

Figure 2.4: Leachate Collection System of landfill

2.3.5 Composite Liner System

Composite liner system consist of geomembranes (12), compated clay (13), and prepared subgrade (14) as shown in figure 2.5. Geomembrane forms a liner made of thick plastic layer, specially made of a special type of plastic called high-density polyethylene or HDPE as HDPE is tough, impermeable and extremely resistant to attack by the compounds that might be in the leachate. This layer also helps to prevent the escape of landfill gas. Compacted clay Is located directly below the geomembrane and forms an additional barrier to prevent leachate from leaving the landfill and entering the environment. This layer also helps to prevent the escape of landfill gas. Prepared subgrade consists of native soils beneath the landfill which are prepared prior to the construction of landfill.

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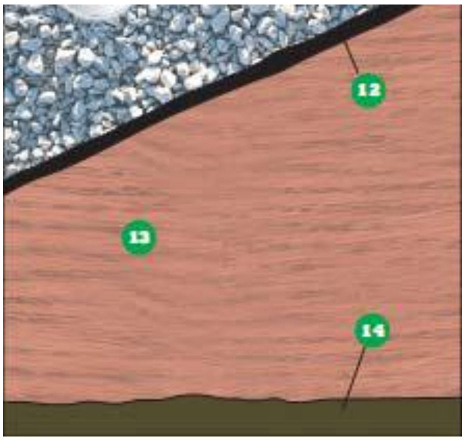

Figure 2.5: Composite Liner System of landfill

2.4 Landfill Types and Liner Systems

Society produces different type of solid wastes that cause different problems to the environment and to community. Different disposal sites are available for the disposal of different type of waste. So for different type of the waste different type of the liner systems are also required. Mainly it may be classified into single or simple, composite, or double liners.

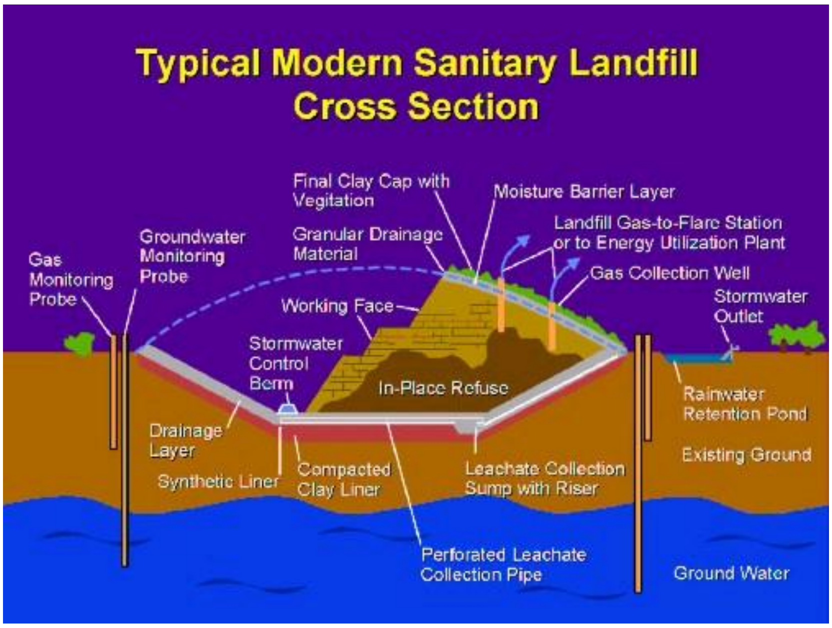

Figure 2.6 Modern landfill

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2.4.1 Single Liner Systems

Single liners as shown in figure 2.7 consist of a clay liner, a geosynthetic clay liner, or a geomembrane especially plastic shitting. Single liners may be used sometimes in landfill design to hold construction and demolition debris. Construction and demolition debris are obtained as a result of building and demolition activities and consist of concrete, shingles, asphalt, bricks, wood, and glass. These landfills do not contain paint, liquid tar, and treated lumber or municipal garbage as waste. Generally single liner systems are usually adequate to protect the environment. It is economical to dispose construction materials in a Construction and demolition debris landfill than in a municipal solid waste landfill because these landfills use only a single liner so it is very easy to build and maintain than other landfills.

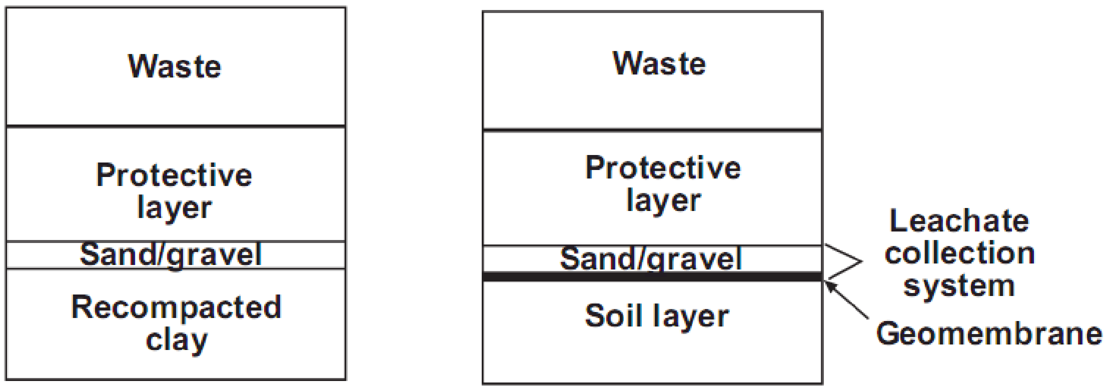

Figure 2.7 Examples of single liner system

2.4.2 Composite Liner Systems

A composite liner is made of geomembrane in combination with a clay liner as shown in figure 2.8. At limiting leachate migration into the subsoil composite-liner systems are more effective than either a clay liner or a single geomembrane layer as said by Hughes in 2008. As Municipal solid waste (MSW) landfills require limiting leachate migration that's why in this type of landfills composite liner system is provided. Municipal solid waste landfills contain waste collected from residential, commercial, and industrial sources. These landfills may also accept Construction and demolition debris, but not hazardous waste. The minimum requirement for the construction of MSW landfills is a composite liner. Frequently, landfill designers and operators will install a double liner system in MSW landfills to provide additional monitoring capabilities for the environment and the community.

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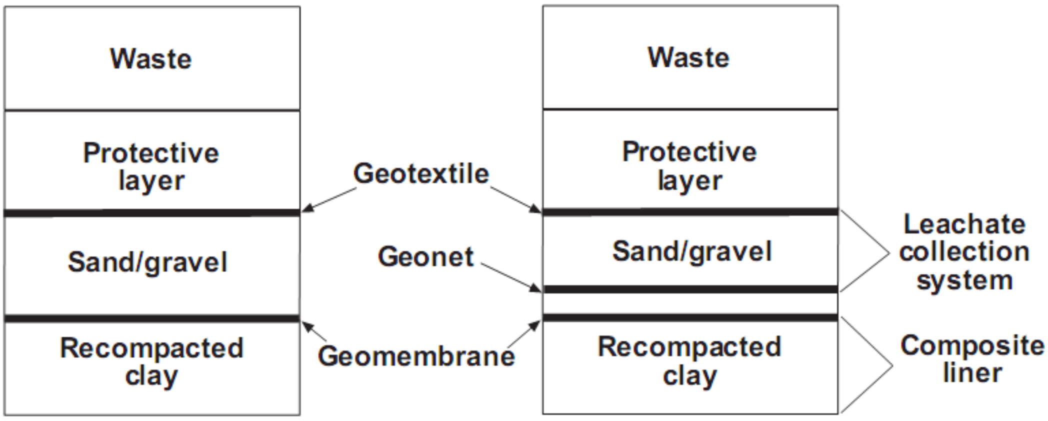

Figure 2.8 Examples of composite liner system

2.4.3 Double Liner Systems

A double liner consists of either two single liners, two composite liners, or a combination of single and a composite liner as shown in figure 2.9. The primary or upper liner usually serve a functions to collect the leachate, while the secondary or lower liner provide a leak-detection system and act as a backup to the primary liner. Double-liner systems are mostly used in hazardous waste landfills. But sometimes it also used in municipal solid waste landfills. Hazardous waste landfills also refer as secure landfills are constructed for the disposal of wastes that become corrosive, reactive, ignitable and toxic. If this type of waste is improperly managed it cause an adverse effect on human health and the environment. Hazardous wastes are produced by commercial, industrial and agricultural activities. These waste must be disposed in hazardous waste landfills. Hazardous waste landfills must have a double liner system with a leachate collection system above the primary composite liner and a leak detection system above the secondary composite liner.

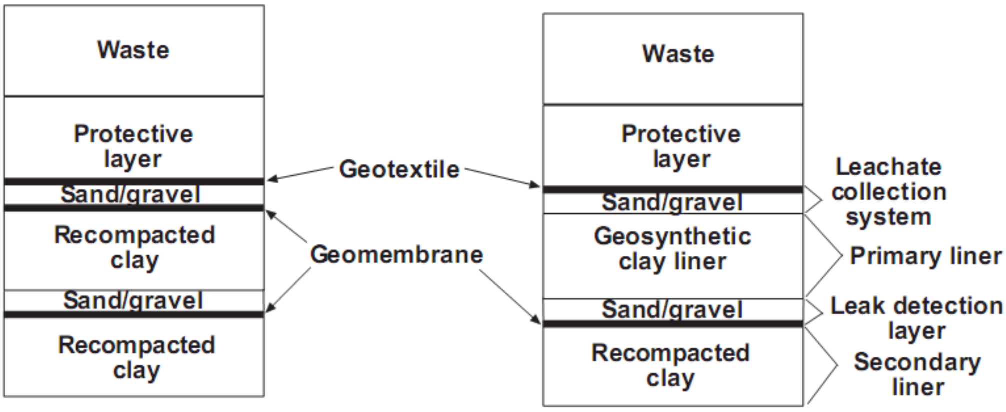

Figure 2.9 Examples of double liner system

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2.5 Migration of landfill Leachate

Gravity cause leachate to move through the landfill, to the bottom and sides, and through the underlying soil until it reaches the groundwater zone or aquifer. Leachate migrated from the bottom of the landfilled waste, which result in contamination of groundwater and soil. As leachate moves down the subsurface, this leachate mixes with groundwater which is held in the soil spaces and this mixture move into the groundwater which make with the contaminated groundwater. The impact of landfill leachate on the contamination of groundwater depends upon various parameters viz. Properties of flow and media through which flow of leachate takes place, and the properties of contaminant, density of waste etc. An exercise to determine the likely impact of leachate migration on groundwater contamination involves taking into account the parameters and process and involved and formulating all those in terms of mathematical model (Kelley 1976).

Review of literature highlights the contributions made by researchers to determine the model parameters like diffusion coefficients in a saturated and unsaturated natural barrier, hydraulic conductivity of barriers and adsorption characteristics for heavy metal removal. The hydraulic conductivity controls the rate of leachate migration this fact is used to design an earthen barrier system. However this assumption now change and recent field studies have indicated that the diffusion is the controlling mechanism of contaminant transport in many fine grained soil (Bagchi 1994)

Rowe (1988) discussed in detail the mechanisms that control the migration of contaminants and the method of modelling the same. How to determine diffusion and distribution coefficients and how to imply the concept of equivalent leachate height into the landfill site is also given by Rowe. These concepts have been used in formulating the model used in this study.

Conca and wright (1990) determine diffusion coefficients of unsaturated gravel and showed that the quartzite gravel had the lowest coefficients. Likewise Rowe and Badv (1996a, 1996b) determined the dispersion and diffusion coefficients of chloride in clayey silt, silt and sand for darcy velocity of the order of 0.018 m/yr. In their study, the effective diffusion coefficient in saturated fine gravel was found to be about 93% greater than that for unsaturated fine gravel. Tests conducted in low velocities encountered in a typical landfill site

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and the modelling results show that there is no significant mechanical dispersion evident in clay, silt or sand under such low flow rate.

