DETERMINATION OF LEACHATE EMISSIONS FROM DUMPSITES IN THE DISTRICT OF COLOMBO

By

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Declaration

The research work described in this thesis was carried out exclusively by me at Faculty of Agriculture, University of Peradeniya under the supervision of Prof. B.F.A.Basnayake. A report on this thesis has not been submitted to any other university, for another degree.

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ABSTRACT

Solid waste management (SWM) is an integral part of the urban environment. It is important to plan the urban infrastructure to ensure a safe and healthy human environment while considering the promotion of sustainable economic growth. The disposal of the solid waste is the last operation in an integrated solid waste management system. Solid waste management is in the interest of the public at large. It is an exclusive service. Also it's non rivaled service. Municipal solid waste disposal has been an important issue for humankind, since waste is always generated as a result of human activities. Land filling is considered to be the most common municipal solid waste management strategy, since it is the simplest and the most economical method in most parts of the world.

This study focused on quantifying and characterizing leachate emissions from the selected dumpsites in the Colombo District and to determine benchmark values of leachate emissions from old and new dumpsites. Leachate samples from Senanayaka, Buthgama, Maharagama and Karadeyana dumpsites were collected and analyzed for pH, electrical conductivity, total dissolved solids, chemical oxygen demand, biochemical oxygen demand, phosphate, calcium, copper, nickel, lead, total suspended solid, chromium, and total nitrogen.

A validated monitoring and assessment procedures are being utilized and developed in many parts of the world and notably in North America. Thus, an effort was made to quantify leachate emissions from various landfill sites in the District of Colombo and the Hydrologic Evaluation of Landfill Performance (HELP) model was used to predict leachate generations in the dumpsites. It is the well configured and very "user friendly" model. Remarkably, it requires only daily climatologic data and wastes plus soil characteristics.

However, the literature review indicates that in semi-arid tropics and tropical climates, this model may not be applicable and validation is required. One of the ways is to confirm by comparing the data from lysimeters with that of the 'model' and applying these values to known dumpsites. Not all of the dumpsites can be monitored accurately due to limitations in scientific methodology, resources and time. However, few of the dumpsites were monitored and they could to be representative locations for the entire district. As expected low emissions were from older dumpsites and the heavy metal concentrations were considerable in the new ones, particularly from the dumpsite at Karadeyanna. It is very likely that heavy metal contaminations were from the surrounding industries. The impact of the scattered dumpsites in the Colombo District on the environment is considerable with BOD and COD values reaching 2500mg/l and 30,000mg/l respectively in the periphery of these dumps. Therefore, mining and rehabilitating these dumpsites should be undertaken as a priority measure to protect the health of the city dwellers and environment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER 1
INTRODUCTION

1.1 Background

Solid waste management (SWM) is an integral part of the urban environment. It is important to plan the urban infrastructure to ensure a safe and healthy human environment while considering the promotion of sustainable economic growth. The disposal of the solid waste is the last operation in the solid waste management. Solid waste management is in the interest of the public at large. It is an exclusive service. Also it's non rivaled service. Municipal solid waste disposal has been an important issue for humankind, since waste is always generated as a result of human activities. Land filling is considered to be the most common municipal solid waste management strategy, since it is the simplest and the most economical method in most parts of the world.

Sri Lanka is a developing country with a per capita GNP of US$ 750, is an island in the Indian ocean off the Southern Coast of India, which has total land area of 65,610 km^2 hosting a population of 18.99 million (2002). Disposal of solid waste is a major environmental problem in Sri Lanka at present and has become a national issue. The National Action Plan of Sri Lanka (1998-2001) has identified solid waste disposal to be one of the major causes for environmental degradation. None of the Local Authorities (LA s), particularly those in Urban areas have proper disposal system in place. The most common way of municipal solid waste (MSW) disposal in the country is open dumping of waste. The issue of MSW is most acute in the Colombo municipal area and in Suburbs, MSW disposal in Sri Lanka is primarily a function of the pubic sector and in most of the urbanized municipalities MSW management is the largest employer of labor and is a very expensive operation. In Sri Lanka, major amount of the MSW management cost is allocated for waste collection and transportation rather than for waste disposal and treatment (ERM, 1997).

The predominant method of waste disposal in the Colombo District is open dumping. Some of these dumpsites are being operated and some have been temporary or presently closed. The local authorities are now under pressure to establish better solutions than indiscriminate open dumping of MSW and it is likely that management of wastes will be improved. However, the existing dumpsites will continue to pollute the environment affecting the populations and future generations. Therefore it is important to quantify the emissions for rehabilitating and mining of these dumpsites.

Most parts of the Colombo District are densely populated with defined urban settlements that are expanding and becoming large towns and cities. Waste generations in these areas are high and unmanageable since capacity mobilization is poor for collection, transportation and recycling of wastes. In addition, waste disposal sites in some of the urban centers have begun to cause noticeable pollution of land, water and air.

The health hazards and environment degradation from the uncontrolled and unlined landfills are well known facts. The most commonly reported danger to human health from these landfills is from the use of polluted ground water contaminated by leachate. Thus, leachate is a significant threat to the quality of groundwater. A number of incidences have been reported in the past, where leachate had contaminated the surrounding soil and polluted the underlying groundwater aquifers or nearby surface waters. Contamination of groundwater by such leachate makes the associated aquifer unreliable for domestic water supply. The current practices of MSW disposal have led to numerous environmental and social problems. Emissions of landfill leachate are due to complex sequences of physical changes associated with biological and chemical reactions in the solid waste placed in a landfill. Therefore, leachate characteristics vary considerably from one landfill to another. The pollutants found in leachate include organic contaminants which are soluble refuse components of municipal solid waste and a variety of heavy metals. In the Western Province, most people use groundwater and surface water for their drinking purposes. This massive resource of water is not suitable for drinking and other day to day activities, since leachate contain various pathogen organisms. Thus driving the authorities responsible for water supply to convey water from far away places to the towns. In fact, leachate is the main culprit for most of the water borne diseases. In addition, to these environmental impacts, many social issues such as loss in property values, waste vehicular traffic movements and health problems are caused by the present practices.

There are major limitations in determining the levels of leachate emissions, particularly form old dumpsites. A validated monitoring and assessment procedures are being utilized and developed in many parts of the world and notably in North America. One such model is the HELP computer based software. However, the literature review indicates that in semi-arid tropics and tropical climates, this model may not be applicable and validation is required. One of the ways is to confirm by comparing the data from lysimeters with that of the 'model' and applying these values to known dumpsites. Not all of the dumpsites can be monitored accurately due to limitations in resources and time. However, few of the dumpsites can be monitored and could to be representative locations for the entire district.

According to the provisions of the Local Government Act, in Sri Lanka, the Local Authorities (LA s) are responsible for collecting and proper disposal of solid waste generated by the people within its territory. The necessary provisions are given under the section 129,130 and 131 of the Municipal Council Ordinance; the section 118,119and 120 of the Urban Council Ordinance; sections 93and 94 of the Pradeshiys Sabha Act. The public health department of the Local Authorities is responsible for solid waste management in addition to many other sanitation aspects.

In Sri Lanka the required basis for integrated solid waste management strategies and the legal provisions is inadequate. The National Strategy for Solid Waste Management put forth by the Ministry of Forestry and Environment in year 2002, endorsing the need for integrated solid waste management provides the overall guidance for the management of the country's vision. The National Environmental Act of 1980 which has subsequently amended in 1988 by Act no. 56 provides the necessary legislative framework for environmental protection in the country. Although the MSW management system in the country is rather unsystematic, the required legislative framework for an appropriate waste management system is in the country.

The current practices of MSW disposal have led to numerous environmental and social problems. The main environmental impacts are the emission of Landfill Leachate and Gas due to complex sequences of physical changes associated with biological and chemical reactions in the solid waste placed in a landfill. Unless necessary control mechanisms are not taken to prevent release of pollutants into the environment, may cause severe problems. Pollutants found in leachate include organic contaminants which are soluble refuse components of decomposition products of biodegradable fractions of municipal solid waste and a variety of heavy metals (Reinhart, 1993 and Brown and Donnelly, 1998).

The existing waste disposal practice has threatened many ecological valuable habitats such as the conservation areas of Attidiya and Muthurajawela wetlands which are used as MSW dumping grounds. In addition to these environmental impacts many social impacts such as loss in property values, traffic congestion and health problems are caused by the present practices. Our country currently has insufficient collection and improper disposal systems of waste. Disposal of solid waste is currently done by open dumping (on land or into water).The options for the treatment disposal of household and commercial waste in the Colombo District have largely been confined to open dumpsites, which constitutes of household and commercial wastes. Landfill is chosen as the most suitable option in most cases, because of its low cost, its availability, and its applicability for wide range of waste.

1.2 Justification

The current practices of MSW disposal have led to numerous environmental and social problems in Sri Lanka, particularly affecting the ecologically valuable habitats of conservation areas of Attidiya and Muthurajawela. The main causes are by dumpsite emissions. An in depth study of Landfill Gas (LFG) and Leachate emissions will provide the basis for managing the dumpsites to reduce these impacts. In this study, an attempt will be made to quantify the uncontrolled leachate emissions that are polluting the water bodies. Although it is difficult to monitor and analyze the leachate emissions as a "process", there are numerous studies and models to predict the pollution levels of dumpsites.

1.3 Objectives

1. To quantify and characterize leachate emissions from the selected dumpsites in the Colombo District.

2. To Determine benchmark values of leachate emissions from old and new dumpsites

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of Waste

Waste –The term wastes(recently given the equivalent term residuals) refers to the materials which are discarded by community activities to the environment and includes solid, and gases (Barten,1979). A Waste is a material which is thrown away or put aside as worthless. The definition of "solid waste" encompasses all of those wastes which are neither waste water discharges nor atmospheric emissions". A so called solid waste may therefore be a semi solid, solid, or even a liquid. Refuse normally means "solid wastes" but the term is avoided here. Garbage is domestic or household food wastes, rubbish is domestic non-food wastes. Municipal (Urban) solid waste is taken as including all waste collected by local authorities. Other than sewage, that is residential waste and other municipal waste, plus commercial waste. Some waste materials have other values if they are properly utilized. But if not so utilized they cause damage to the environment and are a burden to human beings. The types of waste can be categorized as

1. Solid wastes
2. Liquid wastes
3. Dust or Particulate matter
4. Gaseous waste

There are two types of solid waste namely:

- Biodegradable solid waste
- Non- biodegradable solid waste

Biodegradable solid waste

Basic physical and chemical processes can be applied to threat waste for either refuse or disposal purposes, but biological treatments such as compost making can only be applied to the biodegradable waste. Liquid effluent and solid waste pollutant s cause pollution of water bodies such as canals, lakes, rivers, estuaries and seas.

Non-biodegradable solid waste

This type of solid wastes can not be degraded by micro-organisms. The wastes which are considered not hazardous are usually dumped on approved sites. These wastes which are categorized as hazardous (after chemical auditing), need special care in disposal. Many countries have established national systems for monitoring and control of hazardous wastes, e.g. in Sri Lanka the guidelines are developed by the Central Environmental Authority. In developed countries permission has to be obtained from local authorities for the disposal of wastes. There are companies which are responsible for the collection and disposal of non-hazardous wastes.

2.2 Generation of waste streams

It is important to develop a comprehensive understanding of current and future waste generation streams. So that effective policies and strategies could be formulated for managing not only urban solid wastes but also solid wastes arising from other human activities. Therefore, wastes are commonly divided into following categories.

1. Urban (Domestic, Municipal, Commercial)
2. Industrial
3. Agricultural (Vegetation and Animal)
4. Mineral

The wastes from one category could influence other types of waste streams and sometimes industrial wastes too end up as urban wastes. It is very common that urban wastes pollute agricultural lands, forest and aquatic resources.