Shakelford and Daniel (1991) determined the factors that affect the diffusion in aqueous or free solutions and suggested that diffusive transport is slower in free solution as compared to soils. Later, Shakelford and Redmond (1995) also obtained the hydrodynamic dispersion coefficient in the fine grained barrier material and concluded that the diffusion dominates miscible transport at low flow rates in such barriers. Rowe et al. (1998) obtained diffusion and distribution coefficients in saturated undisturbed clayey soils and validated their theoretical model using data obtained from an experimental study. They determined the diffusion and distribution coefficients of a contaminant using undisturbed clayey soil samples while maintaining a Darcy velocity in the range of 0.025 to 0.035 m/yr. Or less is negligible for clay and diffusion is the dominant mechanism for contaminant treanport through clay for seepage velocity between 0.064 m/yr to 0.09 m/yr.

In 1995 Rowe and Booker considered finite thickness of a single solute in a layer and analysed it by using one dimensional contaminant transport model. They considered the combined effects of advection, dispersion, diffusion, and chemical retardation as the finite quantity of pollutant in the landfill which overly a clay deposits with moving groundwater which is beneath the clay deposits. The model formulated by them also included the effect of clogging of leachate into the collection system by the contamination and mounding of leachate over them.

Similarly some researchers have developed the models (Benson and Daniel 1994a) that predict the minimum thickness of the soil liners using a stochastic approach but they only considered advective flow in saturated soil. Further Benson and Daniel (1994b) discuss some difficulties encountered in the analysis of the soil liners. They suggested that the performance of soil liners depends on the minimum travel time and the magnitude of flux subsequent to the first passage measured using probability theory to incorporate the spatial variations of the hydraulic conductivity properties. They recommended minimum thickness of compacted liners should be 0.6m to 0.9m with respect to spatial variability of hydraulic conductivity.

Munro et al. (1997) investigated the retardation of contaminants in shallow clayey soils and later validated their field studies with analytical models of Sudicky (1988). Sawbrick (1994) gave a comprehensive list of all the processes that place in waste deposits. Also an analytical model to assess the risk of groundwater pollution caused by leaks from

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solid waste depositories was developed by Rudakov and Rudakov (1999). These analytical modelling approaches for design of clay liners are simple to use, but overly conservative, hence one needs numerical solution

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Chapter 3

Study Area

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CHAPTER 3
STUDY AREA

3.1 Introduction

India is the second fastest growing economy and the second most polluted country in the world. The population of India is expected to increase from 1029 million to 1400 million during the period 2001-2026, an increase of 36% in 26 at the rate of 1.2% annually. About 742 million people live in rural areas and 285 million live in urban areas. Generally, the higher the percentage of urban population, the greater is the amount of solid waste produced. In modern days disposal of waste into solid waste landfills are very necessary, because it help in minimizing the risks to public health and safety by collection and disposal of waste material into centralized location. But now risk being recognized as a potential health to both surrounding ecosystem and human populations is due to leachate formation from landfills. (Vikash Talyan et al. 2008).

Approximately 7,000 metric tons of solid wastes are generated by Delhi on a daily basis. So the monthly production of leachate reaches to as high as 81.5 m^3 (Kumar et al., 2002). To disposed of these waste into the landfill presently there are four landfill site in Delhi- Narela-Bawana, Bhalaswa, Ghazipur and Okhla. Out of four three (Bhalsawa, Gazipur, and Okhla) landfill sites are unlined and come under category of non-engineerened landfill sites. The fourth one Narela-Bawana which is the latest landfill site are provided with lining. The leachate generated from the above three landfill sites are percolated and mix with the groundwater as well as surface water because it sometime mixed with the sewer and drainage in low lying areas. So the contamination from these landfill are serious threat to our society. The chances of contamination from Narela-Bawana landfill site are very low because barrier provided at its bottom.

Okhla landfill site which is started in 1994 has presently exhausted over its life span. The site situated in south Delhi near Tugalakabad fort at the top of Aravalli ridge, near the bank of the river Yamuna and it receive the waste coming from Central, Najafgarh, South and

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DCB. The waste received by this site is approximately 1200 tonnes per day. The average depth of the disposal of waste is 9m. The site occupied area of 16.2 ha.

The concern over this landfill site is notified when this area was experienced by shortage of groundwater resource. Because according to rules boring is not permitted without prior special permission of Central Ground Water Authority (CGWA 2000). But in actual practice so many government as well private hand pumps are present in the vicinity of landfill site which include all the houses as well in streets of Prahlad Pur both East and West because of political reasons. The groundwater in monsoon seasons is available at the depth of 10-20 m below the surface, which can be easily contaminated by the leachate coming from the nearby landfill site. And most of people in this region are using this groundwater for domestic purposes as well as drinking purpose. This may cause very serious health hazardous to the people of this area. Although, Delhi Jal Board has maintain a constant supply of water in this area but some people who don't have enough knowledge and they use the water from hand pumps whose life is seriously affected by these contaminated water. Apart from that waste to energy plant started in June 2010 at this site which produces 16MW of electricity.

Figure 3.1: Location of Okhla and other landfill sites in Delhi (adopted from Zafar and Alappat, 2004)

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3.2 Geology of the Area

The groundwater available in the national capital territory is controlled by the hydrological situation which is characterized by alluvial formation and quartzite hard rocks. The groundwater occurrence is mainly depends upon the hydro-geological set up the distinct physiographic units.

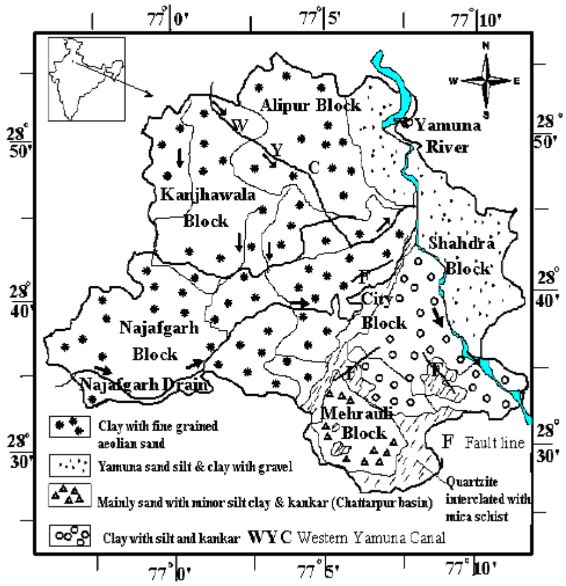

Figure 3.2: Geology of the study area

Table 1: General stratigraphic sequence of the rock formation in Delhi and NCR

	Age Group	Lithology		Hydrological Condition	Groundwater potential
Unconsolidated Formation	Newer Alluvium (Quarternary)	Yamuna sand, slit and clay with gravel		30-40 m thick unconfined to semiconfined aqifers	Very large field 100-280 m^3/hr
	Older Alluvium (Tertiary)	Predominantly clay associated with fined grained aeolian deposits		Fairly thick regional extensive, semi-confined aquifers	Large field prospects 30-100 m^3/hr
		Predominantly clay with slit and kankar		Local, limited thick semi-confined aquifers	Moderate field prospects 23-100 m^3/hr
Consolidated Formation	Delhi super group (PreCambrian)	Mainly sand with minor silt, clay & kankar (chattarpur basin)		Fairly thick regionally extensive aquifers	Low field prospects 10-30 m^3/hr
		Quartzite interclated with mica schist, intruded by pegmatites & quartz veins		Weathered fractured quarzite, highly jointed	Limited field prospects 0-10 m^3/hr

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The Delhi ridge, which is situated at the northernmost extension of Aravalli Mountain, consists of quartzite rocks and extended from southern part of the NCT to western Bank of the river Yamuna for about 35 Km. The Ridge have different nature due to alluvial formation overlaying the quartzite bedrock . The Yamuna flood plain contains a distinct river sediment deposits. The closed Chattarpur alluvial basin occupies an area of about 48 sq. km, occupied by alluvium derived from the adjacent quartzite ridge. The general stratigraphic sequence of the rock formation in the territory is as follows:

3.2.1 Alluvial Deposits

The alluvial deposits are mainly composed of unconsolidated clay silt and sand with different proportions of gravel and kankar etc. The alluvial formation is further divided into two parts the first is consider new alluvium belonging to recent age and refers to the sediment deposited in the flood plains of the Yamuna River. The second are the older alluviums which are the sediments deposited as a result of past cycles of sedimentation of Pleistocene age older alluvium is mainly clayey in nature

3.2.2 Soil Characteristics

The soils of Okhla landfill site are mostly alluvial in origin. The rainfall causes weathering of the soil in the study area. The variation in the type of the soil is due to the change in mineralogy, topography, and drainage pattern. The soils near Okhla landfill site are light grey in colour and sandy loam in texture. These soils are normally alkaline and calcareous in nature.

3.2.3 Hard Rock formation

The hard rock of the Okhla landfill site are pinkish to gray in colour, compact, highly jointed/ fractured and weathered. These occur with inter-beds of mica schist and are available locally by pegmatite and quartz veins. These rocks are available from northeast to southwest with steep dips towards southwest and East except for some local variation due to folding.. Quartzites are ferruginous and gritty types and weathering and subsequent disintegration give rise to coarse sand. The chemical weathering of deeper horizons is also common in Delhi.

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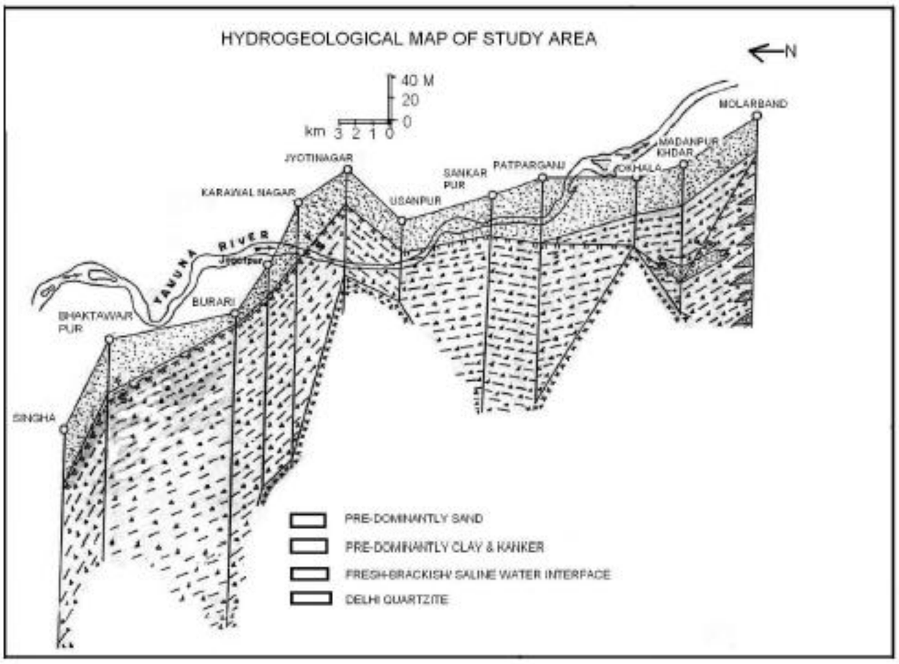

Figure 3.3: Hydro-geological map of study area

3.3 Climatic condition

3.3.1. Rainfall

There are 13 stations in NCT Delhi which records of every day rainfall data they are Chandrawal, New Delhi (Safdarjang), Delhi University, New Delhi (Palam), Okhla, Mehrauli, Delhi Sadar, Nangloi, Shadra, Najafgarh, Badli, Alipur and Narela. The normal annual rainfall in the NCT Delhi is 714 mm. The amount of rainfall is more in northeast as compared to southwest. The maximum amount of rainfall approximately 80 % of annual is received during monsoon season which is started in months of July. The small amount of rainfall is also received in month of January-February which is considered as winter rain or post monsoon. All these monthly rainfall data for 2 years (2012-2013) was collected from Indian Meteorological Department, New Delhi, India. This rainfall data is useful in the study of variation of groundwater quality in the vicinity of the landfill site. Rainfall pay an important role in the generation of leachate from the landfill site. Rainfall data were also used in simulation of solute transport in vicinity of the Okhla landfill because it helps in calculation of recharge in the given study area.

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Table 2: Month wise rainfall data for south Delhi in mm

Year	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec
2012	9.9	0.3	5.4	10.1	1.9	8.7	191.2	292.4	72.4	2.0	1.5	1.1
2013	24.8	73.3	11.3	6.7	0.8	95.1	175.0	166.3	49.3	49	0.0	1.1

The rainfall data obtained from the Indian Meteorological Department was indicated that the most of the rainfall occur in the month of July to August and in rest of month the amount of rainfall is very minimum. Hence, the most of the discharge as well as lechate formation take place in monsoon period.

The rainfall over south Delhi generates surface water runoff through streams, drains and as sheet flow. Considering a runoff, coefficient of 30 % in urban areas and 12 % in other areas, the total surface runoff works out to be 162 mm. The major part-of this runoff generally contributes to Yamuna flow in the mid and downstream part of the river. In 2013 the month of July 175 mm , August 166 mm and September 49 mm reported (Source: IMD, New Delhi).

3.3.2. Evapotranspiration

Evapotranspiration (ET) is defined as the sum of evaporation and transpiration from the surface of the Earth and ocean surface to the atmosphere. The evapotranspiration is very important parameter for study of space and time variation of groundwater quality and simulation of solute transport phenomenon. Evapotranspiration daily data were collected from Indian Meteorological Department, New Delhi, India. The Pan method which is mostly used in India was used for collection of evapotranspiration data. The evapotranspiration data indicate that maximum evaporation takes place during pre-monsoon period in month of June-July because the temperature and humidity during this period is very high. These evapotranspiration data were quite useful for simulation of solute transport and study of groundwater quality in vicinity of the Okhla landfill in Delhi.

3.3.3. Temperature

Temperature data for last 10 years was collected from Indian Meteorological Department, on daily basis. The study of change in temperature or climate change is very important to determine the impact of groundwater contamination in the vicinity of the landfill site. As we

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know India is a tropical country and the change in temperature causes serious impact on number of hydrological parameters like evapotranspiration, humidity, discharge, infiltration and recharge etc. These data was also very useful in simulation of solute transport in the vicinity of the landfill. The climate of NCT Delhi was very extreme. It is very hot in summer (April - July) and very cold in winter (December - January). The average temperature can vary from 25℃ to 45℃ during the summer and 22℃ to 5℃ during the winter.

3.3.4. Humidity

Humidity also affect the hydrological parameters. The humidity data is also collected from the Indian Meteorological Department, New Delhi, India on daily basis. To determine the impact on groundwater quality, it is very essential to know humidity of the study area. High humidity is recorded during the month of July-August, while in the other months humidity is very normal as in a tropical country.

Figure 3.4: The landfill at Okhla has taken the shape of a giant hill of trash

(Sources: Mail today)

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Chapter 4

Contaminant Transport Model for Landfill

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CHAPTER 4

CONTAMINANT TRANSPORT MODEL FOR LANDFILL

4.1 Introduction

Amongst all hydrological and environmental problems the most typical one is ground water contamination. Waste material is to be placed in engineered landfill as ground water contamination can take place due to landfill leachate. In order to design engineered landfill environmental engineers have to refer mathematical models proposed for the landfill. The general model of the ground water layer include various hydrogeological process as contaminant transport, mechanical dispersion, molecular diffusion, sorption, chemical reactions, etc. the time behaviour of a contaminated ground water layer is to be predicted for practical situation. Realistic data for mathematical model is to be analysed using realistic results. Various soil parameters (porosity, dispersivities, sorption, coefficients etc.) are to be used in the model.

The assumption made depend upon the information of the current practice play very important role in mathematical modelling. There are four aspects of any attempt to make quantitative predictions, the need to identify the controlling mechanisms, formulate or select the theoretical model, determines the relevant parameters, solve the governing equation. When dealing with contaminant transport through saturated clayey landfill liners the primary transport mechanism are advection and diffusion/dispersion.

4.2 Mechanisms of contaminant transport

When the leachate drifts over the top of liner, the leachate from landfill tends to migrate to the bottom of the aquifer carrying away with contaminant leached. There are various mechanism which account for the migration of leachate contaminant from landfill into barrier.

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4.2.1 Advection

These motions are associated with mean flow or currents, such as rivers, streams, or tidal motions. They are normally driven by gravity or pressure forces and are usually thought of as primarily horizontal motion. The term advection refers to the transport of something from one region to another. The leachate moves down into a soil which carries contaminant along with it, thus when dealing with the contaminant in leachate the mass of the contaminant transported by advection per unit area per unit time is given by

$$f_a = n\, v_a\, c \qquad (1)$$

where, f_a = Advective mass flux

n = Effective porosity

v_a = Advective Velocity

c = Concentration of contaminant at particular point and time

Then total mass transported from landfill is defined as the product of mass flux and area. So, mass transported by landfill due to advection is given by :

$$M_a = A \int_0^t f_a \, d\tau \qquad (2)$$

where, M_a = Mass transported by landfill due to advection

A = Area of landfill

τ = Tortuosity

Substituting value of f_a from equation (1) the equation of total mass transported becomes

$$M_a = A \int_0^t n v_a c \, d\tau \qquad (3)$$

As we know solute must travel a tortuous path or having many turns so in order to calculate the total flux or total mass transported integrate the equation with respect to τ.

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4.2.2 Diffusion

The process whereby particles of liquids, gases, or solids intermingle as the result of their spontaneous movement caused by thermal agitation and in dissolved substances move from a region of higher to one of lower concentration. There are mainly two types of diffusion processes

4.2.2.1 Molecular diffusion

Molecules of fluid are normally in a random motion, relative to other molecules (Brownian motion) and this lead to a mixing or spreading of fluid particles.

4.2.2.2 Turbulent diffusion

This is the type of mixing similar to molecular diffusion but with much stronger effect. Mixing in this case derives from the larger scale movement of packets of fluid by turbulent eddies. In case of landfill the leachate moves under concentration gradient. So diffusion flux in one dimension is given by

$$f_d = - n\, D_e \frac{\partial c}{\partial x} \qquad (4)$$

Where f_d = Diffusion flux

D_e = Effective molecular diffusion

$\frac{\partial c}{\partial x}$ = Change in concentration in x direction

The negative sign indicates that the transfer of contaminant takes place from higher to lower concentration (with the increase in distance the concentration decrease as we more far from leachate). So the total mass of the contaminant, transport through landfill by diffusion is obtained by integrating the equation (4) :

$$M_d = A \int_0^t \left(-nDe \frac{\partial c}{\partial x}\right) d\tau \qquad (5)$$

Where, M_d = Mass transported by landfill due to diffusion

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4.2.3 Dispersion

The term dispersion is often used interchangeably with term diffusion since both the terms refers to process that tend to spread a fluid property relative to mean transport. Dispersion flux is given by equation :

$$f_{md} = -\, n\, D_{md}\, \frac{\partial c}{\partial x} \tag{6}$$

$D_{md} = \alpha\, v_a$ (Mechanical dispersion or dispersion coefficient)

α = longitudinal dispersivity

But in mathematical modelling these two process lumped together to form a composite parameter, which is denoted by D_h called hydrodynamic dispersion coefficient. Which is given by summing these two coefficient i.e. $D_h = D_e + D_{md}$. (Hydrodynamic dispersion coefficient = effective molecular diffusion + mechanical dispersion) In clayey soil diffusion will usually control parameter than dispersion or diffusion can be important in vapour transport in unsaturated zone. In aquifer or saturated ground water flow dispersion is an important factor which dominant diffusion. Equation (2) can be written as

$$M_{md} = A \int_0^t \left(-n\, D_{md}\, \frac{\partial c}{\partial x}\right) d\tau \tag{7}$$

M_{md} = Mass transported by landfill due to mechanical dispersion

4.2.4 Sorption

It is a physical and chemical process by which one substance becomes attached to another. Specific cases of sorption are treated in the following articles:

- Absorption - The incorporation of a substance in one state into another of a different state. (e.g. liquids being absorbed by a solid or gases being absorbed by a liquid)
- Adsorption - The physical adherence or bonding of ions and molecules onto the surface of another phase (e.g. reagents adsorbed to a solid catalyst surface)

When leachate moves downward some part of contaminant is absorbed by the barrier or liner which is provided at bottom of landfill.

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4.2.4.1 Contaminant transport as linear sorption

Mass of contaminant removed from solution S, is proportional to the concentration c in solution

$$S \propto c$$

$$S = K_d \, c \qquad (8)$$

where K_d = Partitioning or distribution coefficient

S = Mass of contaminant absorbed by liner

c = equilibrium concentration of solute

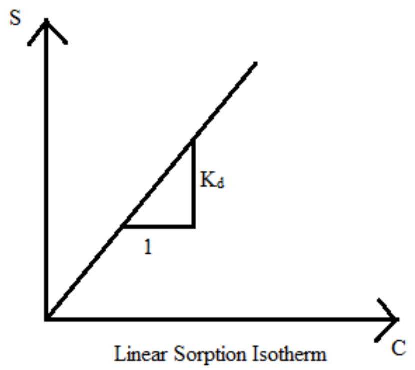

Figure 4.1: Linear sorption isotherm

And rate of mass absorption on solid phase is represented by equation

$$r = \rho_d \frac{\partial S}{\partial t} \qquad (9)$$

So considering the conservation of mass it is deduced that the increase in contaminant concentration within smaller region can be calculated from addition of increase in mass due to advective diffusion and decrease in mass due to sorption, which is given by equation :

$$n \frac{\partial c}{\partial t} = -\frac{\partial f}{\partial x} - \rho_d \frac{\partial S}{\partial t} \qquad (10)$$

where, f is the total mass flux which is the summation of flux due to advection, diffusion and dispersion, given by equation :

$$f = f_a + f_d + f_{md} \qquad (11)$$

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Substituting the values of advective, diffusive and dispersive flux from equation 1, 4 and 6, respectively the equation 11 becomes:

$$f = n\, v_a c - n\, D_e \frac{\partial c}{\partial x} - n\, D_{md} \frac{\partial c}{\partial x} \tag{12}$$

$$f = n\, v_a c - n \frac{\partial C}{\partial x} (D_e + D_{md})$$

$$f = n\, v_a c - n\, D_h \frac{\partial c}{\partial x} \tag{13}$$

where, $D_h = D_e + D_{md}$

D_h = hydrodynamic dispersion coefficient

Substituting value of f from equation (13) the equation (10) becomes:

$$n \frac{\partial c}{\partial t} = - \frac{\partial}{\partial x} \left(n\, v_a c - n\, D_h \frac{\partial c}{\partial x}\right) - \rho_d \frac{\partial}{\partial t} (K_d c)$$

$$n \frac{\partial c}{\partial t} = n\, D_h \frac{\partial^2 c}{\partial x} - n\, v_a \frac{\partial c}{\partial x} - \rho_d K_d \frac{\partial c}{\partial t} \tag{14}$$

$$\frac{\partial C}{\partial t} = D_h \frac{\partial^2 C}{\partial x} - v_a \frac{\partial c}{\partial x} - (R - 1) \frac{\partial c}{\partial t} \tag{15}$$

where, R = Retardation coefficient

$$R = 1 + \frac{\rho_d K_d}{n}$$

ρ_d = Dry density

Solving equation (15), we get:

$$\frac{\partial c}{\partial t} = \frac{D_h}{R} \frac{\partial^2 c}{\partial x} - \frac{v_a}{R} \frac{\partial c}{\partial x} \tag{16}$$

4.2.4.2 Contaminant transport as nonlinear sorption

At high concentration, sorption process is nonlinear and the two commonly used sorption isotherms are Langmuir and freundlich isotherms.