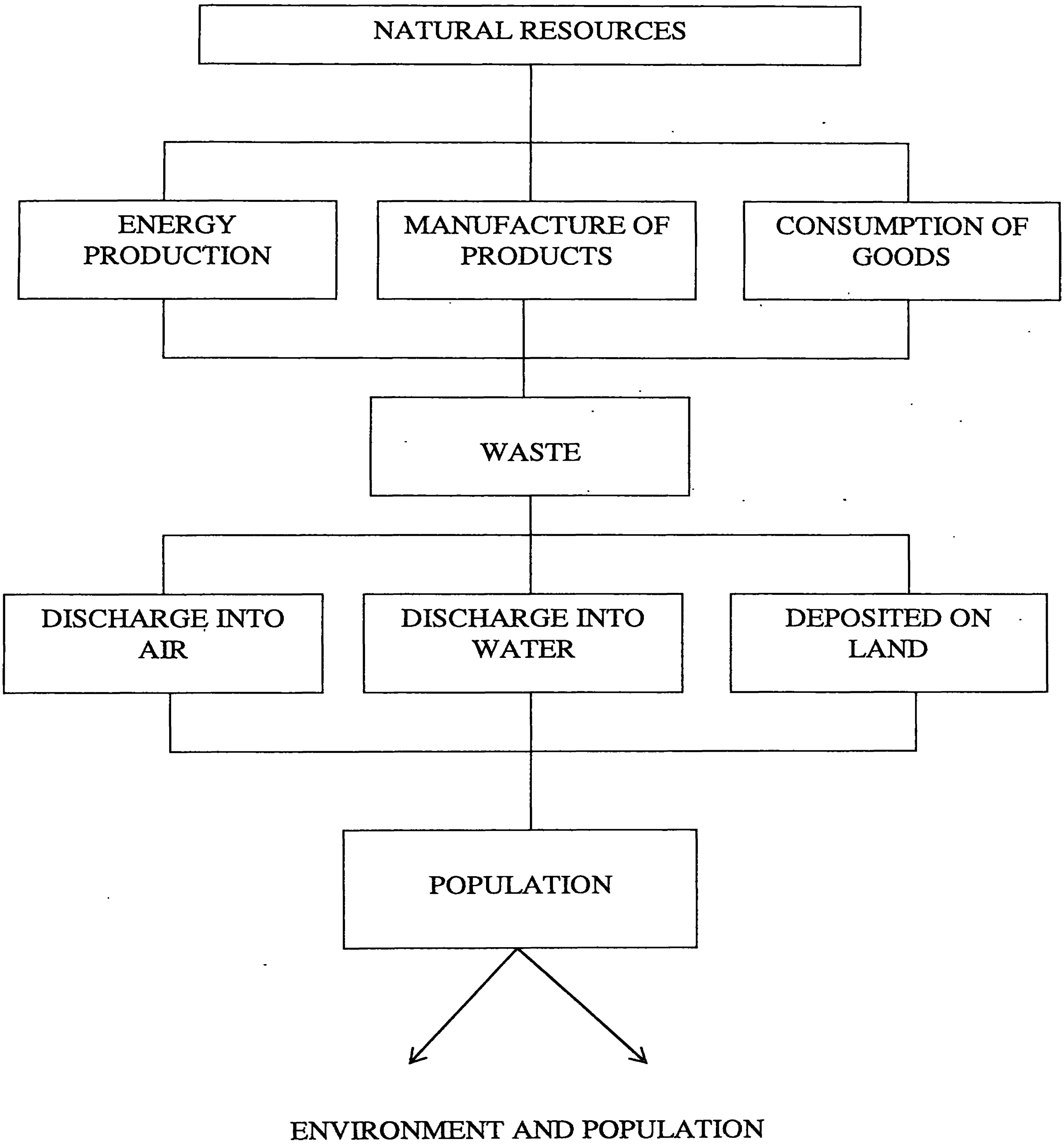

Figure 2.1: Waste Generation Stream and Environment Pollution

2.3 Source of waste

2.3.1 Industrial Waste

The waste generated by many industries, such as chemicals, wastewater, oils etc., may have harmful components, which need to be handled/stored, transported and disposed through special treatments/processes. Such kind of solid waste needs institutionalized arrangements similar to that of hospital wastes.

2.3.2 Domestic and Vegetable Market Waste

Domestic waste comes from households, canteens, hotels etc during cooking and cleaning. It could contain inorganic matters such as old paper, packing material, bottles, crockery, furnishing, foliage etc and the organic matters such as vegetable waste, food grains, edible oils etc.

2.3.3 Commercial Market Waste

This is produced at business premises, shops, offices, go downs, and departmental stores. It comprises of paper, packaging material, spoiled and discarded goods, organic and inorganic matter which could sometimes be chemically reactive and hazardous.

2.3.4 Hospital Waste

Hospital wastes are often toxic and contain harmful and infectious materials. These are sub-divided, besides the general wastes (arising from the hospital kitchens), into infectious wastes, biological wastes and pointed and sharp objects. Careless and unscientific/multiple handling and transport of such wastes, their mixing with general municipal wastes and dumping into open grounds or in sanitary landfills poses serious environmental hazards and health risks for the general population

2.3.5 Miscellaneous Sources

Miscellaneous sources of solid waste includes street sweepings comprising of public littering, road side plantation waste, debris (mud, brickbats, stones, logs etc) from cleaning, demolition, repairs and construction activity. Seasonal variations can significantly affect the nature of MSW. In the rainy season, waste retains much moisture and is denser. In eastern and southern India and Sri Lanka, the "king coconuts" or green coconuts, which are sold on the street as a drink, contribute heavy and bulky items to the waste stream. In the same areas, during the summer months, melon rinds alone can increase the amount of waste in the commercial and market areas by 20 per cent or more.

2.4 Type of waste

2.4.1 Liquid/Solid

Waste material arising from domestic, vegetable markets, commercial, agricultural and industrial activities and public sources, comprises of solids such as vegetable/inorganic matter, inert matter like glass, metal, stones textiles etc., and liquids such as drain and sewer water, and industrial waste water etc. The composition of waste has implications for the transportation to disposal sites.

2.4.2 Degradable/Non-Degradable

Bio-mass component in the MSW is the degradable component whereas plastics and such other materials would be the non-degradable components. This aspect has particular significance in the waste management practices particularly when technologies used for converting the waste into manure or energy is introduced.

2.4.3 Reusable/Non-Reusable

Asian study which estimated that 52 .5%f Indian household's nationwide burn animal dung for heating, cooking and lighting. In one state as many as 65.5% of urban households use dung as a fuel (Barnard and Kristofferson 1985). The slum-dwellers in Asian cities demonstrate how waste materials of all kinds (wood scraps, plastics, paper, gunny bags, tins and iron scrap) are used as construction materials and for repairs. Most of these households use bottles, containers salvaged from the waste.

2.4.4 Recyclable or Non Recyclable

Recyclable materials include clothes and rags, small goods, bottles, plastics of all kinds (especially milk pouches), metals, toys, cinders from coal fires and food wastes.

Some typical examples of the informal recycling industries are those which recycle broken glass into bottles, plastics to toys and shoes, and paper to paper board. The activities are mainly driven by the scarcity of products and low-cost of these raw materials.

2.5 Open Dump Approach

In Sri Lanka 100% of landfills are just open dumpsites. In most Asian countries today, solid waste disposal still means dumping, for reasons such as ignorance (of the health risk associated with dumping of wastes); or acceptance of the status quo due to lack of financial resources to anything better; or lack of political will, at all levels of government, to protect and improve pubic health and the environment. With the accelerated generation of waste caused by an ever-increasing population, urbanization and industrialization, the problem has become one of the primary urban environmental issues (Ranaweera and Trankler, 2001). Open dumping is a traditional and common disposal method at which solid waste is disposed of in a manner that do not regard environmental and health impacts, is susceptible to open burning, and is exposed to the elements, disease vectors and scavengers. These unplanned heaps and uncovered wastes, often burning and surrounded by pools of stagnated polluted water, rat and fly infections with domestic animals roaming freely and families of scavengers picking through the wastes is not only an eyesore but a great environmental hazard (Kurian Joseph et al , 2002).

2.6 Definition of Leachate

Leachate may be defined as liquid that is formed during the decomposition process and water that has percolated through solid waste and has extracted dissolved or suspended materials. Leachate is generated as a result of waste decomposition and the expulsion of liquid from the waste due to its own weight or compaction loading (termed primary leachate) and the percolation of water through the landfill (termed secondary leachate). Percolating water plays a significant role in leachate generation. Leachate that has entered the landfill from external sources, such as surface drainage, rainfall, ground water and from underground springs and the liquid produced from the decomposition of the waste. Leachate from a decomposing landfill contains a range of inorganic and organic chemical and its composition and characteristics are complex. Both the quantity and quality of produced leachate are important issues for landfill design.

2.6.1 Leachate characterization

Leachate from a decomposing landfill contains a range of inorganic and organic chemicals and its compositions and characteristics are complex. The basic processes of waste decomposition affect the quality of leachate. There are three stages in the decomposition of solid waste (Mc Bean et al, 1995)

Stage 1: Aerobic decomposition occurs rapidly, typically for duration of less than one month. Once available oxygen within the waste is used up (except in the vicinity of the surface), this phase of decomposition terminates.

Stage 2: Anaerobic and facultative organisms (acidogenic bacteria) hydrolyze and ferment cellulose and other putrescible materials. It produces simpler, soluble compounds such as volatile fatty acids which cause high biochemical oxygen demand (BOD) value and ammonia.

Stage 3: Slower growing methanogenic bacteria gradually become established and start to consume simple organic compounds, producing the mixture of carbon dioxide and methane (plus various trace constituents) that constitutes landfill gas. This phase is more sensitive than stage 2.

The transition from stage 2 to stage 3 can take many years and may not be completed for decades. Sometime it is never completed (McBean et al, 1995). However, some wastes have been known to reach stage 3 in a few months. In stage 3, bacteria gradually become established and are able to remove the soluble organic compounds (mainly fatty acids) that are largely responsible for the characteristics of stage 2 leachates. Leachates generated during stage 3 are often referred to as "stabilized," but at this stage the landfill is biologically at its most active level. A dynamic equilibrium is eventually established between acetogenic and methanogenic bacteria, and wastes continue to actively decompose. Leachate produced during stage 3 is characterized by relatively low BOD values and low ratios of BOD to COD. However, ammonia nitrogen continues to be released by the first- stage acetogenic process and is present at high levels in the leachate. Inorganic substances such as Iron, Sodium, Potassium, Sulfate, and Chloride may continue to dissolve and leach from the landfill for many years.

Because of the sequential nature of biochemical reactions in a MSW landfill, the leachate coming from a single location is highly variable over time. Likewise, leachate varies greatly from location to location as well. Some locations will be at one phase of decomposition, while others will be at a very different stage. The leachate bottom of the waste is a result of the processes that have occurred in the waste above. Although leachate quality differs from municipal landfill to another, common factor affecting the composition of leachate are as follows:

i. Solid waste composition
ii. Depth of the solid waste
iii. Age of the landfill
iv. Final cover condition
v. Operation of the landfill such as water addition, leachate recirculation
vi. waste compaction, thickness of dumped layers, rate of placement
vii. Climate variables such as annual rainfall and ambient temperature
viii. Hydrologic conditions in the vicinity of the landfill sites
ix. Conditions within the landfill such as chemical and biological activities moisture content. Temperature, ph, and degree of stabilization

(Ehrig, 1989; Lu et al., 1995; McGinley and Kmet, 1984; Qasim and Burchninal, 1970; Straub and Lynch, 1982):

Young landfills typically generate leachate having high biodegradable organics. As a landfill ages, its contents degrade and produce more complex organics and inorganic, that are not so readily amenable to biodegradation. Characteristics of leachate produced, as well as differences in the quality of leachate generated, by municipal, co disposal, hazardous waste landfill have been documented(USEPA, 1988).

2.6.2 Factors affecting leachate quantity

The quantity of leachate generated is both site specific and waste specific. The amount of leachate produced is affected by precipitation, type of site, groundwater infiltration, surface water infiltration, waste composition and moisture content, preprocessing of the waste (baling or shredding), density of the waste, thickness of the waste, climate, evaporation, evapotranspiration, gas production, final cover design, and surface flow pattern.

- Precipitation

  Precipitation represents the largest single contribution to the production of leachate. The amount of rain falling on a landfill influences leachate quantity significantly. As with all cases of infiltration, the most critical situation occurs during periods of light rainfall over a long lapse of time; short bursts of heavy rainfall during a storm result in a quick saturation of the cover material, the remainder is shed as runoff, so there is a little net infiltration. Precipitation depends on geographical location.

- Waste Condition

  Waste condition can include waste composition, waste moisture content, preprocessing of the waste (baling or shredding), thickness of the waste, and density of the waste. Leachate quantity will increase if the waste releases pore water when squeezed because of increasing waste filling depth and density of the waste. Unsaturated waste continues to absorb water until it reaches field capacity. Waste in a state lower than its field capacity will reduce leachate formation. Sludge residues from sanitary treatment facilities, combined sewer system, industrial filter materials, and other quasi-solid are being permitted by many regulatory groups for disposal in MSW landfills.

Depending upon their moisture content and quantity, sludge has a major effect on leachate quantity and quality.

2.7. Colombo Metropolitan area

The Colombo metropolitan area has a resident population of 600,000 and a daily migrant labour influx from the surrounding countryside that adds another 40,000. The city Municipal Engineer has the city divided into two sections: north and south which are further sub-divided into districts. Each section is headed by a Superintending Engineer assisted by District Engineers who are responsible for all municipal functions. Drainage is handled by a separate board.

Under each District Engineer, a Cleansing Superintendent is there with two Cleansing Inspectors to assist him. The wards (47 of them) are the basic unit of cleansing management, each with a Cleansing Supervisor controlling about 100 laborers. A unique feature of the administration is the presence of women engineers and managers. Solid wastes account for 6.9 per cent of the revenue figure and health services and inspection take up 9 per cent.

Refuse generation rates are the order of 0.5 kg/person/day with a daily total of 700 tones for the city. Refuse is highly organic and wet with low levels of paper, plastics, metals, and glass. No more than 20 per cent of daily wastes are handled by enclosed compaction vehicles which are mainly in down-town Colombo. Market wastes are handled by a fleet of side-loader refuse vehicles. Those are operated in early and late night shifts. There is no on site disposal of hospital wastes. These are double bagged and buried at the base of the landfill site. The Colombo Municipal Council provides the hospitals with a shuttle tractor and trailer for this purpose. Local by-laws have been amended to allow fines for litter offences.

A total of 4,000 laborers give a daily house-to-house service in all the areas except the places that are served by the compactor vehicles. Each person is expected to collect waste from approximately 70 families. When they have finished their collection, these laborers are then expected to engage in street sweeping, litter picking, drain cleaning, weed clearance, and similar tasks. Wages are low, no more than 7,000-10,000 rupees per month for a sanitary worker. The waste is disposed in the waste hillock of Bleomendhal and it is one of the major problems facing the authorities.