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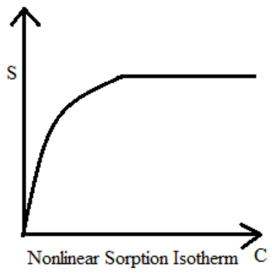

Figure 4.2: Nonlinear sorption isotherm

According to freundlich isotherm, the mass absorbed by the dry liner can be calculatee as:

$$S = K_f c^b \tag{17}$$

where, b and K_f are the material constants for the soil- solute system.

Now, substituting the value of S from equation (17) and f from equation (13) in equation (10), we get:

$$n \frac{\partial c}{\partial t} = -\frac{\partial f}{\partial x} - \rho_d \frac{\partial S}{\partial t}$$

$$n \frac{\partial c}{\partial t} = -\frac{\partial}{\partial x}\left(n\, v_a\, c - n\, D_h \frac{\partial c}{\partial x}\right) - \rho_d \frac{\partial}{\partial t}\left(K_f\, c^b\right)$$

$$\frac{\partial c}{\partial t} = D_h \frac{\partial^2 c}{\partial x} - v_a \frac{\partial c}{\partial x} - \frac{\rho_d\, K_f\, C^{b-1}\, b}{n} \frac{\partial c}{\partial t} \tag{18}$$

$$\frac{\partial c}{\partial t} = D_h \frac{\partial^2 c}{\partial x} - v_a \frac{\partial c}{\partial x} - (R_f - 1) \frac{\partial c}{\partial t} \tag{19}$$

where, R_f = Retardation coefficient for freundlich isotherm

$$R_f = 1 + \frac{\rho_d K_f C^{b-1} b}{n}$$

On solving equation (19), we get:

$$\frac{\partial c}{\partial t} = \frac{D_h}{R_f} \frac{\partial^2 c}{\partial x} - \frac{v_a}{R_f} \frac{\partial c}{\partial x} \tag{20}$$

Equation (20) represents mathematical modelling of contaminant transport using advection dispersion phenomenon for a non-linear sorption isotherm.

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4.3 Boundary Condition

Both boundary condition and initial conditions are needed to obtain solutions to any differential equation, and the advection Diffusion equation is one of them. Boundary condition apply to specific locations in the modelled physical domain, and are usually specified in one of three ways.

1. Specify concentration (e.g. $C = C_0$ at $x = 0$), possibly time dependent. In combination with velocity, this gives advective flux.
2. Specify gradient (also possibly time-dependent), which in combination with the diffusivity, gives diffusive flux.
3. Specify total flux, as a (linear) combination of both diffusive and advective fluxes.

Boundary condition play a very important role in determining the behaviour of a particular solution, and care should be taken in specifying the correct condition for any given problem. This is particularly true when solutions are desired near one of the boundary of the system domain. In some cases, where the numerical solutions are applied it is useful to define additional grids or nodes outside of the actual system being modelled, and to apply the boundary conditions at the limit of these additional grids. That way, the boundary condition itself does not directly affect as strongly the solution at the point of interest. Solve the advection-diffusion equation subject to the following initial and boundary condition.

Initial condition $C\ (x \geq 0, t = 0) = 0$

Boundary condition $C\ (x = 0,\ t \geq 0) = C_0$

Boundary condition $C\ (x = \infty,\ t \geq 0) = 0$

4.4 Numerical solution to the advection diffusion equation

Many authors have written about the basic methodology used in numerical approaches for solving the advection-diffusion equation. Both finite difference and finite element models are possible, though finite difference representations for the derivatives are a much more

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common practice for this equation. Finite differences also are more directly related to bulk segmentation, or box models, common in water quality and mass balance modelling for contaminants in surface water systems.

Finite difference methods are broadly classified as either explicit or implicit. Explicit methods express all derivatives in terms of known values, while implicit method use some of unknown values leading to the need for solving simultaneous equations. In finite difference time and space steps are denoted by Δt and Δx respectively. In the explicit method, the new function values (at time i+1) are all calculated on the basis of values from the previous time step (time i), which are known. Initial conditions must be specified (for i=0) in order to start the process. Programming for explicit method is generally straightforward, but these methods tend to have stability problems. Fully implicit method generally avoid stability problems but may require longer running times. They are based on simultaneous calculation of function values at the new time step.

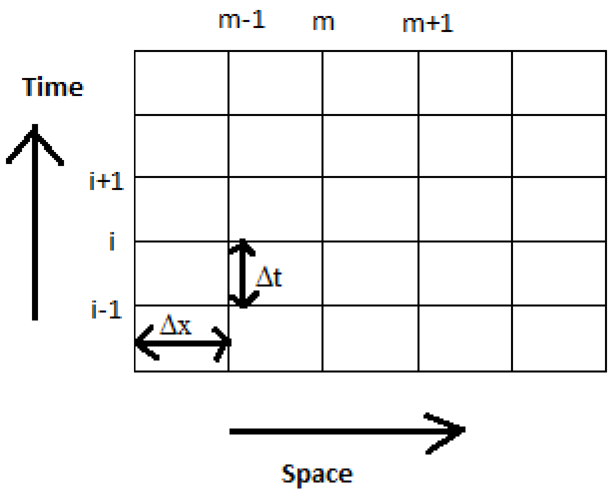

Figure 4.3: Finite Difference computational grid with time and space

4.5 Model Solution

The solution to the contaminant transport model represent by equation (20) subjected to boundary conditions and was implemented using the numerical method, explicit finite

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difference method with or without upwind correction describing the contaminant transport model for landfill include terms representing derivatives of continuous variables. Finite difference method are based on the approximation of these derivatives by discrete linear changes over small discrete intervals of space and time.

General finite difference formulation for the solution to the one dimensional advection-diffusion equation assuming a conservative substance (no reactions) and constant v_a and D_h using a forward difference for the time derivative.

$$\frac{C_i^{m+1}+C_i^m}{\Delta t} = \frac{D_h}{R_f \Delta x^2}\{(1-\omega)\times(C_{i+1}^{m+1} - 2C_i^{m+1} + C_{i+1}^{m+1}) + \omega\times(C_{i+1}^m - 2C_i^m + C_{i-1}^m)\} - \frac{v_a}{R_f \Delta x}\{(1-\omega)$$

$$[\alpha(C_{i+1}^{m+1} - C_i^{m+1}) + (1-\alpha)(C_i^{m+1} - C_{i-1}^{m+1})] + \omega[\alpha(C_{i+1}^m - C_i^m)] + (1-\alpha)(C_i^m - C_{i-1}^m)\} \quad (21)$$

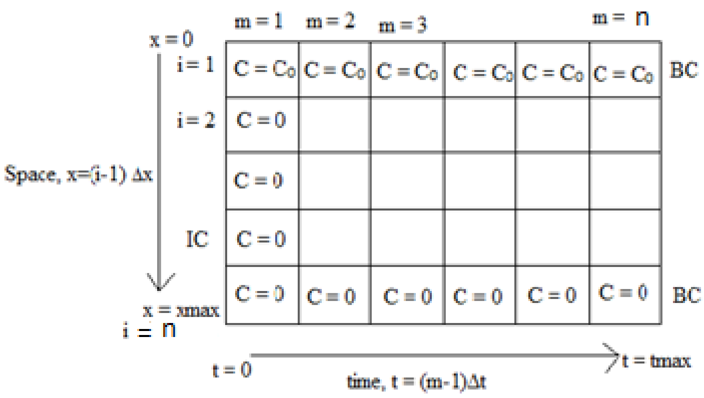

Figure 4.4: Schematic diagram of Finite Difference Method

Where, ω is weighting factor that allows different weighting for implicit and explicit terms, with ω = 1 method is fully explicit.

$$\frac{C_i^{m+1}+C_i^m}{\Delta t} = \frac{D_h}{R_f \Delta x^2}(C_{i+1}^m - 2C_i^m + C_{i-1}^m) - \frac{v_a}{R_f \Delta x}\{[\alpha(C_{i+1}^m - C_i^m)] + (1-\alpha)(C_i^m - C_{i-1}^m)\} \quad (22)$$

Where, α is the weighting factor for first spatial derivative. For backward difference α = 0 and for central difference $\alpha = \frac{1}{2}$

Substituting, $\alpha = \frac{1}{2}$ in equation(22) and on solving we get:

$$\frac{C_i^{m+1}+C_i^m}{\Delta t} = \frac{D_h}{R_f \Delta x^2}(C_{i+1}^m - 2C_i^m + C_{i-1}^m) - \frac{v_a}{R_f \Delta x} \times \frac{1}{2}(C_{i+1}^m - C_{i-1}^m) \quad (23)$$

Multiplying all the terms by Δt in equation (23) and solving, we get:

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$$C_i^{m+1} = C_i^m - \frac{v_a \Delta t}{R_f \Delta x} \times \frac{1}{2}(C_{i+1}^m - C_{i-1}^m) + \frac{D_h \Delta t}{R_f \Delta x^2}(C_{i+1}^m - 2C_i^m + C_{i-1}^m)$$

$$C_i^{m+1} = C_i^m - K_1 \times (C_{i+1}^m - C_{i-1}^m) + K_2 \times (C_{i+1}^m - 2C_i^m + C_{i-1}^m)$$

$$C_i^{m+1} = C_i^m \times (1\text{-}2K_2) - C_{i+1}^m \times (K_1 - K_2) + C_{i-1}^m \times (K_1 + K_2) \tag{24}$$

Where, $K_1 = \frac{1}{2} \times \frac{v_a \Delta t}{R_f \Delta x}$, $K_2 = \frac{D_h \Delta t}{R_f \Delta x^2}$

The equation (24) is the solution for explicit finite difference solution without upwind correction.

For upwind correction the central difference is changed with backward difference in equation (23), we obtain:

$$\frac{C_i^{m+1} + C_i^m}{\Delta t} = \frac{D_h}{R_f \Delta x^2}(C_{i+1}^m - 2C_i^m + C_{i-1}^m) - \frac{v_a}{R_f \Delta x} \times \frac{1}{2}(C_i^m - C_{i-1}^m) \tag{25}$$

By solving the equation (25) as above, equation becomes:

$$C_i^{m+1} = C_i^m \times (1\text{-}2K_1\text{-}2K_2) + C_{i+1}^m \times K_2 + C_{i-1}^m \times (2K_1 + K_2) \tag{26}$$

The equation (26) represents the advection-dispersion model with ‘upwind’ correction.

Under condition of space Δx and time step Δt is the explicit 1-D finite method stable. The accuracy of explicit formulation is 0, (Δt, Δx^2) and for 1-D method it is numerically stable (stable means that the solution remain bonded) so long as the following stability criterion is met.

$$\frac{D_h \Delta t}{R_f \Delta x^2} + \frac{1}{2} \times \frac{v_a \Delta t}{R_f \Delta x} \leq \frac{1}{2}$$

Thus entire domain divided into m_n= T/Δt, and i_n = Z/Δx. Initial and boundary conditions are considered by keeping C_i^m at beginning of solution zero everywhere so,

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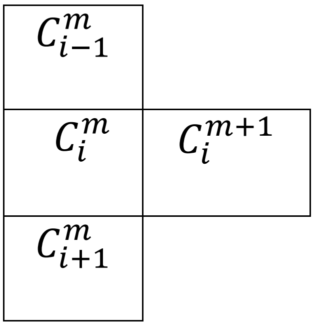

Figure 4.5: Finite Difference Method Node

$$C_i^2 = C_i^3 = C_i^4 = C_i^5 = C_i^6 = C_i^7 = C_i^8 \ldots\ldots\ldots\ldots\ldots\ C_i^{m_n}$$

$$C_1^m = C_2^m = C_3^m = C_4^m = C_5^m = C_6^m = C_8^m \ldots\ldots\ldots\ldots\ldots\ C_{i_n}^m$$

substituting i = 1, m = 1 in equation (26), we get:

$$C_1^2 = C_1^1 \times (1\text{-}2K_1\text{-}2K_2) + C_2^1 \times K_2 + C_0^1 \times (2K_1+K_2)$$

At the next time step, the solution is marched from i = 2 to (n-1) such that the equation becomes

$$C_2^2 = C_2^1 \times (1\text{-}2K_1\text{-}2K_2) + C_3^1 \times K_2 + C_1^1 \times (2K_1+K_2)$$

$$C_3^2 = C_3^1 \times (1\text{-}2K_1\text{-}2K_2) + C_4^1 \times K_2 + C_2^1 \times (2K_1+K_2)$$

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$$C_{i_{n-1}}^1 = C_{i_{n-1}}^1 \times (1\text{-}2K_1\text{-}2K_2) + C_{i_n}^1 \times K_2 + C_{i_{n-2}}^2 \times (2K_1+K_2) \quad (27)$$

Similarly, for the next cycle of time step, one would write the equation as,

Now, i = 2, m = 2

$$C_2^3 = C_2^2 \times (1\text{-}2K_1\text{-}2K_2) + C_3^2 \times K_2 + C_1^2 \times (2K_1+K_2)$$

$$C_3^3 = C_3^2 \times (1\text{-}2K_1\text{-}2K_2) + C_4^2 \times K_2 + C_2^2 \times (2K_1+K_2)$$

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$$C_{i_{n-1}}^{3} = C_{i_{n-1}}^{2} \times (1\text{-}2K_1\text{-}2K_2) + C_{i_n}^{2} \times K_2 + C_{i_{n-2}}^{2} \times (2K_1+K_2) \quad (28)$$

Similarly, for the last cycle of time step, one would write the equation as,

$$C_{2}^{m_n} = C_{2}^{m_{n-1}} \times (1\text{-}2K_1\text{-}2K_2) + C_{3}^{m_{n-1}} \times K_2 + C_{1}^{m_{n-1}} \times (2K_1+K_2)$$

$$C_{3}^{m_n} = C_{3}^{m_{n-1}} \times (1\text{-}2K_1\text{-}2K_2) + C_{4}^{m_{n-1}} \times K_2 + C_{2}^{m_{n-1}} \times (2K_1+K_2)$$

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$$C_{i_{n-1}}^{m_n} = C_{i_{n-1}}^{m_{n-1}} \times (1\text{-}2K_1\text{-}2K_2) + C_{i_n}^{m_{n-1}} \times K_2 + C_{i_{n-2}}^{m_{n-1}} \times (2K_1+K_2) \quad (29)$$

This is the solution of the model which result a matrix that provide spatial and temporal variation of concentration of contaminant below landfill.

4.6 Validation of Model

Model developed in this study was tested for two parameters of field data (T.L.T. Zhan et al. 2014) for an uncontrolled landfill at Huainan, China. Field data from this site was adopted to use to validate the numerical model. The field profile of chloride in the media was compared with the numerical model developed in the study. The results obtained by the mathematical model assuming pure diffusion. The advection and dispersion was not considered in this case. The migration depth of chloride was less than 3mwhen assuming pure diffusion. It is obvious that this assumption underestimate the migration depth of chloride. Advection and dispersion may be the main mechanisms controlling chloride migration in the underlying soils in this site since the observed migration depth is over 7m. Because chloride is an inherently stable and non-degradable conservative solute a retardation factor of 1.0 was used when modelling the migration of chloride in the leachate (Munro et al., 1997; Rowe et al., 2004). Orders of magnitude between 0.003 and 0.03 m^2/s were used for the effective diffusion coefficients to evaluate the measured chloride profiles at the different scales (Kugler et al., 2002; Smith et al., 2004; Cuevas et al., 2012). The effective diffusion coefficients of chloride for the three soil layers (i.e., plowed earth, silty clay and old clay) were assumed to be 0.02, 0.018 and

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0.024 m^2/yr, respectively. Longitudinal dispersivity has been frequently shown to increase with the scale of measurement, owing to many independent processes, including advection, local dispersion and diffusion, the nonstationary nature of hydraulic conductivity fields, and sampling bias (Schulze-Makuch, 2005). Longitudinal dispersivity can vary from 0.06m to over 100m for different types of geological media (Schulze-Makuch, 2005). Munro et al. (1997) indicated that the dispersivity of the clay is in the range of 0.05–0.14m based on the contaminant migration distance of 2 to 4 m. According to Gelhar et al. (1992), the dispersivity of the soils here could be assumed to be one tenth of the vertical thickness of the soils. It is very difficult to use a single predicted concentration profiles to fit the observed chloride concentration profiles when using the advection–dispersion models. This is due to the scatter natural of the data. Two values of the Darcy velocity of the soils were adopted to make the observed data fall into the predicted profiles The Darcy velocity is in the range of 0.015 m/yr, 0.105 m/yr. The low hydraulic conductivity of the soils suggests that the migration process may be dominated by diffusion. In this study, the obtained hydraulic conductivity of the soil was 0.10 m/yr, 4.73 m/yr and the Darcy velocity was 0.015 m/yr, 0.105 m/yr. Advection and mechanical dispersion are thus important for the contaminant migration through the soils.

Table 3: Model parameters for chloride (T.L.T. Zhan et al. 2014)

S.No.	Model Parameter	Unit	Value
1	Depth	m	7
2	Effective molecular diffusion coefficient	m^2/yr	0.023
3	Porosity		0.40
4	Retardation factor		1.0
5	Advective velocity	m/yr	0.04
6	Dispersivity	m	0.05

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Table 4: Simulated and observed chloride concentration (17 years)

Depth (m)	Observed chloride concentration (mg/l)	Simulated chloride concentration (mg/l)
0.5	2528	2358
1.0	2253	1817
2.0	1209	1365
3.0	659	1146
4.0	604	1010
5.0	549	914
6.0	425	843
7.0	502	786
8.0	457	738
9.0	412	697

The possible uncertainties in the chloride source function, comparison of the field data and numerical results were considered to be good if the model simulation fit the declining concentrations in the top 2-3 m of the profile. For greater depths, their model results did not agree with the observed data and the sharp localized concentration changes identified beyond 3 m were attributed to the variations in the source concentration within the landfill and due to unidentified changes in local geochemistry. The simulated concentration of chloride with respect to depth is shown in figure 4.6

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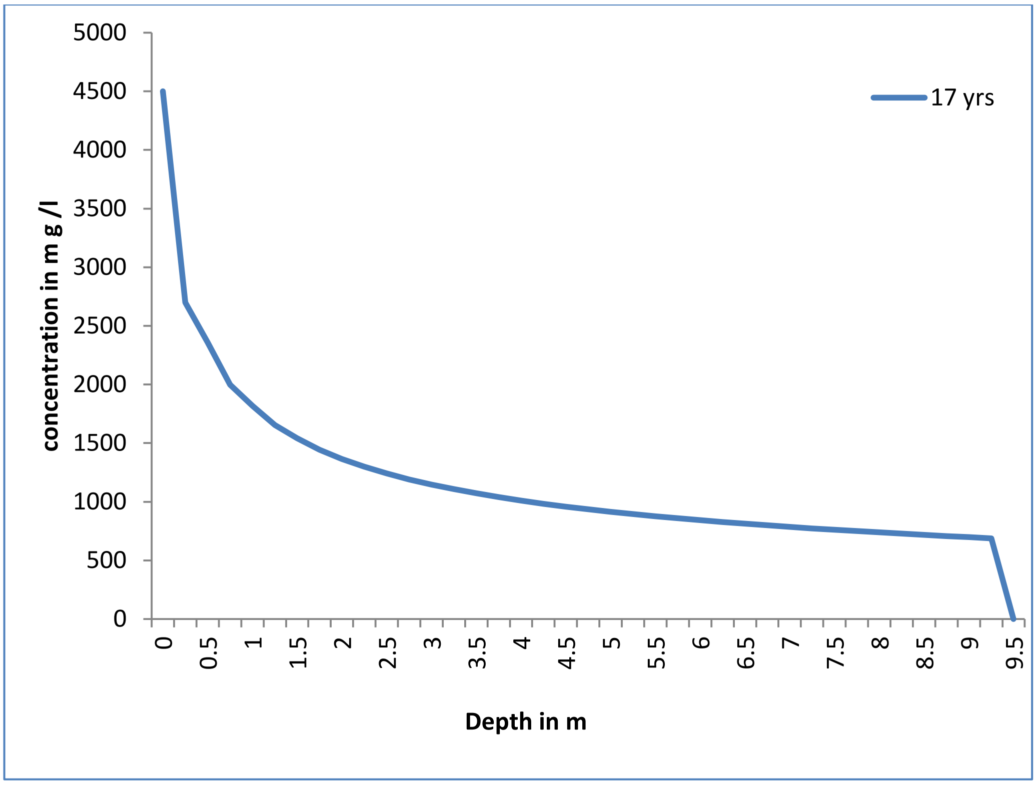

Figure 4.6: Results of chloride concentration using the numerical model of diffusion and advection

The effective diffusion coefficient of sodium for the soils was assumed to be 0.025 m^2/yr on the basis of the published data provided by Rowe et al. (2004). The retardation factor of the soils was assumed to be 1.5. This value is in the range of the published data (i.e., 1–5) provided by Rowe et al. (2004). The predicted migration depth of sodium assuming pure diffusion was about 2m. This value also underestimate the observed migration depth (i.e., about 4 m). The observed data fall into the range of the predicted curves using the advection–dispersion model. However, it is also difficult to obtain a well-fitted curve using the advection–dispersion model. The source concentrations of sodium, i.e., 5500 mg/L were used in the simulations.