The experience in Colombo highlights the importance of both the collection and the disposal systems. Comprehensive administrative machinery for the collection by itself is not adequate. One finds a mix of technology support for transportation. Very clearly, one can observe a marked difference in the higher quality of cleaning and transportation in areas where compactors are used.

2.7.1 Leachate Quantity of Municipal Solid Waste Dumpsites in Colombo District

Sanitary land filling is the widely accepted method for municipal solid waste disposal. In developing countries, more than 90% of the landfills are unorganized open dumps leading to a number of environmental problems (Visvanathan et al., 2003).One of the severe problems associated with the solid waste dump sites is the infiltration of leachates and the subsequent contamination of the surrounding land and water. Examples for such events include leachate pollution (Bacterial and chemical contamination) in private wells around open dump sites in Colombo District. Landfill without protection liners have been reported to cause leachate contamination problems over a period of time. The leached soluble contaminants along with the washout of fines and colloids results in highly contaminated leachate. It contains a host of toxic and carcinogenic chemicals harmful to both humans and the environment. The quality and quantity of leachates produced in landfills depend on several factors. The quantity is controlled by moisture content, refuse age, segregation compaction, permeability, practical size, density, settlement, vegetation, cover, side walls, liner materials, gas and heat generation and transport. Quality is controlled by the pretreatment method, separation recoverable materials, leachate recirculation and locations of the sites. Therefore, it is difficult to generalize at a time.

In developed countries, proper remedial measures are used to mitigate the environmental impacts of dumpsites. Leachate quality data are useful to choose suitable remedial methods. Colombo District, having major metropolitan cities of Sri Lanka, with a population of 1.3 millions generates about 1200 tons of solid waste per day. Currently, this is dumped in Karadeyana, Kotte Senanayaka ground, Buthgama, Maharagama, Attidiya, and Muthurajawella. These sites are located in densely populated areas. The present study was aimed to assess the quality at above selected dumpsites in District of Colombo.

2.8 Problems Risen from Municipal Solid Wastes

There are four main health and environmental aspects associated with wastes as described below.

2.8.1 Presence of Human Fecal Matter

Most municipal refuse contains human fecal matter. In developed countries, its presence is largely attributable to the prevalent practice of using disposable diapers for infants and toddlers. In developing countries its presence is more likely to be attributable to inadequacies of the sanitation infrastructure and management.

2.8.2 Presence of Industrial Waste

Most municipal refuse is likely to contain some industrial waste, even in cities where private haulers are engaged to service industrial establishments. Small –scale enterprises are likely to use the municipal system for at least some of the time. Furthermore, many cities which require private hauling of industrial wastes allow co-disposal of those same wastes within the municipal landfill. Although the level of industrial activity is much lower in developing countries than it is in developed countries, the degree of hazard associated with the waste generated is likely to be similar.

2.8.3 Atmospheric Emissions and Release of Chemical Constituents

The decomposition by-products of materials within municipal solid waste can release chemical constituents into drainage, seepage and atmospheric emissions associated with either treatment of disposal of the refuse. In developing countries where open dumping of waste in wetlands or borrow pits is the most prevalent form of disposal, the principal pathway for these chemicals would be leaching into ground and surface waters.

2.8.4 Continuous Burning of Dump Sites

Smoke from continuous burning of dumps creates extensive pollution in many cities of developing countries. Refuse in dumps has a high organic content and when exposed and sun-dried at the surface, spontaneous combustion occurs readily. Where methane gas is being continuously generated by anaerobic decomposition of organic substances within the refuse, fires can spread underground and go on for years.

Life expectancy in low income countries is markedly lower than in industrialized countries, averaging about 50 years for low- income countries as opposed to about 74 for industrialized countries (Cointreau, 1982). In general, the short life expectancy reflects very high death rates among children under five years of age. In the poorest regions of low income countries, half of all children are reported to die during the first year of life. The primary cause of death is diarrhea related diseases: responsible for one quarter to one half of the deaths under age five.

Human excreta is a critical vehicle for transmission and spread of a wide range of communicable diseases, municipal refuse is often overlooked as an important pathways for the pathogens contained in excreta. The most obvious route is direct, whereby refuses collection workers, scavengers and contaminated hands in their mouths or on their food.

A less direct root occurs when vectors such as flies and cockroaches transport disease carrying agents in their intestinal tracts, subsequently contaminating food they contact. Furthermore, pathogens and irritants leading to infection may be directly inhaled as wind transports fine- grained refuse material from the open collection points or from the activities of transferring refuse from one please to another. This is most apparent in the refuse collection system in which pay loaders pick up refuse from the ground and places it in open trucks; dust from the refuse is unavoidable while residents tend to the stand around and watch the activities of the very large and noisy equipment.

Once they are excreted, the survival of pathogens in refuse is dependent on their basic nature as well as their environment. Viruses tend to decrease in number following excretion; bacteria may multiply if they themselves in a nutrient-rich, conductive environment: protozoa normally pass through an asymptomatic carrier state, with the carrier responsible for eventual transmission; parasitic worms, or helminthes generally decrease in number following excretion, except for trematodes which can multiply in their intermediate hosts. Survival of most bacteria and viruses within faces appears to be up to five months, While helminth ova survival for many months. Despite this general trend, bacteria have been shown to survive for years in suitable environments; and a recent study of landfills showed faecal-indicator v-bacteria existing nine years after one municipal landfill was closed.

2.9 Introduction to HELP Model

The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data, and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, Evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The program was developed to conduct water balance analysis of landfills, cover systems and solid waste disposal and containment facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to open, partially closed, and fully closed Sites, is a tool for both designers and permit writers.

2.9.1 Program Definitions, Options and Limitations

The HELP program was developed for landfill designers and regulators to provide a tool for rapid, economical screening of alternative designs. The program can be used to estimate the magnitudes of various components of the water budget, including the volume of leachate produced and the thickness of water-saturated soil (head) above liners.

The results may be used to compare the leachate production potential of alternative designs, to select and size appropriate drainage and collection systems, and to size leachate treatment facilities. The program uses weather (climatic), soil and design data to generate daily estimates of water movement across, into, through and out of landfills. To accomplish this objective and compute a water balance, daily precipitation is partitioned into surface storage (snow), snowmelt, interception, runoff, infiltration, surface evaporation, evapotranspiration from soil, subsurface moisture storage, liner leakage (percolation), and subsurface lateral drainage to collection, removal and recirculation systems. This section discusses data requirements, nomenclature, important assumptions and limitations, and other fundamental information needed to run the program. The program documentation report (Schroeder et al., 1994) contains detailed explanations of the solution techniques employed and the computer programs. The HELP program requires three general types of input data: weather data, soil data and design data. A summary of input options and data requirements is presented in this section. Section 4 provides step-by-step input instructions.

2.9.2 Weather Data Requirements

The weather data required in the HELP model are classified into four groups as evapotranspiration, precipitation, temperature, and solar radiation data. The HELP user may enter weather data using several options depending on the type of weather data being considered. The requirements for each weather data type are listed below. The units used are also listed next to each data type and/or variable. Customary units are based on the US Customary units, and Metric implies SI units.

- **Landfill General Information**

1. Project title
2. Landfill area *(Customary or Metric)*
3. Percentage of landfill area where runoff is possible
4. Method of initialization of moisture storage (user-specified or program initialized to near steady-state)

5. Initial snow water storage (optional, needed when moisture storage is user-specified)

- **Lateral Drainage Layer Design Data**

1. Maximum drainage length *(Customary or Metric)*
2. Drain slope, percent
3. Percentage of leachate collected from drainage layer that is recirculated
4. Layer to receive recirculated leachate from drainage layer

- **Geomembrane Liner Data**

1. Pinhole density in geomembrane liner *(Customary or Metric)*
2. Geomembrane liner installation defects *(Customary or Metric)*
3. Geomembrane liner placement quality (six available options)
4. Geomembrane liner saturated hydraulic conductivity (vapor diffusivity), cm/sec
5. Geotextile transmissivity, cm^2/sec (optional, when placed with geomembrane)

- **Runoff Curve Number Information**

Three methods are available to define a SCS AMC II runoff curve number.

1. User-specified curve number used without modification
2. User-specified curve number modified for surface slope and slope length
3. Curve number computed by HELP program based on surface slope, slope length,
4. Default soil texture, and quantity of vegetative cover

2.10 Effluent Discharge Standards in Sri Lanka

All countries have their own effluent discharge standards. Central Environmental Authority is the organization responsible for generate effluent discharge standards in Sri Lanka.

Table 2.1Effluent discharge standards in Sri Lanka.

Parameter	**Unit, Type of limit**	**Discharge into inland waters**	
		Class II *	**Class III****
pH at ambient T^0		6.0 -8.5	6.0 – 9.0
TSS	mg/l, max	20	50
BOD (BOD_5 at 20^0C)	mg/l, max	30	50
COD	mg/l, max	150	250
Odor		Unobjectionable	Unobjectionable
Detergents/Surfactants	mg/l, max	2	3
Oil and Grease	mg/l, max	10	10
Cadmium (as Cd)	mg/l, max	0.1	0.2

Chromium, total (as Cr)	mg/l, max	0.5	2
Chromium, Hexavalent (Cr6+)	mg/l, max	0.1	0.1
Copper (as Cu)	mg/l, max	0.5	2
Iron (as Fe)	mg/l, max	3	3.5
Lead (as Pb)	mg/l, max	0.1	0.5
Mercury (as Hg)	mg/l, max	0.0005	0.005
Nickel (as Ni)	mg/l, max	0.5	2
Selenium (as Se)	mg/l, max	0.05	0.1
Zinc (as Zn)	mg/l, max	2	3

Figure: 2.2 Indian Standards for Disposal of Landfill Leachates into Inland Surface Water

Table 2.2 The Indian Standard for disposal of landfill leachates into inland surface water

Metal	Cd	Cr	Cu	Ni	Pb	Zn
Limits .(micro gram/L)	1000	2000	3000	3000	1000	5000

Leachate Quality of Municipal Solid Waste Dumpsites at Chennai, India

Table2.3 Characteristics of Leachate from Perungudi Dumping Ground

SI NO	Sample No	No of sample	EC mg/L	TDS mg/L	COD mg/L	BOD mg/L	K^+ mg/L	Ca^{+2} mg/L	Mg^{+2} mg/L	Po_4^- ^{3}mg/L
1	Oct-02	4	11.47	6157	1198	58	1111	121	130	28
2	Nov-02	5	3.44	2061	397	30	316	107	56	16.8
3	Dec-02	4	9.19	4632	760	54	600	96	57	23.8
4	Jan-03	4	10.86	5006	823	52	804	255	98	24.8
5	Feb-03	4	12.23	5819	831	46	827	64	138	19.5
6	Mar-03	3	11.84	5928	847	25	871	121	147	29.3
7	Apr-03	3	12.78	6241	1069	53	797	109	162	27.7
8	May-03	3	12.15	6301	1043	33	848	217	219	2.6
9	Jun-03	3	12.42	6338	1047	40	848	183	241	6.5
10	Minimum	-	3.44	2061	397	25	316	64	56	2.6
11	Maximum	-	12.78	6338	1198	58	1111	255	241	29.3
12	Mean	-	10.71	5387	891	43	780	141	139	19.9

Table2.4 Characteristics of Leachate from Kodungaiyur Dumping Ground

Sl NO	Sampling month	No of samples	EC mg/l	TDS mg/l	COD mg/l	BOD mg/L	Na^+ mg/l	K^+ mg/l	Ca^{+2} mg/l	Po_4^{-3} mg/l
1	Sep-02	5	7.33	6173	572	15	730	88	382	3.3
2	Oct-02	2	12.98	8124	1370	25	1620	1535	286	20.5
3	Nov-02	5	1.71	1391	131	8	123	191	137	5.9
4	Dec-02	1	3.86	2932	232	8	241	235	136	18
5	Jan-03	1	4.42	3088	340	18	473	476	176	42
6	Feb-03	1	4.96	3320	272	18	568	561	128	23
7	Mar-03	1	4.91	3408	287	30	568	529	144	51
8	Apr-03	1	5.42	3562	480	18	417	508	128	45
9	May-03	1	5.47	4124	400	18	769	548	180	14
10	Jun-03	-	5.67	3836	397	30	769	620	224	6.9
11	Minimum	-	1.71	1391	131	8	123	88	128	3.3
12	Maximum		12.98	8124	1370	30	1620	1535	382	51
	Mean		5.67	3996	448	19	628	519	192	22.97

Soil Layer (45cm)

Waste Layer (250cm)

Natural Clay

Figure 3.1: Layer arrangement of Senanayaka Dumpsite in Newalla

3.1.2 Buthgama Dumpsite in Kotte

Buthgama dumpsite lies at 6.90 North and 78.87East. The total area of this site is about 3.0 acres in which about 2.5 acres is used for dumping. The waste depth in this site is about 2.0m. Currently the dumping rate of the above site is 50t/day. Water courses are on either side of the dumpsite of the low lying lands.

Plate 3.2: Buthgama Dumpsite in Kotte

Soil Layer (30cm)

Waste Layer (200cm)

Peat

Figure 3.2: Layer arrangement of Buthgama Dumpsite in Kotte.