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Table 5: Model parameters for Sodium ion (T.L.T. Zhan et al. 2014)

S.No.	Model Parameter	Unit	Value
1	Depth	m	4
2	Effective molecular diffusion coefficient	m^2/yr	0.025
3	Porosity		0.40
4	Retardation factor		1.5
5	Advective velocity	m/yr	0.275
6	Dispersivity	m	0.14

Table 6: Simulated and observed sodium concentration (17 years)

Depth (m)	Observed chloride concentration (mg/l)	Simulated chloride concentration (mg/l)
0.5	2803	2915
1.0	2441	2265
2.0	2441	1726
3.0	1265	1446
4.0	1305	1304
5.0	1185	1191
6.0	1157	1106
7.0	1129	1038
8.0	1156	981
9.0	1074	931

The results of simulations was obtained for this case are compared with the observed field data. Simulated results match well with the observed values. The uncertainties in the sodium source function, is quite less as compared to chloride at the depths up to 9m. The simulated concentration of sodium with respect to depth is shown in figure 4.7

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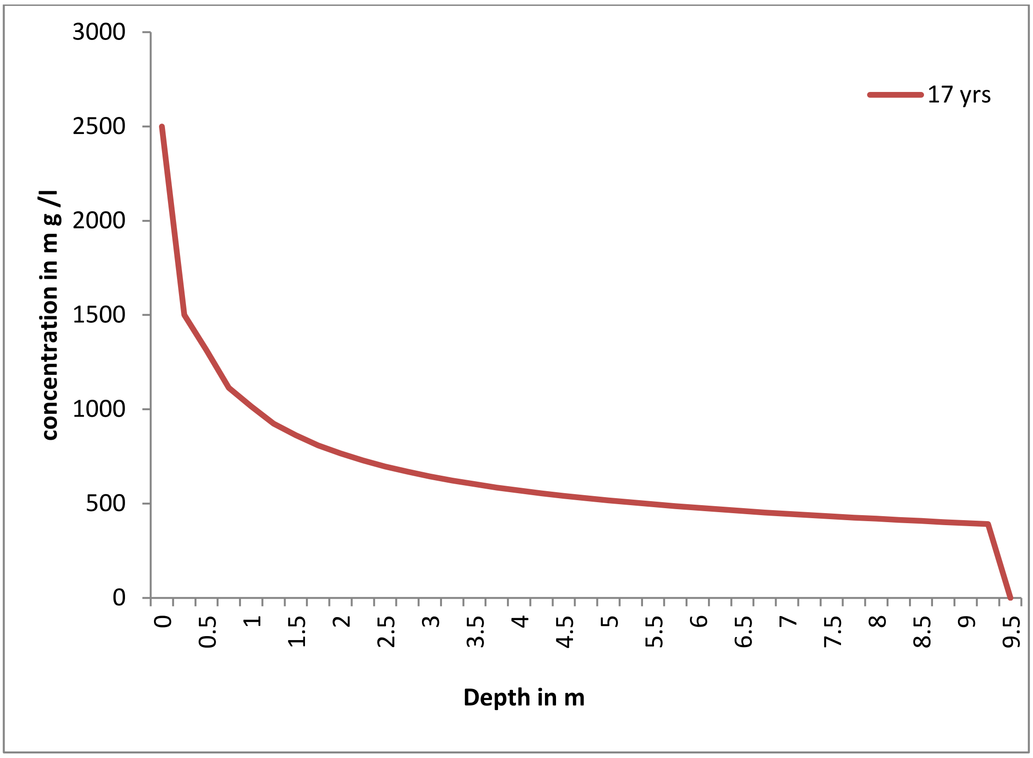

Figure 4.7: Results of sodium concentration using the numerical model of diffusion and advection

4.7 Advantages of Present Model

The model developed in this study has several advantages over the existing software available. These advantages are as under:

1. The use of public domain software is not advisable for the determination of transport from landfills, as the problem are expected due to variations in mass transport that may occur because of variations in landfill operations; also the migration of contaminant through landfill barrier is quite different from contaminant migration in aquifers.

2. For the determination of contaminant transport from landfill, special boundary conditions, i.e. finite mass boundary condition, a thin layer of secondary leachate

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system and variation of concentration due to infiltration of water needs to be incorporated, and such facilities do not exists in software available in public domain. The data preparation of general purpose solute transport model is tedious process for the case of landfill.

3. The analytical solution available in public domain can be used only when the boundary concentration is a constant concentration condition. Also, it is assumed in the analytical solution that the natural clay barrier the landfill is of infinite depth. The analytic solution could give erroneous results if used for the case of finite thickness of the barrier.

4.8 Limitations of Present Model

Limitations of model developed in this study are due to the following assumptions made in the formulation of model.

1. Advection and diffusion/dispersion are considered as the primary transport mechanism considered for the development of model. The density effect have been assumed to be insignificant, thus the migration of concentrated light or dense non aqueous phase contaminant is not considered.

2. There is no chemical reaction between migrating chemical species.

3. The medium is assumed to be saturated since the water content used in compacted liners is on the west side of the optimum water content value, very close to saturation water content.

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Chapter 5

Result and Discussion

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CHAPTER 5

RESULT AND DISCUSSION

The model developed in this study was applied to determine the likely impact of migration of landfill leachate on the groundwater quality in its vicinity of actual landfill site for key quality parameters. The landfill site selected for the application of the model was Okhla landfill located in Delhi. The methodology for the application of model consisted of collection and analysis of samples of landfill laechate and groundwater for key water quality parameters in the areas surrounding of Okhla landfill. Suitable values of model parameters were adopted taking into account the subsurface geography of the region.

5.1 Characteristics of leachate and ground water near landfill site

Study conducted to determine the impact of solid waste disposal at Okhla landfill site in New Delhi has revealed that the ground water is being contaminated due to chloride and heavy metals in leachate. The ground water sample collected at radial distance from the landfill shown in table below.

Table 7: Analysis of Landfill Leachate and Groundwater Samples

Parameter	Concentration in landfill leachate (mg/l)	Concentration in ground water at radial distance from landfill (mg/l)				
		120 m	180 m	240 m	500 m	1000 m
Chloride	3998.7	1010	744.72	479.85	399.87	389.87
Iron	4.13	2.139	1.436	1.410	1.123	0.921
Zinc	4.441	2.778	2.444	2.293	2.029	0.590
Nickel	0.3248	0.060	0.059	0.052	0.049	0.042
Copper	0.609	0.09	0.079	0.048	0.39	0.31

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For the purpose of application and validation of contaminant transport model developed in this study, the likely impact of leachate migration from Okhla landfill site was determine by carrying out the simulation of model and the result of simulation run were compared with that of result of analysis of groundwater samples from an area in the vicinity of landfill site.

5.2 Application of Present Model

The data used for simulation of chloride migration from the landfill is given in table 7. The Okhla landfill site located in south Delhi near Tugalakabad fort at the top of aravalli ridge, near the bank of river Yamuna. The geology of landfill is alluvium with patches of quartzite. So hydraulic conductivity is taken as 10 m/day, advective velocity is taken as 0.5 m/yr and diffusion coefficient is taken as 0.02 m^2/year. Porosity taken as 0.40, Retardation factor taken as 1, area of Landfill is taken as 16.2 m^2, Height of leachate has been taken on the basis of total mass of the chloride present in landfill, maximum concentration of chloride present in leachate. The landfill has been started about 20 years back, with continuous addition of solid waste, resulting in increasing of its height.

The result of analysis of leachate sample and groundwater samples at varying radial distances are shown in Table 7. The result of ground water sample analysis clearly indicate that the contaminant concentration reduces with increasing radial distance away from landfill site. The ground water sample collected from 5 locations . The sample were collected from bore wells. The depth of these bore wells in the area was around 10 m from the ground surface.

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Table 8: Model parameters for chloride transport from Okhla Landfill site

S.No.	Model parameter	Unit	Value
1	Time	year	40
2	Depth of Groundwater	m	10
3	Effective molecular Diffusion Coefficient	m^2/yr	0.02
4	Dispersivity	m	0.015
5	Porosity		0.4
6	Reatrdation Factor		1.0
7	Advective Velocity	m/yr	0.5
8	Area of landfill	m^2	16.2
9	Maximum concentration of chloride in landfill leachate	mg/l	4000

Variation in chloride concentration at depth of 10 m below the bottom of landfill are shown in fig 5.1, it can be observed that the variation of chloride concentration shows typical behaviour of a conventional landfill system. Simulated chloride concentration in groundwater at depth of 10 m below the landfill facility initially increases, reaches a peak, and then declines. The observed concentration of chloride in groundwater sample within 120 m of Okhla landfill has been found to be 1010 mg/l. As landfill started in 1994, 20 years back the simulated concentration was approximately 1300 mg/l whichis quite in agreement with observed concentration.

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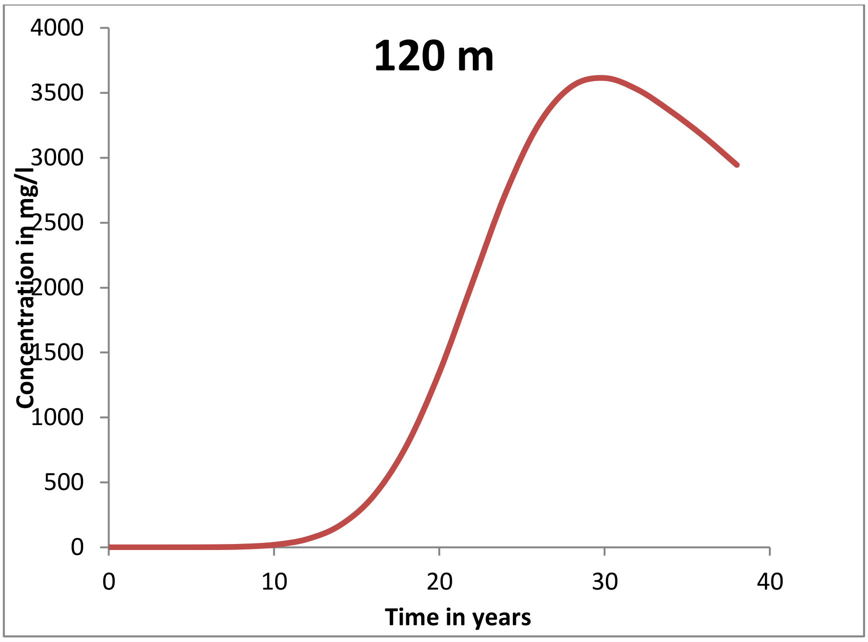

Figure 5.1 Variation of chloride concentration below landfill, and at 120 m radial distance from landfill site

However, the landfill facility is being continually progressing in the absence of availability of new landfill site, the total mass of chloride is expected to increase, which may further increase in concentration of chloride in groundwater. With the passage of time water requirement is expected to increase, and additional burden being passed on to the groundwater. As if now about 30% of population in Delhi watershed depends upon groundwater. Due to presence of toxic constituent in leachate, its unchecked release into the environment poses a substantial risk to local resource users.

5.3 Impact of Okhla Landfill site on Groundwater

Analysis of model results was carried out to determine the impact of model parameters viz. time period of simulation, equivalent height of leachate and depth on the transport of contaminants from Okhla Landfill. Simulation of model was carried out by varying the time period and depth of landfill leachate. Analysis of chloride concentration was carried out for

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the time period of 5, 10, 15, 20 and 25 years. Equivalent height of leachate is consider as 10 and 20 m.