3.1.3. Maharagama Dumpsite

Maharagama dumpsite lies at 6.90 North and 78.87 East. It is a low lying and poorly drained area of marshy land. The total area of this site is about 5 acres in which about 4.5 acres are used for dumping. The waste depth in this site is about 3.5m. Currently the dumping rate of the above site is 80t /day.

Plate 3.3: Maharagama dumpsite in Kotte

Soil Layer (45cm)

Waste Layer (120cm)

Decomposed Layer (60 cm)

Clay (formally a paddy field)

Figure 3.3: Layer arrangement of Maharagama Dumpsite.

3.1.4 Karadeyanna Dumpsite

Karadeyanna dumpsite lies at 6.90 North and 78.87 East. It is a low lying and poorly drained area of marshy land. This land is adjacent to the alluvial low land of Bolgoda lake. The total area of this site is about 10 acres used for dumping. The waste depth in this site is about 4m. Solid wastes have been dumped since 1991 and it is operational. Currently the dumping rate of the above site is 400 t /day.

Plate 3.4: Karadeyanna dumpsite

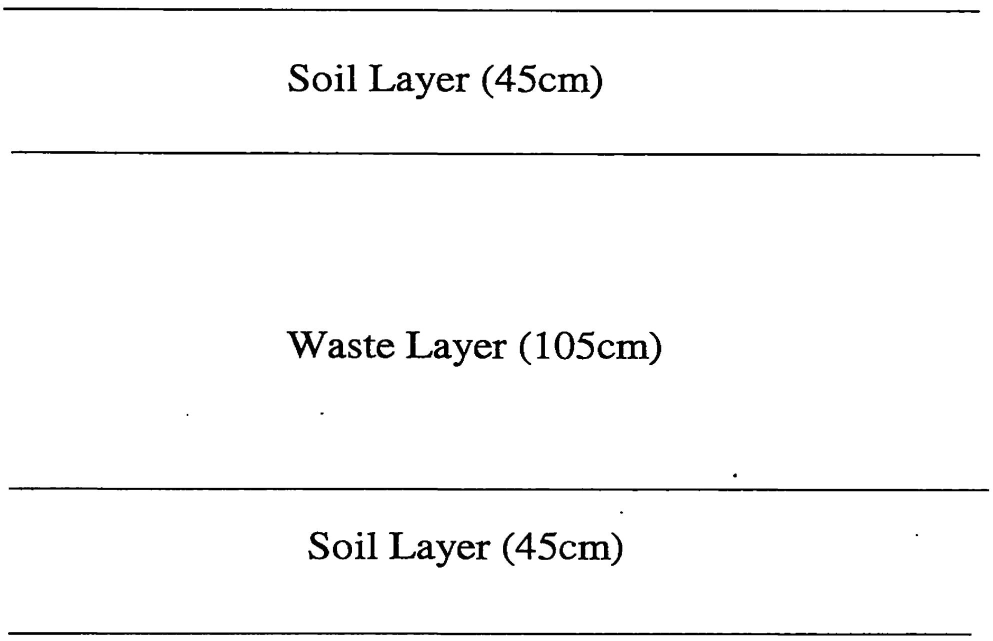

Figure 3.4: Layer arrangement of Karadeyanna Dumpsite.

3.2 Determination of leachate quantity

In an effort to develop a method for determination of leachate quantity from various landfill sites in the District of Colombo, the Hydrologic Evaluation of Landfill Performance (HELP) model has been used to predict leachate generation in the dumpsites. The HELP model is the well configured and is very "user friendly". The model requires only daily climatologic data and wastes plus soil characteristics.

❖ Program Input

Version 3 of the HELP program is started by the typing “HELP3” FROM THE DOS prompt in the directory where the program resides (Schroeder et al., 1994a). The program starts by displaying a title screen, a preface, a disclaimer, and then the main menu. The user moves from the title screen to the main menu. The user moves from the title screen to the main menu by striking any key, such as the space bar. Upon reaching the main menu. The user can select any of the following options:

1. Enter/Edit Weather Data,
2. Enter/ Edit Soil and Design Data,
3. Execute Simulation,
4. View Results,
5. Print Result,
6. Display Guidance, and
7. Quit

The program automatically solicits input from the user based on the option selected. In general, the HELP model requires the following data. Some of which may be selected from the default values (Schroeder et al., 1994a):

1. Units,
2. Location,
3. Weather data file names,
4. Evapotranspiration information,
5. Precipitation data,
6. Temperature data,
7. Solar radiation data,
8. Soil and design data file name,
9. General landfill and site information,
10. Landfill profile and soil/ waste/geomenbrane data, and
11. SCS runoff curve number information.

❖ Program Output

The HELP program always produces out put consisting of the identifying labels and input data (except daily precipitation) supplied by the user, and a summary of the simulation results. Daily, monthly, and yearly output may be obtained at the option of the user.

The actual leachate generations of a known experiment can be used in view of the HELP model validation for tropical climates. Therefore, due to lack of time, the model verifications were done for the lysimeter study conducted at the University of Peradeniya. However, the model outputs were generated for a particular soil type which may or may not persists in the dumpsites that were evaluated.

3.3 Leachate Collection systems

Leachate collection systems were established at three selected locations in each of the dumpsites. Daily samples were collected during July 2006-August 2006. The samples were refrigerated at 4°C and used for chemical analyses.

- Points of Sampling

The Maharagama site being very accessible, sampling was done; in the centre of the dumpsite (1), in another point, just below the filling (2) and the last one was taken from the watercourse (3). In the Senenayake dumpsite all of the three points were taken from the marsh. Similar to Maharagama, the sampling was done at Buthgama. At Karadiyanna, all of the sampling points were from the dumpsite surface.

3.4. Characterization of Leachate

Chemical parameters were determined following standard methods. Leachate samples were analyzed for pH, Electrical conductivity (EC), Total Dissolved Solid (TDS), Total Suspended Solid (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Heavy metals, Phosphate, and metals.

3.5. Calculation Parameters

- ❖ BOD_5 (Of the leachate)
- ❖ COD (Of the leachate)
- ❖ TDS (Of the leachate)
- ❖ TSS (Of the leachate)

3.5.1 Biochemical Oxygen Demand (BOD)

BOD_5 = (BOD Sample- BOD Blank) * D

BOD_5 = 5 th day BOD Value
BOD_5 Sample = 5 th day BOD Value of sample
BOD_5 Blank = 5 th BOD Value of blank
D = Dilution Facture

3.5.2 TSS-Total Suspended Solid

The known amount of leachate (V ml) was filtered though the known weight of oven dried filter paper (W1 g). This filter paper was placed into known weight of empty oven dried crucible (W2 g). Then these contents were measured (W3 g) and placed in an oven until the sample reached a constant weight (W4 g).

TSS = (W4-W2-W1) x 1000/V) g/L

3.5.3 Total Nitrogen Content:

$NH_3 + H_3BO_3 = NH_4^+ + H_3BO_3$: ammonia trapping

$H^+ + H_3BO_3 = H_3BO_3$: titration

Number of meq distilled NH4:

(V – V0)ml * t meq/ml = (V – V0) t meq

Where, V = volume H_2SO_4 (HCl) added to the sample.
V0 = volume H_2SO_4 (HCl) added to the blank solution.

t = normality of H_2SO_4 (HCl)
(= 0.01 eql-1 or meq ml^{-1})

Number of mg N present in the sample.
(V-V0) t meq * 14 mg/meq N = .14 (V-V0)

Where : N = nitrogen.

Amount of nitrogen per thousand (gKg^{-1} or mgg^{-1})

3.5.4 Organophosphate Concentration

Organophosphate, mg/L as P= C*1000/V

Where,
C-Phosphorous concentration determined by the calibration curve mg/L
V- Volume of sample analyzed in ml

Table 3.1: Methods of Test

Type of Test	Method of test	Frequency
Leachate quality		
i. TSS	Oven Drying	3samples/ Day in one site
ii. TDS	Oven Drying	3 samples/ Day in one site
iii. Conductivity	Conductivity Meter	3 samples/ Day ,,
iv. pH	pH Meter	3samples/ Day ,,
v. BOD	Wrinkler Titration Method	3 samples/ Day ,,
vi. COD	Oxidizing Organic matter	3samples/ Day ,,
i. Total Nitrogen content	By Kjeidahl method	3 samples/ Day ,,
ii. Phosphate con.	By Spectrophotometer	3 samples/ Day ,,
iii. Heavy Metals	By Atomic Abortion Photometer	3 samples/ Day ,,

CHAPTER 4

RESULTS AND DISCUSSION

The study shows the relationship among different parameters of the pH, TSS, TDS, Heavy Metals, Phosphate, EC, BOD, COD and Total Nitrogen. This has been discussed critically as follows.

Table 4.1: Characteristics of Leachate from Maharagama Dumpsite.

Date	S No	EC Ms/cm	TDS mg/l	pH	PO_4^{-3} (mg/l)	COD mg/l	BOD mg/l	BOD/CO ratio
17-Jul	1	3.72	1350	8.21	2467.5	29800	4850	0.163
	2	4.62	1367	7.74	842.5	16800	3200	0.190
	3	5.85	1360	7.5	810.2	10200	3600	0.353
19-Jul	1	3.65	1365	7.59	2450.5	28000	5200	0.186
	2	4.2	1370	8	800.2	16000	2846	0.178
	3	5.6	1364	7.45	792.6	10000	3300	0.330
21-Jul	1	2.58	1350	8.25	2617.5	29000	4900	0.169
	2	3.99	1369	7.8	838.5	16400	3600	0.220
	3	4.58	1362	7.64	805.4	10600	2900	0.274
23-Jul	1	3.02	3732	8.75	1712.5	30000	4600	0.153
	2	4.65	1367	9.01	840	17400	2850	0.164
	3	5	1358	7.58	820.3	9600	3500	0.365
25-Jul	1	2.98	3520	8.98	1497.5	26200	4700	0.179
	2	0.48	1364	9.46	830.1	15800	3152	0.199
	3	8.33	1351	7.32	808.45	11000	3017	0.274
27-Jul	1	2.65	3540	8.75	1490	27000	5150	0.191
	2	0.45	1350	9.4	825.6	15650	4010	0.256
	3	8.23	1340	7.3	805.2	11100	3125	0.282

Table 4.2: Heavy Metal Profile of Leachates from Maharagama Dumping ground during 2006-July measured in ppm.

Date	Sample No	Cu	Ni	Pb	Zn	Ca
17-Jul	1	0.072	0.065	0.011	0.005	16.3
	2	0.013	0	0	0.89	10.85
	3	0.042	0	0	0	10.88
19-Jul	1	0.074	0.068	0.014	0.031	36.5
	2	0.02	0	0	0.75	12.85
	3	0.04	0	0	0	10.52
21-Jul	1	0.072	0.061	0.011	0.006	15.69
	2	0.011	0	0	0.632	11.23
	3	0.042	0	0	0	10.25
23-Jul	1	0.073	0.066	0.013	0.029	12.58
	2	0.013	0	0	0.589	10.45
	3	0.04	0	0	0	10.25
25-Jul	1	0.071	0.06	0.01	0.02	13.5
	2	0.012	0	0	0.92	11.2
	3	0.04	0	0	0	10.8

Table 4.3: Characteristics of Leachate from Senanayaka Dump site in the Newalla

Sampling days	Sample No	EC Ms/cm	TDS mg/l	pH	PO_4^{-3} (mg/l)	COD mg/l	BOD mg/l	BOD/COD	Total N
17-Jul	1	1.56	1135	6.95	1117.5	31800	4500	0.142	0.056
	2	0.54	1222	7.05	317.5	2600	3800	1.462	0.053
	3	0.58	1036	6.9	532.5	4000	3250	0.813	0.051
19-Jul	1	1.55	1898	7.14	1517.5	17400	4800	0.276	0.054
	2	1.64	1200	7.01	202.5	3000	4200	1.400	0.048
	3	1.85	1140	7.11	485.6	14600	3700	0.253	0.053
21-Jul	1	2.75	1450	6.98	1485.2	18000	4700	0.261	0.045
	2	1.8	1150	7.05	320.4	4400	3500	0.795	0.052
	3	1.82	1278	7.12	550.75	10400	3100	0.298	0.05
23-Jul	1	3.76	1880	7.89	1510.2	15600	4400	0.282	0.055
	2	1.82	1265	7.02	318.95	3000	3800	1.267	0.052
	3	1.84	1036	7.15	520.45	14000	3300	0.236	0.051
25-Jul	1	2.95	1897	8.18	1564.8	16400	5020	0.306	0.482
	2	1.79	1300	7.96	312.5	3400	3100	0.912	0.046
	3	1.02	1025	7.03	508.65	13600	3200	0.235	0.052
27-Jul	1	2.65	1850	8.12	1550	15800	5100	0.323	0.056
	2	1.74	1295	7.78	310.5	3410	2800	0.821	0.052
	3	1	1018	7.01	505.9	13400	3600	0.269	0.053

Table 4.4: Heavy Metal Profile of Leachates from Senanayaka Dumpsite during 2006-July measured in ppm.