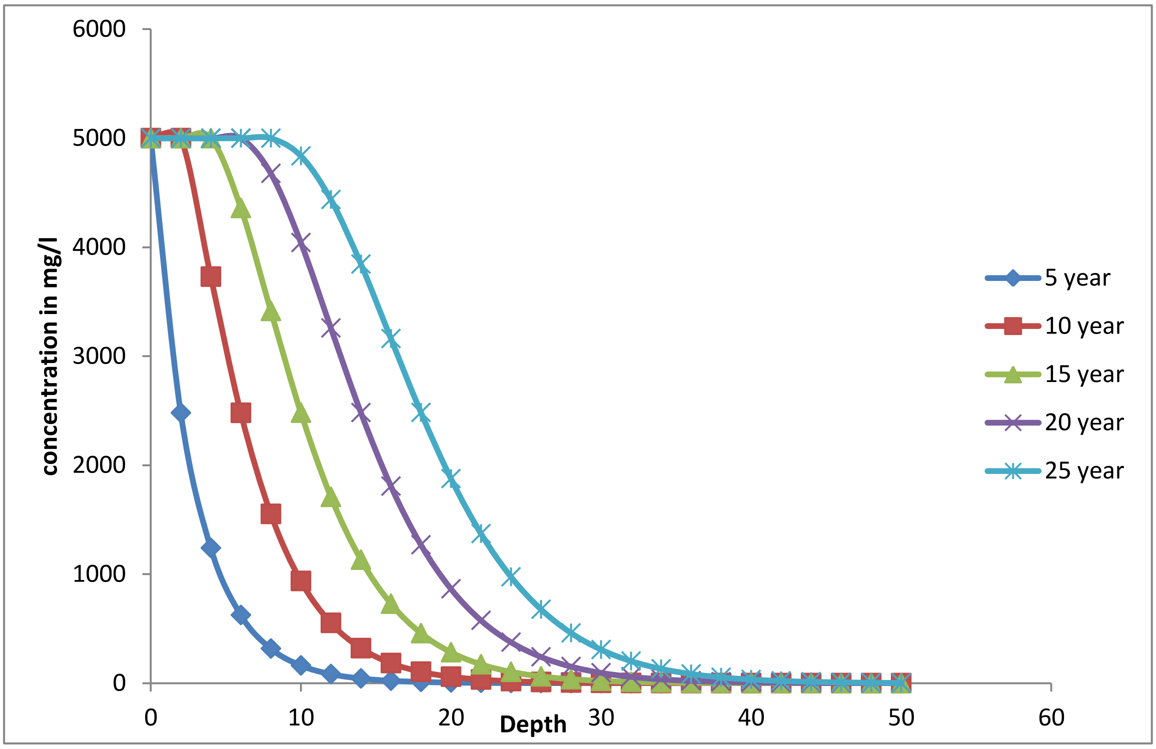

Figure 5.2: Variation of Chloride Concentration From landfill at leachate height 10m

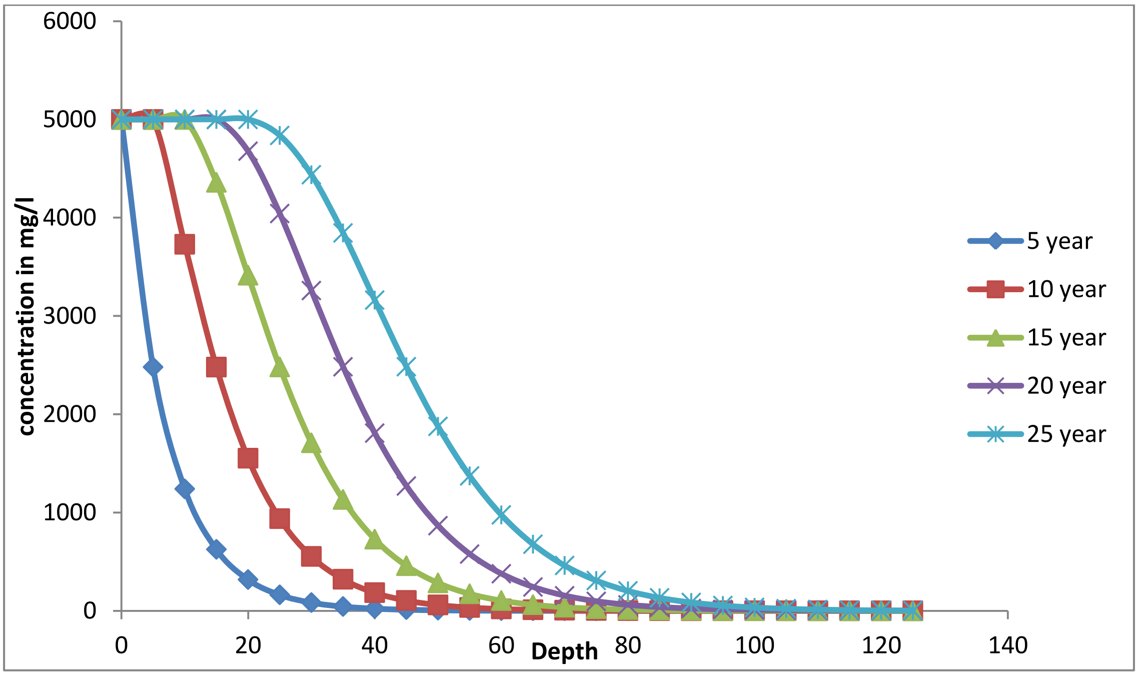

Figure 5.3: Variation of Chloride Concentration From landfill at leachate height 20m

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5.4 Simulation of model with and without upwind correction by varying parameters

A sensitivity analysis of model was carried out to determine the sensitivity of the model results. For this purpose simulation of model was carried out for different values of parameters i.e. advective velocity, and dispersion coefficient. Analysis was carried out for time period 50 years. Advective velocity taken as 0.25, 0.20, 0.15, 0.0075 and 0.00075 m/yr. Hydrodynamic diserpsion coefficient 0.01 and 0.05 m^2/yr.

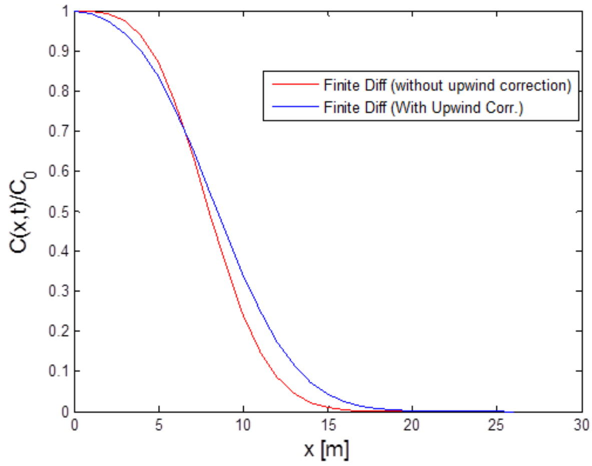

Figure 5.4: Finite difference with and without upwind correction V = 0.25 m/yr

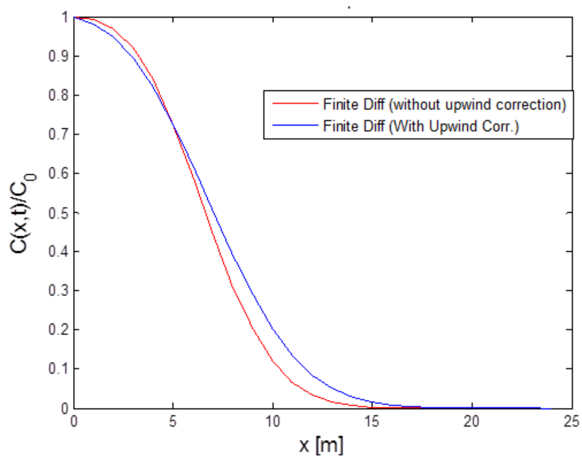

Figure 5.5: Finite difference with and without upwind correction V = 0.2 m/yr

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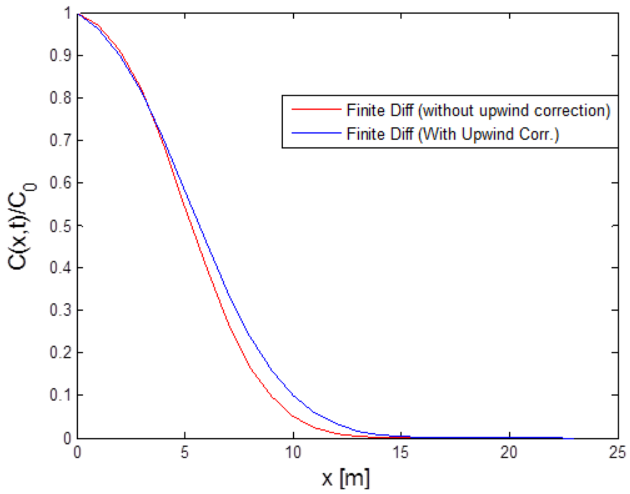

Figure 5.6: Finite difference with and without upwind correction V = 0.15 m/yr

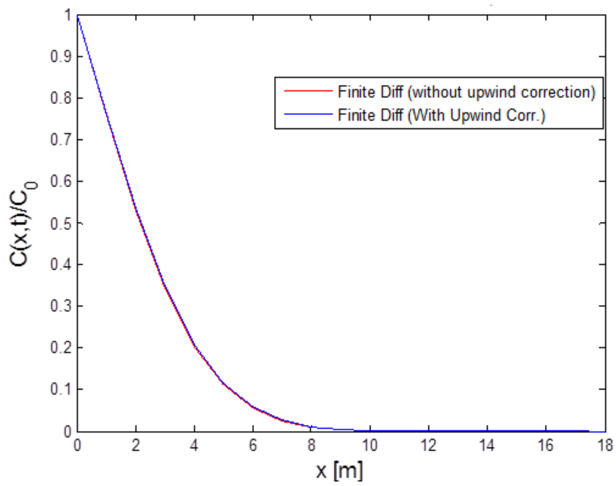

Figure 5.7: Finite difference with and without upwind correction V = 0.0075 m/yr

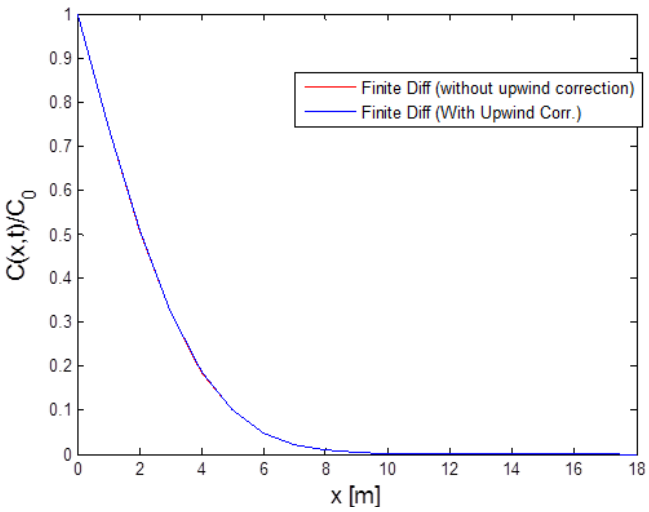

Figure 5.8: Finite difference with and without upwind correction V = 0.00075 m/yr

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From the simulation of results of the above graphs 5.4-5.8, it is observed that when advective velocity was 0.00075 m/yr and 0.0075 m/yr the error between finite difference with and without upwind correction was negligible. As the velocity increased to 0.15 the error slightly showed u between finite difference with and without upwind correction as shown in figure 5.6. As the velocity kept increasing to 0.20 m/yr and 0.25 m/yr the error between finite difference with and without upwind correction kept on increasing to higher value. So, it can be inferred from the above obtained graphs that as the velocity keeps on increasing the error between the finite difference with and without upwind correction kept on increasing and as the velocity decreases the error keeps on decreasing. So, it can be farmed that advective velocity and error between finite difference with and without upwind correction are directly proportional to each other.

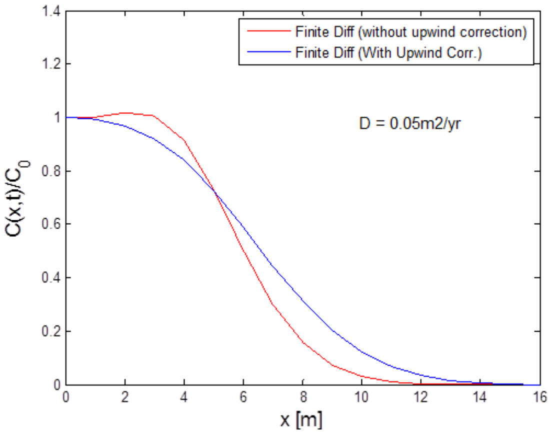

Figure 5.9: Finite difference with and without upwind correction D=0.05m^2/yr

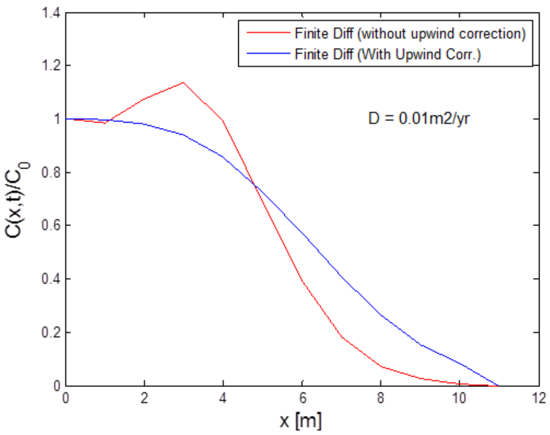

Figure 5.10: Finite difference with and without upwind correction D=0.01m^2/yr

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From the simulation of results of the above graphs 5.9-5.10, it is observed that when hydrodynamic dispersion coefficient increased from 0.01 and 0.05 m^2/yr keeping the advective velocity 0.2 m/yr, the error between finite difference with and without upwind correction decreased. So, it can be inferred that with increase in hydrodynamic dispersion coefficient the error decreased. It can be framed that hydrodynamic dispersion coefficient and the error between finite difference with and without upwind correction are indirectly proportional to each other.

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Chapter 6

Conclusions and Recommendations

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Study was carried out focused on the mass transport of contaminants from landfill leachate. Following conclusions were drawn from the present study:

1. The landfills of the National Capital Territory (NCT), Delhi, collectively produce a significant amount of leachates, hazardous in terms of its groundwater contamination potential. According to the International standards, India is water-stressed presently and is likely to face severe water scarcity by 2050. Delhi, as the rapidly developing capital of India, is facing difficulties in terms of both the groundwater quality and quantity. Disposal of solid waste in landfills is of major concern because of its high groundwater contamination potential. A liner is to be provided in landfills so as to avoid the leakage of leachate to groundwater leading to its contamination.

2. Migration of landfill leachate to the bottom and sides, results in contamination of groundwater and soil. The impact of landfill leachate on the contamination of groundwater depends upon various parameters of flow and media through which flow of leachate takes place, and the properties of contaminant, density of waste etc.

3. Model developed in the present study has been applied on Okhla Landfill site at Delhi. Simulated chloride concentration at the depth of 10 m below the landfill was found to be consistent with the observed Chloride concentration at the same depth.

4. The concentration of all the parameters in the groundwater samples collected from the vicinity of Okhla landfill site has been found to be radially decreasing in outward direction.

5. Chloride concentration in leachate from Okhla landfill site was found to be 3998.7mg/l. Concentration of iron and zinc was found to be 4.13mg/l and 4.44mg/l respectively. Nickel, copper and other heavy metal was found to be in small amount.

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Concentration of chloride around landfill site was found to be varying from 1010mg/l to 389.87mg/l at radial distance of 1-1.5km in the direction of flow.

6. From the simulation of model it was observed that the error between finite difference with and without upwind correction increases with increase in advective velocity and vice versa, i.e., is directly proportional. And the error between finite difference with and without upwind correction increases with decrease in hydrodynamic dispersion coefficient ,i.e., is indirectly proportional.

6.2 Recommendations

On the basis of the present study, following recommendations are made:

1. Solid waste disposal practice, being followed in Delhi and in all, other municipalities in India mostly consists of open dumping of waste without any regard to observance of sound engineering principles for the disposal of solid waste. Any new landfill should be design and constructed on the basis of sound engineering principles.

2. A landfill should not be constructed without adequate provision of bottom barrier for the prevention of groundwater contamination due to migrating leachate. A bottom barrier is essential in suitable thickness for the protection of groundwater sources in the country which are already under pressure from the contamination by large number of sources.

3. Okhla landfill was found to be contributing to the groundwater contamination in its vicinity. The landfill is being operated as open dumping facility. The leachate from landfill site must be collected, isolated and disposed of in proper manner after suitable treatment.

4. Landfill should be provided with gas collection and utilization system for the collection of methane gas. This will not only increase the revenue from landfill but also reduce emission of greenhouse gases.

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6.3 Scope of Future Work

The research in any field can never be achieved to its completion there is always a chance of improvement in any work and this was apply to the present study as well. The scope for future work in present study can be extended as under:

1. The model developed in this study is improved by taking into account for two dimensional solute transport equations.
2. Design of landfill liners, their compositions, material used for liner also includes in future scope of this study.

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References

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References

Abu Rukah,Y. and Al-Kofahi, O. (2001). “The assessment of the effect of landfill leachate on ground water quality, a case study El-Akader landfill site –north Jordan”. Journal of Arid Environments, Vol 49 pp 615 - 630.

A.L. Ramanathan, (2006). “Study of groundwater contamination through landfill Site, NCT Delhi”.

Arvind K. Jha, S.K. Singh, G.P. Singh, Prabhat K. Gupta, (2011). “Sustainable municipal solid waste management in low income group of cities: A Review”, International Society of tropical ecology, Vol. 52, pp 123-131.

B. Ataie Ashtiani, S.A. Hosseini, (2004). “Numerical Errors of explicit finite difference approximation for two-dimensional solute transport equation with linear sorption”, Environmental Modelling and Software, Vol. 20, pp 817-826.

B. Brunone, M. Ferrante, N. Romano and A. Santini, “Numerical Simulations of One-Dimensional Infiltration into Layered Soils with the Richards Equation Using Different Estimates of the Interlayer Conductivity.”

Bagchi, A. (1994). “Design, construction, and monitoring of landfills”, Wiley interscience publication, John Wiley & sons inc. 605 third Avenue, New York, NY 10158-0012.

Bharat Jhamnani and SK Singh (2009). “Chloride Transport from Landfill”. Journal of IPHE India. Vol 2009-2010, pp 2

Bharat Jhamnani and SK Singh (2009). “Groundwater Contamination due to Bhalaswa Landfill Site in New Delhi”, World Academy of Science, Engineering and Technology Vol. 3 pp 03-26

,

Bharat Jhamnani and S.K. Singh, (2009). "Migration of Organic Contaminants from Landfill: Minimum Thickness of Barriers". The Open Environmental Pollution & Toxicology Journal, Vol. 1, pp 18-26.

Boateng, S. and cawlfield, J.D. (1999). "Two dimensional sensitivity analysis of contaminant transport in the unsaturated zone", Ground Water, Vol. 37 pp 185-193.

Central Ground Water Board (CWGB) (2003). "Groundwater in Delhi: Improving the sustainability through rainwater harvesting", CGB Report, New Delhi.

Central pollution Control Board (CPCB) (1995-2004), Annual Report on groundwater quality of Delhi. Central Pollution Control Board, East Arjun Nagar, Delhi.

Conca, J.L. and Wright, (1990). "Diffusion coefficient in gravel under unsaturated conditions", Water resources research, Vol. 26, pp 1055-1066.

Crooks, V.E., and Quigley, R.M. (1984). "Saline Leachate Migration through Clay : A Comparative Laboratory and Field Investigation", Canadian Geotechnical Journal, Vol. 21, pp 349-362.

Demetracopoulos, A.C., Sehayek, L and Erdogan, H. (1986). "Modelling leachate production from municipal landfills", Journal of Environmental Engineering (ASCE), Vol. 112 pp 849-866.

Hillel Rubin, Joseph Atkinson, (July 2001). "Environmental Fluid mechanics", publisher Taylor and francis, Edition 2 illustrated, pp 423-488.

Jagloo K. (2002). "Groundwater risk analysis in the vicinity of landfill", A case study in Mauritius, Royal institute of technology, Stockholam.

,

Kelley, W.E.(1976). “Groundwater pollution near a landfill”, journal of environmental Engineering (ASCE), Vol. 10 pp 1129-1134.

Korfiatis, G.P. (1984). “ Modelling the moisture transport through solid waste landfills”, Dissertation, Rutgers University.

Kugler H, Ottner F, Froeschl H, Adamcova R, Schwaighofer B., (2002). “Retention of inorganic pollutants in clayey base sealings of municipal landfills”, Apply clay science, Vol 21, pp 45-58.

Kumar, D. Kahre. M,. Alappat, B.J., (2002). “Threat to the groundwater from the municipal landfill sites in Delhi, India”, International journal of environment and pollution Vol. 19 pp 454-465.

Manas Ranjan Ray, Sanghita Roychoudhury, Gopeshwar Mukhrjee, Senjuti Roy, Twisha Lahiri, (2005). “Respiratory and general health impairments of workers employed in a municipal solid waste disposal at an open landfill site in Delhi”, International journal of hygiene and Environmental Health, Vol. 208, pp 255-262.

Mechanisms of Solute Movement”, U.S. Geological Survey, Water-R es. Inv. Rept, Vol. 87, pp 41-44.

Munro, I.R.P., MacQuarrie, K.T.B, Valsangkar, A.J. and Kan, K.t. (1997). “Migration of landfill leachate into a shallow clayey till in southern New Brunswick: A field and modelling Investigaton”, Canadian Geotechncal journal, Vol. 34, pp 204-219.

New Delhi Waste Processing Company Private Limited (2006) “Environmental impact assessment of integrated municipal solid waste processing facility okhla, Delhi.

Raveh, A. And Avnimelech, Y (1979), “Leaching of pollutant from sanitary landfills models”, journal of water pollution control federation, Vol. 51, pp 2705-2716.

,

Reilly, T.E., Franke, O.L., Buxton, H.T., Bennett, G.D.(1987). "A Conceptual Framework for Groundwater Solute Transport Studies with Emphasis on Physical"

Rowe, R.k. and Badv, K. (1996a). "Advective-diffusive contaminant migration in unsaturated sand and gravel", Journal of Geotechnical Enginering (ASCE), Vol. 122, pp 965-975.

Rowe RK and Badv K.,(1996). "Chloride migration through clayey silt underlain by fine sand or silt Underlain by fine sand or silt", Journal of Geotechnical Engineering (ASCE), Vol. 122, pp 60-68.

Rowe, R.K. and Nadarajah, (1993). "Evaluation of the Hydraulic Conductivity of Aquitarde", Canadian Geotechnical Journal Vol. 30,No 5, pp 781-800.

Rowe RK and Quigely RM, Brachman RWI, Booker JR, (2004). "Barrier system for waste disposal facilities", London: Taylor and Francis.

Rudakov, D.V. and Rudakov, V.C. (1999). "Analytical modelling of aquifer pollution caused by solid waste depositories", Groundwater, Vol. 37, pp 352-357.

Schulze-Makuch D. (2005). "Longitudinal disersivity data and imlications for scaling behaviour. Ground Water Vol. 43 pp 443-456.

Straub, W.A. and Lynch, D.R, (1982a). "Models of landfill leaching: Moisture flow and inorganic strength", Journal of Environmental Engineering (ASCE), Vol. 108, pp 231-250.

T.L.T. Zhan, C. Guan, H.J. Xie, Y.M. Chen, (2014). "Vertical migration of leachate pollutants in clayey soils beneath an uncontrolled landfill at Huainan, China: A field and theoretical investigation", Science of the total Environment, Vol. 470-471, pp 290-298.

,

Thornthwaite, C.W. and Mather, J.R. (1995). “the water balance”, climatology, Vol. 8, pp 419-615.

V.Singh, and A. K. Mittal, (2009).“Toxicity Analysis and Public Health Aspects of Municipal Landfill Leachate: A Case Study of Okhla Landfill”, Delhi Author manuscript, published in "8th World Wide Workshop for Young Environmental Scientists WWW-YES 2009: Urban waters resource or risks Arcueil : France

Vikas Talyan, R.P. Dahiya, T.R. Sreekrishnan (2008). “State of municipal solid waste management in Delhi, the capital of India”, waste management, Vol. 28, pp 1276-1287.

Young, A. (1989). “Mathematical modelling of landfill gas extraction, Journal of Environmental Engineering (ASCE), Vol. 115, pp 1973-1989