Days	Sample No	Cu	Ni	Pb	Zn	Ca	Cr
17-Jul	1	0.03	0.194	0	0.008	13.85	0.01
	2	0.012	0	0	0	38.66	0
	3	0.014	0	0	0	11.59	0
19-Jul	1	0.031	0.18	0	0.007	12.52	0.098
	2	0.038	0	0	0	35.6	0
	3	0.014	0	0	0	10.8	0
21-Jul	1	0.03	0.185	0	0.006	13.42	0.021
	2	0.077	0	0	0	36.3	0
	3	0.013	0	0	0	11.2	0
23-Jul	1	0.002	0.19	0	0.006	14.5	0.02
	2	0.076	0	0	0	29.42	0
	3	0.014	0	0	0	10.8	0
25-Jul	1	0.025	0.192	0	0.059	14.21	0.095
	2	0.04	0	0	0	24.3	0
	3	0.019	0	0	0	10.12	0

Table 4.5: Characteristics of Leachate from Buthgamuwa Dumpsite in the Kotte

Day	Sam No	EC ms/cm	TDS mg/l	pH	PO_4^{-3} (mg/l)	COD mg/l	BOD mg/l	BOD/COD ratio	Total N
17-Jul	1	2.83	2306	7.39	1232.5	4800	1850	0.385	0.042
	2	2.1	223	7.14	457.5	1600	1500	0.938	0.043
	3	2.5	241	7.18	552.5	1400	1240	0.886	0.041
19-Jul	1	4.5	1898	7.12	1122.5	5200	2520	0.485	0.042
	2	2	256	7.41	425.3	1900	1430	0.753	0.051
	3	3.4	242	7.01	550.1	1560	1200	0.769	0.056
21-Jul	1	3.35	2530	7.05	2580.6	5000	1763	0.353	0.043
	2	2.18	225	8.01	398.5	1500	1480	0.987	0.041
	3	3.2	220	7.49	492.1	1600	1130	0.706	0.042
23-Jul	1	8.48	2416	8.21	1850.4	5200	3020	0.581	0.053
	2	0.28	266	7.45	420.1	1600	1510	0.944	0.054
	3	3.1	248	7.02	551.3	1540	1200	0.779	0.052
25-Jul	1	11.66	1775	7.45	3732.5	4800	3000	0.625	0.051
	2	0.4	242	7.1	410	1800	2500	1.389	0.042
	3	3.4	250	7.65	549.5	1600	2100	1.313	0.043
27-Jul	1	11.55	1776	7.4	3720.2	5000	4250	0.850	0.058
	2	0.42	240	7	405	1840	2850	1.549	0.05
	3	3.32	260	7.63	545.9	1700	2300	1.353	0.038

Table 4.6: Heavy Metal Profile of Leachates from Buthgamuwa Dumping ground during 2006-July, measured in ppm.

DAYS	Sam No	Cu	Ni	Pb
17-Jul	1	0.125	0.011	0.171
	2	0.244	0	0
	3	0	0	0
19-Jul	1	0.123	0.044	0.123
	2	0.071	0	0.028
	3	0	0	0
21-Jul	1	0.1	0.133	0.108
	2	0.06	0	0
	3	0	0	0
23-Jul	1	0.12	0.064	0.105
	2	0.071	0	0
	3	0	0	0
25-Jul	1	0.121	0.12	0.12
	2	0.065	0	0
	3	0	0	0

Table 4.7: Characteristics of Leachate from Karadeyanna Dump site

Day	Sam No	EC ms/cm	TDS mg/l	pH	PO_4^{-3} (mg/l)	COD mg/l	BOD mg/l	BOD/COD ratio	Total N
19-Jul	1	6.11	2598	6.11	6922.5	11600	3996	0.344	0.045
	2	6.09	1256	6.09	3692.5	8400	2500	0.298	0.048
	3	7.38	1430	7.38	3654.5	7500	2600	0.347	0.051
21-Jul	1	18.54	2430	6.5	5840	10000	4000	0.400	0.042
	2	10.02	1350	7.2	3525.4	8000	1850	0.231	0.056
	3	5.01	1400	7.54	2968.5	7540	2540	0.337	0.048
23-Jul	1	19.45	2400	8.62	6010.8	11000	3882	0.353	0.053
	2	19.49	1325	7.23	4172.5	8000	2400	0.300	0.051
	3	8.06	1425	7.99	3525	7400	2550	0.345	0.055
25-Jul	1	16.37	2520	8.53	6748.5	10400	4010	0.386	0.046
	2	5.04	1526	6.5	4025.8	8600	2250	0.262	0.041
	3	12.3	1418	7.25	3625.1	7350	2500	0.340	0.052
27-Jul	1	16.2	2525	8.5	6750	10200	3956	0.388	0.05
	2	5.02	1520	6.4	4024.3	8400	2300	0.274	0.048
	3	12	1419	7.2	3620.1	7420	2450	0.330	0.053

Table 4.8: Heavy Metal Profile of Leachates from Karadeyana Dumping ground during 2006-July, measured in ppm.

Day	Sam No	Cu	Ni	Pb	Zn	Ca	Cr
19-Jul	1	0.233	1.49	1.725	0.045	72.4	6.035
	2	0	0.9	0.253	0	12.05	0.414
21-Jul	1	0.038	1.32	1.647	0.023	70.3	6.05
	2	0	0.844	1.25	0	12.04	0.314
23-Jul	1	0.046	1.398	1.823	0.624	68.9	5.82
	2	0	0.706	0.986	0	10.82	0.42
25-Jul	1	0.174	1.485	1.582	0.26	70.3	6.04
	2	0	0.908	1.342	0	11.8	0.035

4.1 Comparison of dumpsite leachate Characteristic

Table 4.9 Comparison of dumpsite leachate electrical conductivity (EC)

Sampling Days	EC -S	EC-B	EC-M	EC-K
17-Jul	0.89	2.48	4.73	0
19-Jul	1.68	3.3	4.48	6.53
21-Jul	2.12	2.91	3.72	11.19
23-Jul	2.47	3.95	4.22	15.67
25-Jul	1.92	5.15	3.93	11.24
27-Jul	1.80	5.1	3.78	11.07

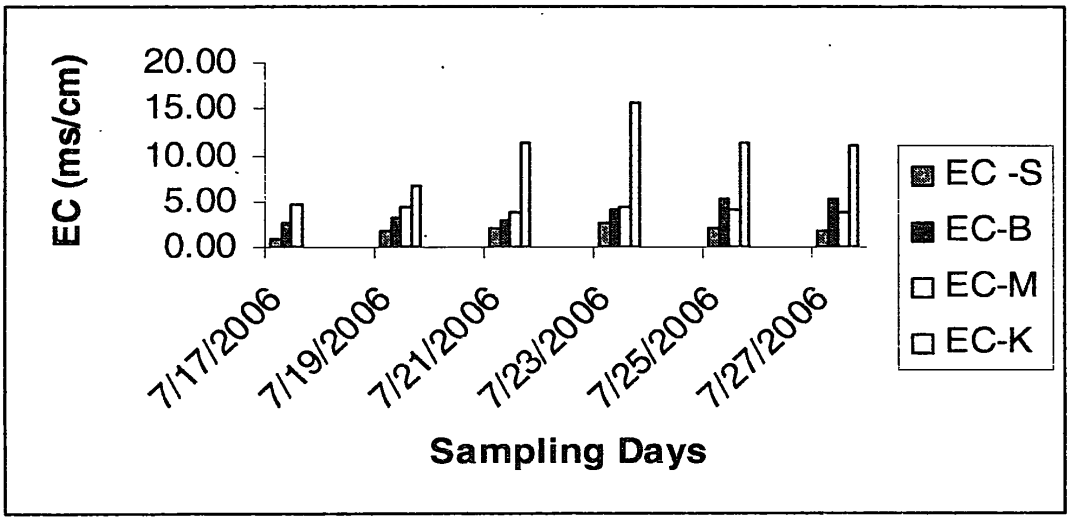

Figure 4.1: Comparison of average electrical conductivity values of Maharagama, senanayaka, Buthgama and Karadeyanna dumpsites leachates

Biochemical Oxygen Demand (BOD)

Table 4.10 Comparison of dumpsite leachates Biochemical Oxygen Demand (BOD)

Sampling Days	BOD-S	BOD-B	BOD-M	BOD-K
17-Jul	3850	1326.62	3883.33	0
19-Jul	4233.33	1716.67	3782	3032
21-Jul	3666.67	1457.67	3800	2796.67
23-Jul	3833.33	1910	3650	2944
25-Jul	3773.33	2533.33	3623	2920
27-Jul	3833.33	3133.33	4095	2902

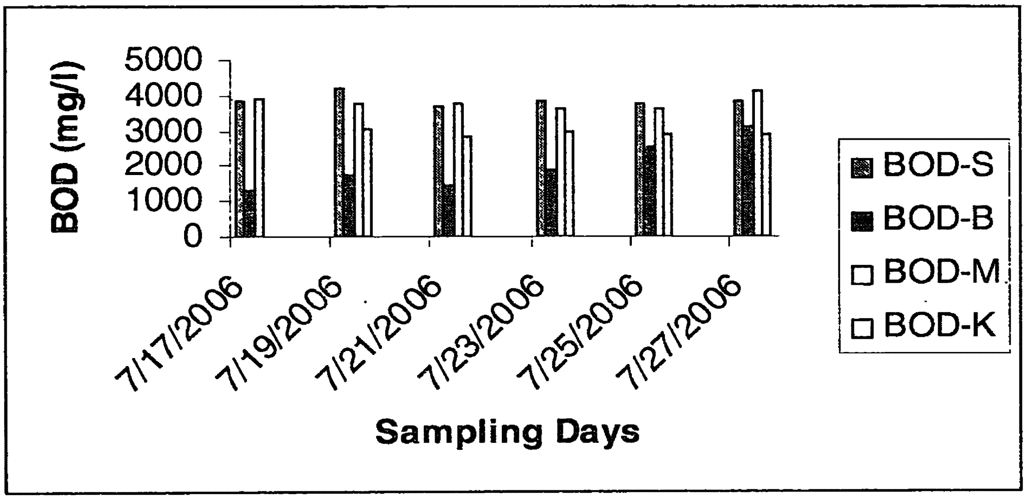

Figure 4.2: Comparison of average Biochemical Oxygen Demand Values of Maharagama, senanayaka, Buthgama and Karadeyanna dumpsites leachates

Chemical Oxygen Demand (COD)

Table 4.11 Comparison of dumpsite lachates Chemical Oxygen Demand (COD)

Sampling Days	COD-S	COD-B	COD-M	COD-K
17-Jul	12800	2600	18933.33	0
19-Jul	12133.33	2886.67	18000	9166.67
21-Jul	10933.33	2700	19333.33	8513.33
23-Jul	10866.67	2780	17733.33	8800
25-Jul	11133.33	2733.33	17666.67	8783.33
27-Jul	10870	2846.67	17916.67	8673.33

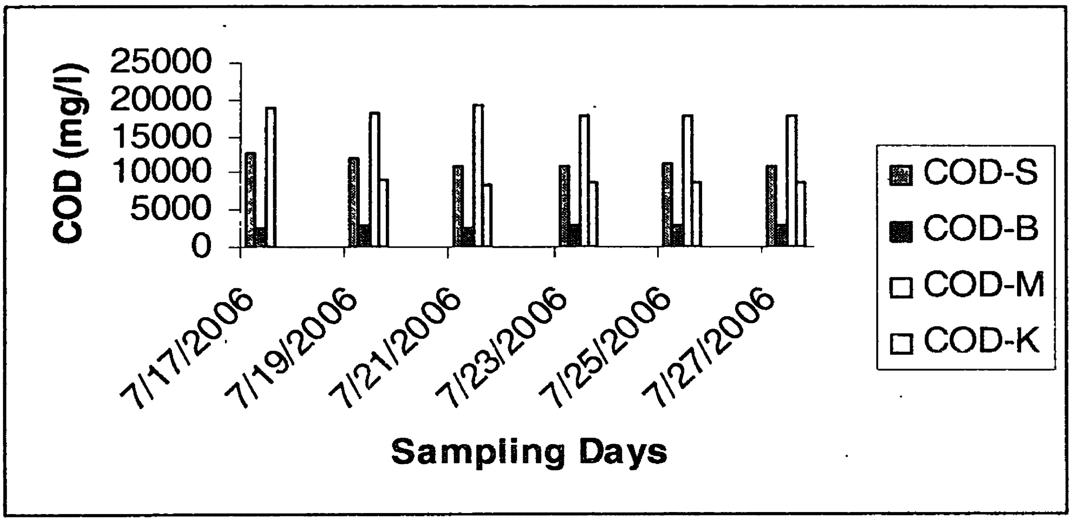

Figure 4.3: Comparison of Chemical Oxygen Demand Values of Maharagama, senanayaka, Buthgama and Karadeyanna dumpsites leachate

BOD/COD Ratio

Table 4.12 Comparison of dumpsite leachates BOD/COD Ratio

Sampling Days	S	B	M	K
17-Jul	0.813	0.736	0.24	
19-Jul	0.253	0.669	0.23	0.33
21-Jul	0.298	0.682	0.22	0.32
23-Jul	0.236	0.768	0.23	0.33
25-Jul	0.235	1.109	0.22	0.33
27-Jul	0.269	1.251	0.24	0.33

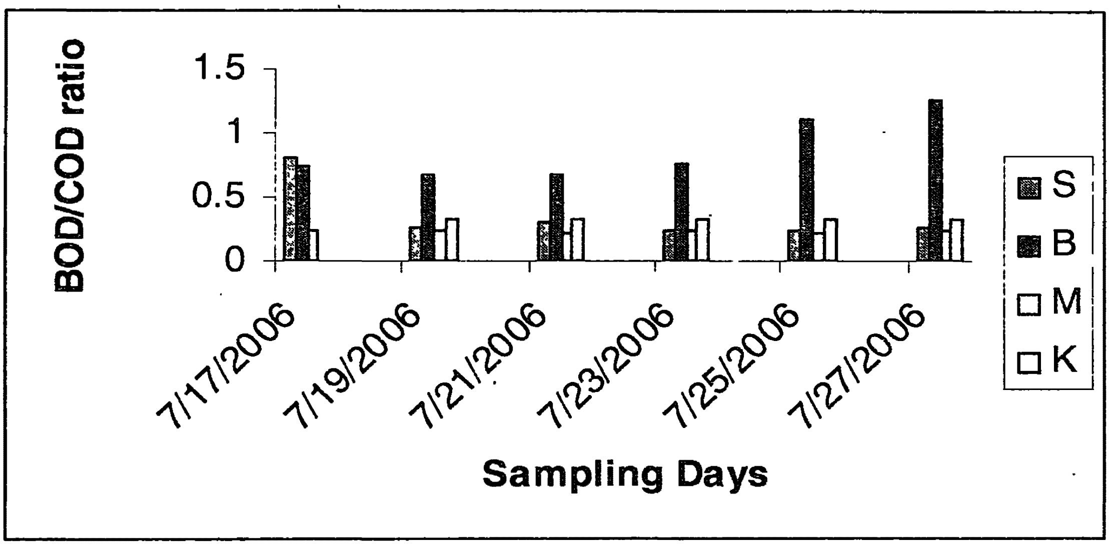

Figure 4.4: Comparison of BOD/COD ratio of Maharagama, senanayaka, Buthgama and Karadeyanna dumpsites leachate.

PH

Table 4.13Comparison of dumpsite Leachate pH

Sampling Days	PH-S	PH-B	PH-M	PH-K
17-Jul	6.97	7.24	7.82	0
19-Jul	7.09	7.18	7.68	6.53
21-Jul	7.05	7.52	7.9	7.08
23-Jul	7.35	7.56	8.45	7.95
25-Jul	7.72	7.4	8.59	7.43
27-Jul	7.64	7.34	8.48	7.37

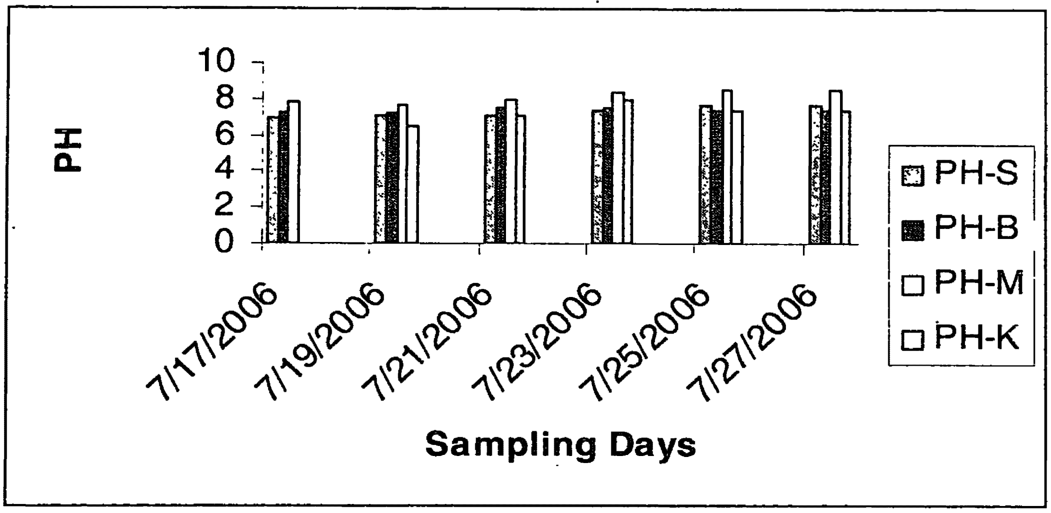

Figure 4.5: Comparison of Ph values Maharagama, senanayaka, Buthgama and Karadeyanna dumpsites leachates

Phosphate

Table 4.14 Comparison of dumpsite Leachate Phosphate concentration

Sampling Days	PHO-S	PHO-B	PHO-M	PHO-K
17-Jul	655.83	747.5	1373.4	0
19-Jul	735.2	699.3	1347.77	4756.5
21-Jul	785.45	1157.07	1420.47	4111.51
23-Jul	783.2	940.6	1124.27	4569.43
25-Jul	795.32	1564	1045.35	4799.79
27-Jul	788.8	1557.03	1040.27	4798.13

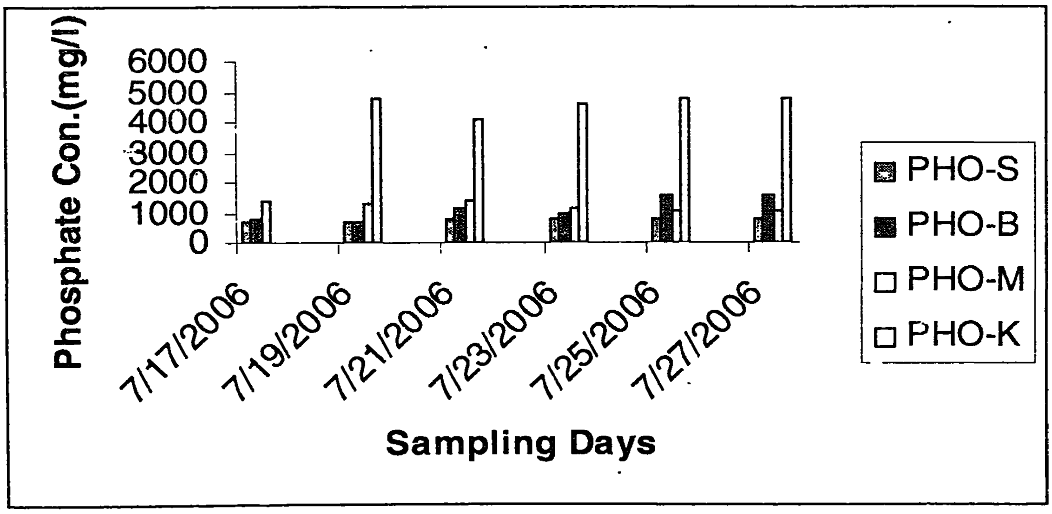

Figure 4.6: Comparison of phosphate concentration in Maharagama, senanayaka, Buthgama and Karadeyanna dumpsites leachates

Total Nitrogen

Table 4.14 Comparison of Dumpsite Leachate Total Nitrogen

Sampling Days	S	B	M	K
17-Jul	0.053	0.028	0.015	0.042
19-Jul	0.052	0.031	0.02	0.04
21-Jul	0.049	0.028	0.0148	0.038
23-Jul	0.053	0.036	0.016	0.043
25-Jul	0.193	0.048	0.021	0.051
27-Jul	0.054	0.043	0.023	0.056

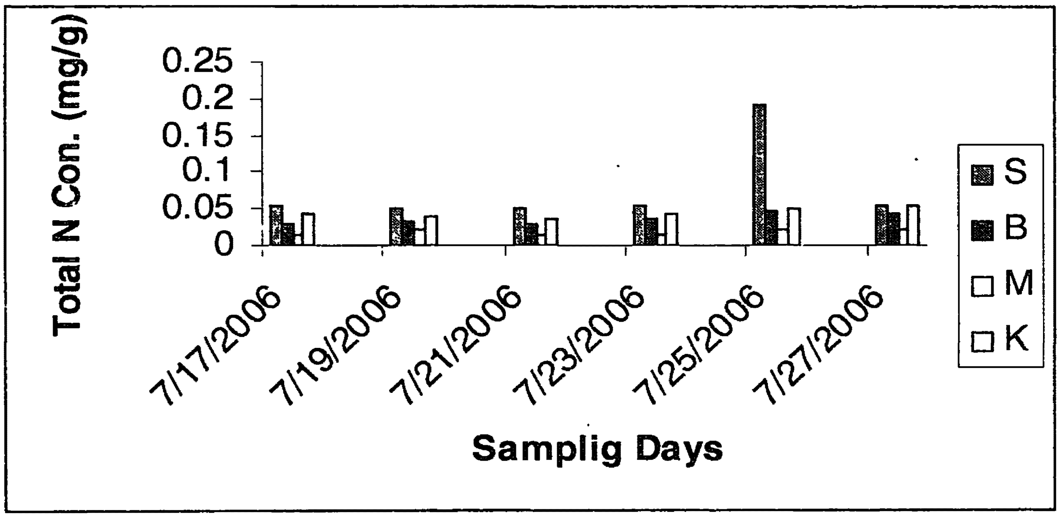

Figure 4.7: Comparison of total nitrogen concentration in Buthgama, Senanayaka, Maharagama and Karadeyanna dumpsites leachates

Electrical Conductivity (EC)

There was hardly any accumulation of ions from the dumpsite of Maharagama, since the sampling point in the watercourse show higher EC values than in the centre of the dumpsite or in between the first and third point. Thus, leaching takes place in a regular manner. The EC values of Senanayake cannot be compared since all of the sampling points were in the marsh. Unlike Maharagama being an old dump, the EC values of Buthgamuwa was different indicating higher EC values in the waste as compared to lower down in the watercourse. In the Karadeyanna dumpsite, leachate contained higher electrical conductivity than that of other dumpsites. Also the Senanayaka dumpsite leachate contained lowest electrical conductivity values.

Total Dissolved Solid (TDS)

At Maharagama the TDS levels were higher than Senenayaka and they both have regular discharge values. In the landfill surface of Buthgamuwa, the TDS values were relatively higher than the other two mentioned above but lower down on the middle sampling point and in the watercourse were very low. Very high values were found at the Karadeyanna.

Phosphate

Contrary to EC values, there seems to be an accumulation of phosphates on the surface of the dumpsite in Maharagama. It was so for Buthgamuwa as well with higher concentrations than Maharagama. The highest values were at Karadeyanna, which had attained 6922mg/l.

COD and BOD

Although Maharagama was an old dumpsite, the high values of COD and BOD indicate that there is active decomposition taking place on the surface. Similarly at Senenayaka, the values were high. However, at Buthgamuwa, the values were surprisingly low, similar to Karadeyanna. In all of the monitored points, there were hardly any variations between the days of sampling. Nevertheless, there have been large variations in the sampling points in the marsh of Senenayaka. In some occasions, the variations were so high from about 31000 mg/l to 2600mg/l of COD. Notably the Senanayaka and Maharagama dumpsites, leachate contained higher average BOD values, see Figure4.2 On the contrary, the leachate of Karadeyanna dumpsite contained lower BOD values. These differences in BOD may be attributed to the variations in decompositions, meaning aerobic/anaerobic conditions prevailing of the solid waste at the sampling point of Senanayaka, Maharagama, Buthgama and Karadeyanna dumpsites.

Variations in organic indicator ratio (BOD/COD) of the leachates obtained from Senanayaka, Buthgama, Maharagama and Karadeyanna dumpsites are presented in figure 6. BOD/COD ratios indicate the proportion of biodegradable organic matter, which decreased with age of the landfill.

Table 4.15 : Heavy metal profile of leachate from Maharagama Dumpsite.

Sampling Days	Cu	Ni	Pb
17-Jul	0.042	0.022	0.004
19-Jul	0.045	0.023	0.005
21-Jul	0.042	0.02	0.004
23-Jul	0.042	0.022	0.004
25-Jul	0.041	0.02	0.003
27-Jul	0.04	0.021	0.025

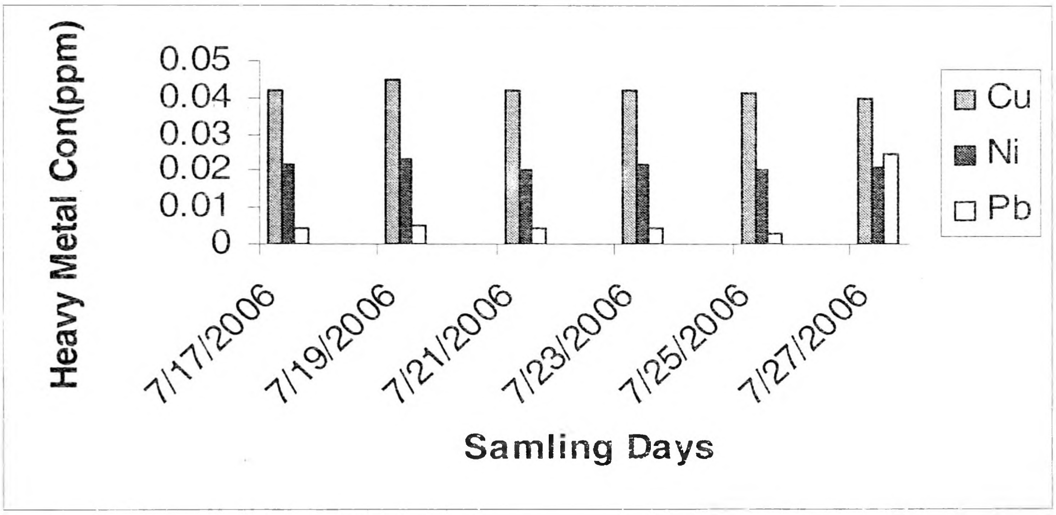

Figure 4.8: Comparison of Heavy Metal concentration in Maharagama dumpsites leachates

Table 4.16 : Heavy Metal Profile of Leachate from Senanayaka Dumpsite

Sampling Days	Cu	Ni	Zn
17-Jul	0.019	0.065	0.003
19-Jul	0.028	0.06	0.002
21-Jul	0.04	0.062	0.002
23-Jul	0.031	0.063	0.002
25-Jul	0.028	0.064	0.02
27-Jul	0.025	0.061	0.025

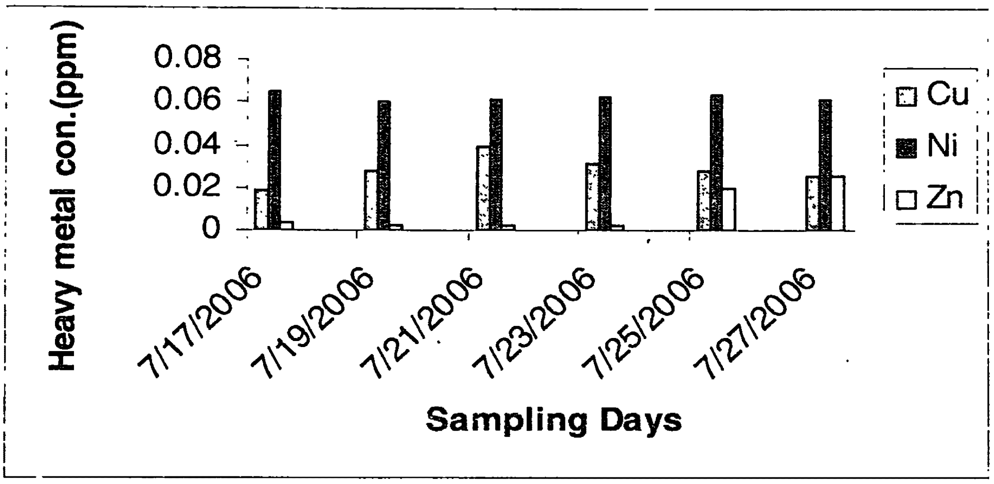

Figure 4.9: Comparison of Heavy Metal concentration in Senanayaka Dumpsites Leachates

Table 4.17 : Heavy metal profile of leachate from Buthgama Dumpsite

Sampling Days	Cu	Ni	Pb
17-Jul	0.18	0.01	0.17
19-Jul	0.1	0.04	0.08
21-Jul	0.08	0.13	0.11
23-Jul	0.1	0.06	0.11
25-Jul	0.09	0.12	0.12
27-Jul	0.08	0.15	0.14

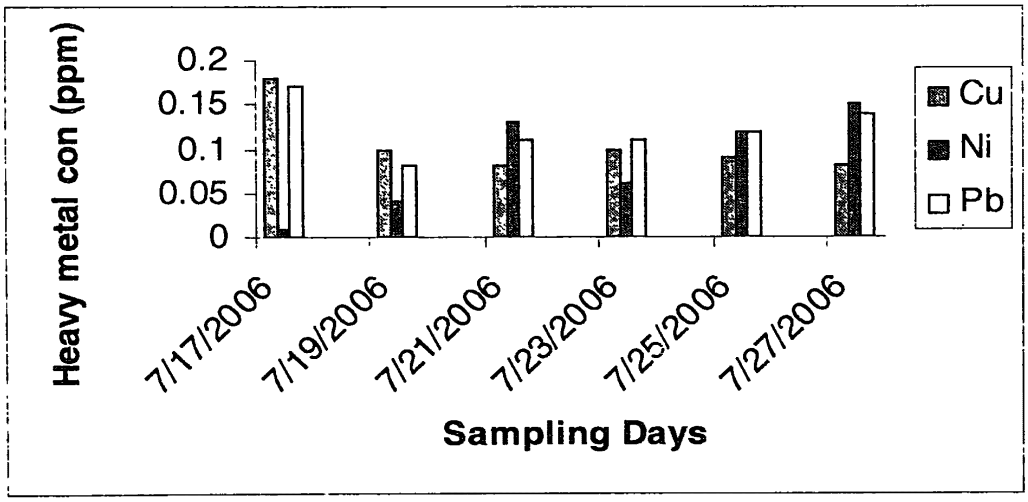

Figure 4.9: Comparison of Heavy Metal concentration in Buthgama dumpsites leachates

Table 4.18: Heavy Metal Profile of Leachate from Karadeyanna Dumpsite

Sampling Days	Cu	Ni	Pb	Zn
19-Jul	0.233	1.195	0.989	0.045
21-Jul	0.038	1.082	1.449	0.023
23-Jul	0.046	1.052	1.405	0.624
25-Jul	0.174	1.197	1.462	0.26
27-Jul	0.164	1.232	1.325	0.421

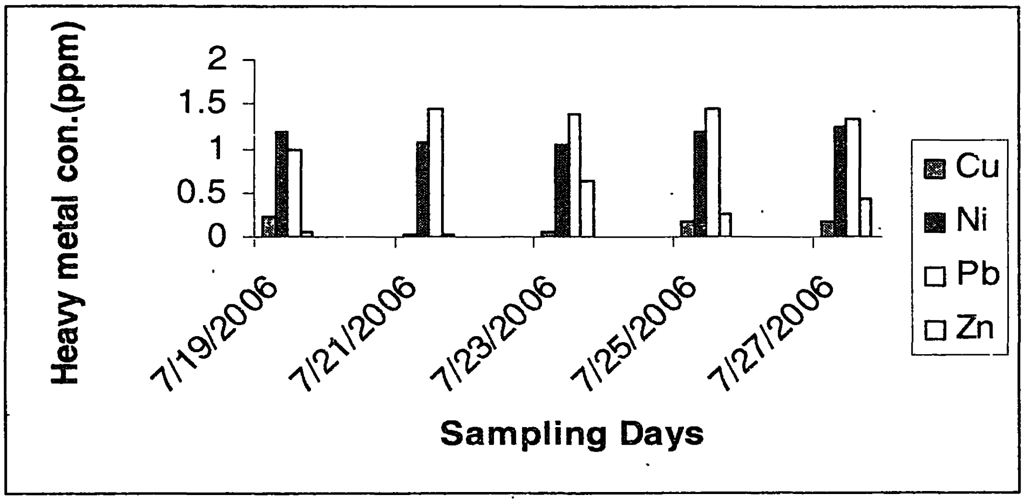

Figure 4.10: Comparison of Heavy Metal concentration in Karadeyanna dumpsites leachates

Heavy Metals

Copper concentrations on the surface ponds of the Maharagama dumpsite were higher than in the middle but with an increase in the watercourse. Both nickel and lead were found on the surface of the dump but not lower down in other two points of sampling. Interestingly, there seems to be an accumulation of zinc in the middle point of sampling. In other words, zinc is being held and thus leaching is not taking place of this heavy metal. As expected, slightly higher concentrations were found on the surface, lesser amount in the middle and slightly less in the watercourse.

Chromium was not detected at Maharagama. However, the levels at Senenayaka were very low as compared to Karadeyanna. Copper concentrations at Senenayaka were lower than Maharagama, but nickel concentrations were higher. Lead was totally absent in the samples tested from Senenayaka. However, calcium levels were much higher than Maharagama. Nickel concentrations in the surface leachate were 0.066, 0.133 and 0.195 respectively for Maharagama, Buthgama and Senenayaka. Like Nickel, the concentrations of lead were not found in the sampling points lower down in the middle and in the watercourse. The heavy metal concentrations at Karadeyanna were exceptionally high, except for copper in comparison with other locations. The chromium levels were as mush as 6.0

4.2 Quantifying Leachate Generations

There were number of attempts to run the HELP model and the version 3.07 may not be suitable for tropical conditions. However, it was tested for Maharagama and Karadeyanna dumpsites so that actual values could be monitored in the next phase of the study. The output indicates that 41% of the rainfall contributed to leachate for year 2002. The water balance is given in Figure 4.11. A high percentage is evaporated and the reaming is the runoff and sorption.

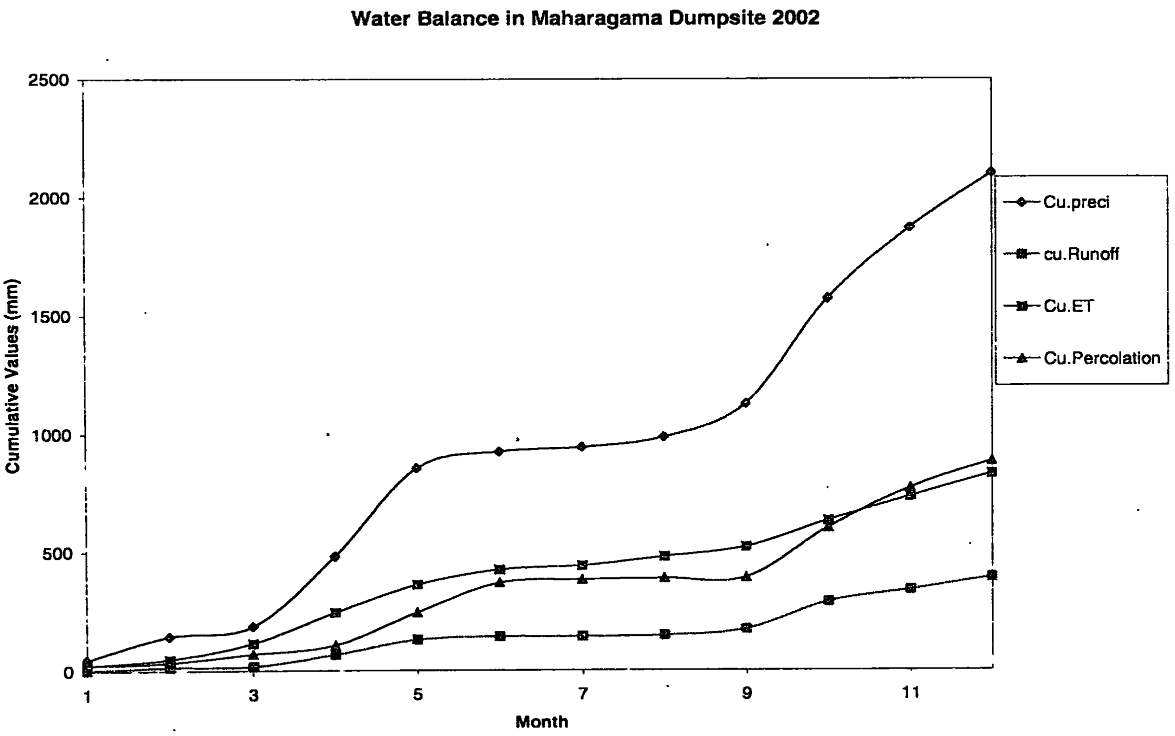

Figure 4.11 Water Balance in Maharagama Dumpsite 2002

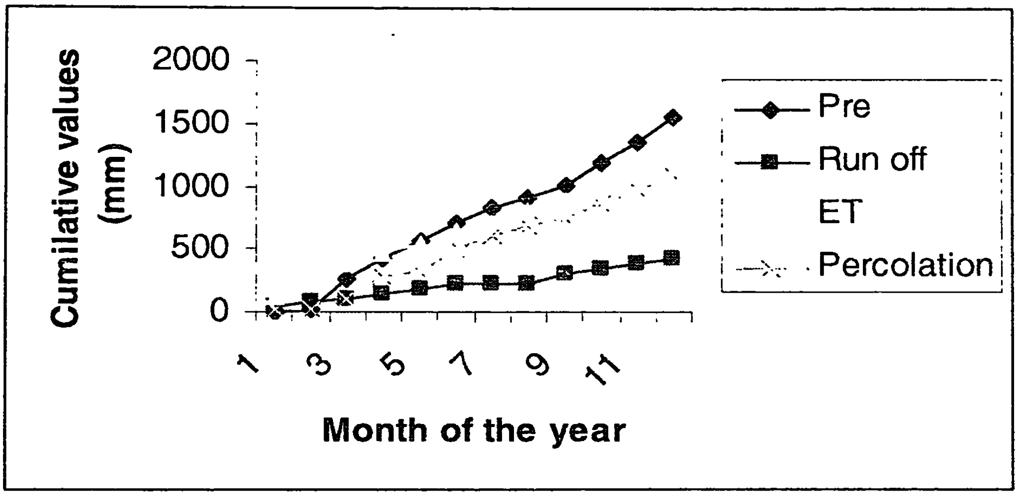

Figure 4.12 Water Balance in Maharagama Dumpsite 2001

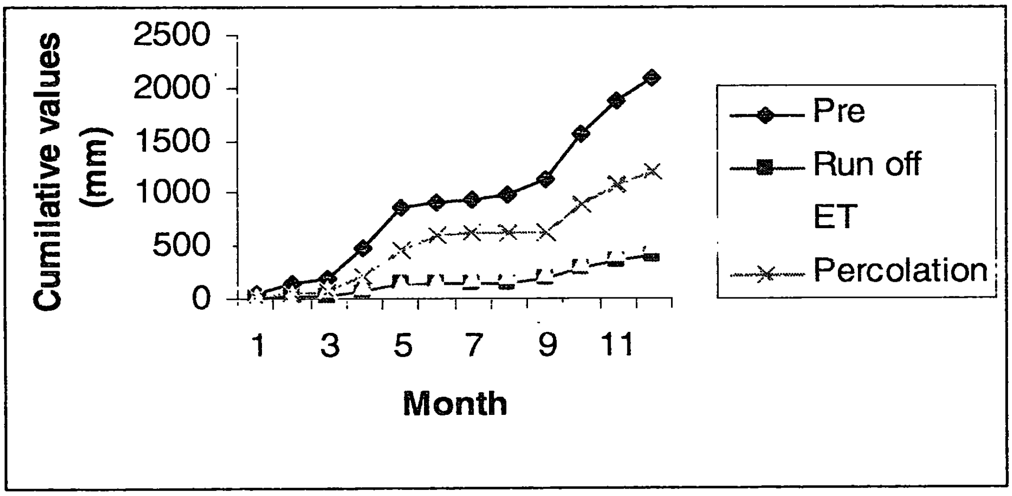

Figure 4.13 Water Balance in Karadeyanna Dumpsite 2001

4.3 General Discussion

Unorganized dumping of solid waste is predominant in developing countries like Sri Lanka and cause adverse impacts on the environment. Sources such as electronic goods, electro plating waste, painting waste, used batteries, etc., when dumped with municipal solid waste increase the heavy metals in landfills. Similarly, solid waste dumping without the separation of hazardous waste can raise toxic environmental effects. Slow leaching of these heavy metals under acidic environment during the degradation process lead to the leachates with high metal concentrations. Since leachates are one of the potential sources of ground water pollution, monitoring heavy metal content in dumpsites can facilitate the recommendation of suitable remedial measures.

Karadeyanna dumpsite which contain high amount of hazardous metals such as lead, nickel, copper, chromium and zinc is a potential problem for the local authorities using the dump. Such levels of heavy metals may be due to both small and large scale industries located in urban centers often disposing their industrial and hazardous wastes along with municipal solid waste. The environmental problem with heavy metals is that they are unaffected during degration of organic waste and have toxic effects on living organism when exceeding a certain concentration. When the compost from MSW is used as manure some heavy metals are being subjected to bioaccumulation and may cause risk to human health when transferred to the food chain. Exposure of heavy metals may cause blood and bone disorders, kidney damage and decreased mental capacity and neurological damage.

Most of the dumpsites exceed water quality standards set by Sri Lanka and it will continue to do so for at least another ten to fifteen years. Therefore, the rehabilitation measures should be taken to curtail heavy metal contaminations and also reduce the leachate concentrations similar to values found in Chennai, see section 2 and table2.2 and table 2.3. It is very interesting to compare with the Sri Lanka water quality standards. Only two of the dumpsites manifested chromium in the leachate and at Karadeyanna the values exceeded much above the threshold level of 0.5 mg/l. When copper was compared, it was found that all of the dumpsites are much less than the standard. Both Karadeyanna and Buthgama, the lead concentrations were high and above the required value, while Maharagama had traces of lead and none at Senenayaka. Incredibly high amounts of nickel were present in the samples that were from Karadeyanna. They were as much as 200% above the accepted concentrations by the authorities. As mentioned above copper as well as zinc were much below the accepted norms for discharging into water bodies.

CHAPTER 5

CONCLUSION

The influence of hydrodynamic properties on biochemical transformations of the dumpsites that were analyzed indicate that all of the dumpsites are polluting. Thus, the evaluations of most important indicative parameters point towards high levels of organic loading. Such loadings will influence and exert high pollution levels for a considerable duration of the life span expected of the dumpsites.

These dumps then should be rehabilitated and the degree of rehabilitation should be viewed from the potential of pollution such as high COD and BOD levels. All of the dumpsites exceed the water quality standards for these two parameters set for discharging into water bodies. Furthermore, leachate from both Buthgama and Karadeyanna far exceeds threshold levels of heavy metal concentrations, more so from the dumpsite at Karadeyanna.

Further research on monitoring is required to substantiate the findings. Also accurate predictions of the leachate generation rates are important to assess the total loading on water bodies and wetland ecosystems. The present problems of accurate predictions with the HELP model should be overcome or else another model should be developed for the tropical countries like Sri Lanka.

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APPENDIX 1

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***********************************************************************
*********

      TITLE:  LEACHATE EMISSION FROM THE KARADEYANNA DUMPSITE IN 2001

***********************************************************************
*********


      NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
WERE
                COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                         LAYER  1
                                         --------

                           TYPE 1 - VERTICAL PERCOLATION LAYER
                               MATERIAL TEXTURE NUMBER   6
            THICKNESS                     =      45.00    CM
            POROSITY                      =       0.4530 VOL/VOL
            FIELD CAPACITY                =       0.1900 VOL/VOL
            WILTING POINT                 =       0.0850 VOL/VOL
            INITIAL SOIL WATER CONTENT    =       0.1639 VOL/VOL
            EFFECTIVE SAT. HYD. COND.     =  0.720000011000E-03 CM/SEC
          NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY
1.80
                    FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                         LAYER  2
                                         --------

                           TYPE 1 - VERTICAL PERCOLATION LAYER
                               MATERIAL TEXTURE NUMBER  19
            THICKNESS                     =     120.00    CM
            POROSITY                      =       0.1680 VOL/VOL
            FIELD CAPACITY                =       0.0730 VOL/VOL
            WILTING POINT                 =       0.0190 VOL/VOL
            INITIAL SOIL WATER CONTENT    =       0.0730 VOL/VOL
            EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC


                                         LAYER  3
                                         --------

                           TYPE 1 - VERTICAL PERCOLATION LAYER
                               MATERIAL TEXTURE NUMBER  11
            THICKNESS                     =      60.00    CM
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```
          POROSITY                         =      0.4640 VOL/VOL
          FIELD CAPACITY                   =      0.3100 VOL/VOL
          WILTING POINT                    =      0.1870 VOL/VOL
          INITIAL SOIL WATER CONTENT       =      0.3666 VOL/VOL
          EFFECTIVE SAT. HYD. COND.        =  0.639999998000E-04 CM/SEC



              GENERAL DESIGN AND EVAPORATIVE ZONE DATA
              ----------------------------------------

         NOTE:  SCS RUNOFF CURVE NUMBER WAS USER-SPECIFIED.

        SCS RUNOFF CURVE NUMBER                =      94.00
        FRACTION OF AREA ALLOWING RUNOFF       =      60.0    PERCENT
        AREA PROJECTED ON HORIZONTAL PLANE     =       5.0000 HECTARES
        EVAPORATIVE ZONE DEPTH                 =      20.0    CM
        INITIAL WATER IN EVAPORATIVE ZONE      =       1.700  CM
        UPPER LIMIT OF EVAPORATIVE STORAGE     =       9.060  CM
        LOWER LIMIT OF EVAPORATIVE STORAGE     =       1.700  CM
        INITIAL SNOW WATER                     =       0.000  CM
        INITIAL WATER IN LAYER MATERIALS       =      38.131  CM
        TOTAL INITIAL WATER                    =      38.131  CM
        TOTAL SUBSURFACE INFLOW                =       0.00   MM/YR



              EVAPOTRANSPIRATION AND WEATHER DATA
              -----------------------------------

         NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
                 MAHARAGAMA            COLOMBO

             STATION LATITUDE                          = ****** DEGREES
             MAXIMUM LEAF AREA INDEX                   =   1.00
             START OF GROWING SEASON (JULIAN DATE)     =     93
             END OF GROWING SEASON (JULIAN DATE)       =    336
             EVAPORATIVE ZONE DEPTH                    =  20.0  CM
             AVERAGE ANNUAL WIND SPEED                 =   4.80 KPH
             AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  76.45 %
             AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  77.83 %
             AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  76.83 %
             AVERAGE 4TH QUARTER RELATIVE HUMIDITY     =  76.15 %


         NOTE:  PRECIPITATION DATA FOR     COLOMBO
 WESTERN
                 WAS ENTERED BY THE USER.


         NOTE:  TEMPERATURE DATA FOR     COLOMBO                WESTREN
                 WAS ENTERED BY THE USER.
```

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               NOTE:  SOLAR RADIATION DATA FOR      COLOMBO
WESTREN

                           MONTHLY TOTALS (MM) FOR YEAR 2002
  ----------------------------------------------------------------------
-----------

                                      JAN/JUL FEB/AUG MAR/SEP APR/OCT
MAY/NOV JUN/DEC
                                      ------- ------- ------- ------- ----
--- -------

 PRECIPITATION                         46.1    98.2    42.3   296.4
372.0    69.0
                                       18.2    42.5   140.3   445.2
299.5   231.8

 RUNOFF                                 2.15   11.75    2.85   54.69
66.31   13.38
                                        0.00    4.84   27.65  115.64
49.50   52.42

 EVAPOTRANSPIRATION                    21.48   24.89   45.36   26.96
27.79   26.68
                                       27.14   16.72   28.13   85.76
92.14   86.34

 PERCOLATION/LEAKAGE THROUGH           25.227  19.752  36.464 140.109
229.183 151.405
   LAYER  3                            17.031   9.188   3.097 261.196
178.526 119.151

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                                ANNUAL TOTALS FOR YEAR 2002
  ----------------------------------------------------------------------
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                                                  MM           CU. METERS
PERCENT
                                              ----------      ----------
-------
   PRECIPITATION                               2101.50        105074.992
100.00

   RUNOFF                                       401.191        20059.545
19.09

   EVAPOTRANSPIRATION                           509.382        25469.088
24.24

   PERC./LEAKAGE THROUGH LAYER  3              1190.328740     59516.434
56.64
```

```
   CHANGE IN WATER STORAGE                  0.599           29.946
0.03

   SOIL WATER AT START OF YEAR            381.311        19065.568

   SOIL WATER AT END OF YEAR              381.910        19095.514

   SNOW WATER AT START OF YEAR              0.000            0.000
0.00

   SNOW WATER AT END OF YEAR                0.000            0.000
0.00

   ANNUAL WATER BUDGET BALANCE             -0.0004          -0.019
0.00

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          AVERAGE MONTHLY VALUES (MM) FOR YEARS 2002 THROUGH 2002
  ---------------------------------------------------------------------
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                       JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV
JUN/DEC
                       -------  -------  -------  -------  -------
-------
   PRECIPITATION
   -------------
     TOTALS             46.10    98.20    42.30   296.40   372.00
69.00
                        18.20    42.50   140.30   445.20   299.50
231.80

     STD. DEVIATIONS     0.00     0.00     0.00     0.00     0.00
0.00
                         0.00     0.00     0.00     0.00     0.00
0.00

   RUNOFF
   ------
     TOTALS             2.148   11.747    2.852   54.693   66.314
13.378
                        0.000    4.839   27.654  115.643   49.500
52.423

     STD. DEVIATIONS    0.000    0.000    0.000    0.000    0.000
0.000
                        0.000    0.000    0.000    0.000    0.000
0.000
```

```
   EVAPOTRANSPIRATION
   ------------------
     TOTALS                  21.479    24.885    45.357    26.956    27.795
26.681
                             27.142    16.719    28.130    85.760    92.139
86.339

     STD. DEVIATIONS          0.000     0.000     0.000     0.000     0.000
0.000
                              0.000     0.000     0.000     0.000     0.000
0.000

   PERCOLATION/LEAKAGE THROUGH LAYER  3
   ------------------------------------
     TOTALS                  25.2267   19.7522   36.4640 140.1090
229.1833 151.4045
                             17.0312    9.1879    3.0969 261.1962
178.5256 119.1511

     STD. DEVIATIONS          0.0000    0.0000    0.0000    0.0000
0.0000   0.0000
                              0.0000    0.0000    0.0000    0.0000
0.0000   0.0000


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      AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 2002
THROUGH 2002
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                                             MM               CU. METERS
PERCENT
                                   --------------------     -----------

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  PRECIPITATION                    2101.50     (    0.000)     105075.0
100.00

  RUNOFF                            401.191    (   0.0000)      20059.54
19.091

  EVAPOTRANSPIRATION                509.382    (   0.0000)      25469.09
24.239

  PERCOLATION/LEAKAGE THROUGH      1190.32874  (   0.00000)     59516.437
56.64187
    LAYER  3

  CHANGE IN WATER STORAGE             0.599    (   0.0000)         29.95
0.028

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                 PEAK DAILY VALUES FOR YEARS 2002 THROUGH 2002
    -----------------------------------------------------------------
-------
                                                       (MM)       (CU.
METERS)
                                                     ----------   -------
-----
       PRECIPITATION                                 132.40
6620.000

       RUNOFF                                         60.852
3042.6211

       PERCOLATION/LEAKAGE THROUGH LAYER  3           38.425045
1921.25220

       SNOW WATER                                      0.00
0.0000


       MAXIMUM VEG. SOIL WATER (VOL/VOL)                         0.3941

       MINIMUM VEG. SOIL WATER (VOL/VOL)                         0.0850

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                    FINAL WATER STORAGE AT END OF YEAR 2002
    -----------------------------------------------------------------
------
                    LAYER           (CM)          (VOL/VOL)
                    -----          ------         ---------
                      1            7.4065          0.1646

                      2            8.7600          0.0730

                      3           22.0245          0.3671

                  SNOW WATER       0.000

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