UNIVERSITY OF NAIROBI

Department of Civil and Construction Engineering

Impact of Poor Solid Waste Management in Kenya on Groundwater

BY:

SIMEON OTIENO DULO

F80/7377/95

A Thesis submitted in Fulfilment for the Requirements of the Degree of Doctor of Philosophy in Civil Engineering of the University of Nairobi

July 2009

DECLARATION

I certify that although I may have conferred with others in preparing this document, and drawn upon a range of sources cited in this document, the content of this thesis is my original work and has not been presented for the award of a PhD degree at this or in any other university. All views and opinions expressed herein remain the sole responsibility of the author, and do not necessarily represent those of this University.

....

Dulo S. O.

Mr. Dulo S.O has submitted this project for examination with my approval as the University Supervisor.

....

Prof. P.M.A. Odira

DEDICATION

To the common good of mankind as expressed by dear wife Nyangi, and sons Mac, Andy and Paul, *'for we all pool together today to realize our tomorrow'*.

Beloved, let us love one another, for love is of God; and everyone who loves is born of God, and knows God. (1 John 4:7)

ACKNOWLEDGEMENT

I would like to thank the University of Nairobi's administration for the opportunity to undertake this study, a process that has greatly broadened my perspectives to service delivery in the solid waste sector in Kenya. I would also like to appreciate the efforts of my peers in the review of the document before finalization. I would like to express my sincere gratitude and appreciation to my supervisors, Prof. P.M Odira and Dr. Z.I. Oonge of the Department of Civil and Construction Engineering, University of Nairobi for their constant guidance and words of encouragement throughout the research work.

This thesis was developed through a process of literature review, field studies and laboratory investigations where experiences were shared. In view of this, special thanks go to all those who participated for their contributions that have greatly enriched the thesis. I would also like to thank all those organisations that shared information either through interviews or availing of literature. Special appreciation goes to my research assistants, Gichohi, Robert, Nesline, and Makori. God bless them abundantly. My gratitude also goes to Mr. Ng'anga and Mr. Thion'go of the Public Health Laboratory.

2009

ABSTRACT

One of the most obvious impacts of rapid urbanisation and economic development can be witnessed in the form of uncollected municipal solid waste. Solid waste tends to have moisture contents as high as 70%. This moisture translates into leachate as the waste drains. This study reports on solid waste management in selected towns in Kenya. It reviews the collection, handling, policy support, institutional development, private sector involvement, user participation, technical development and waste management. The study revealed that the urban councils were grappling with challenges of preventing environmental degradation due to non-systematic solid waste management and the impetus in pollution control was rather slow and seems to be mostly crisis driven. Review of the institutional strength and development revealed a low collection efficiency (all were between 30 to 40 % in the study period) and not comparable to even the worst performing cities in the world. In the three towns, Nairobi, Mombasa and Kisumu, there should be a decentralisation of authority and administrative measures, to build the powers and capacities of local governments commensurate with their solid waste management (SWM) responsibilities.

In this study, waste from test holes at a dumpsite located next to residential halls at the University of Nairobi were investigated for selected quality parameters in the laboratory. A leachate extraction setup was also developed for long-term quality variation study. From the leachate quality results the specific conductivity, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS) and Iron modelled linearly, gave good results with coefficient of determination (r^2) of 0.79, 0.73, 0.77, 0.88 and 0.75 respectively. The specific conductivity and TDS gave better results, with the poly fits of r^2 values of 0.89 and 0.95 respectively. On the other hand, the Turbidity and BOD exhibited better r^2 values of 0.71 and 0.82.

The other parameters tested in this study were not able to fit well in the three categories of fits, indicating the degree of variability in their biological and physical processes with time. The heavy metal concentrations expressed the widest variation over the study period, though the linear trend (with r^2 values of copper 0.25; zinc 0.26; Iron 0.75) fitted better in the heavy metal concentration than the exponential fits. The samples revealed that the concentration of COD, BOD, total hardness, TDS, chlorides, nitrates, iron and conductivity decreased with depth while those of Dissolved Oxygen (DO), pH and alkalinity increased with depth. The study further revealed that the level of pollution in the leachate generated from solid waste was higher than that for the leachate after it infiltrates into the soil.

The results of the parameters investigated were tested in linear and exponential models with the exponential fits giving the best possible results. The best fits were with the Total hardness, alkalinity, BOD, DO and TDS with r^2 values of 0.7, 0.64, 0.73, 0.65 and 0.72 respectively.

The study concluded that solid waste management problems facing Kenya were due to the lack of an appropriate waste management system in the urban centres. Inefficiency contributed to pollution by accumulations in uncollected waste and use of poor disposal techniques. The underlying consequence of this state is the deterioration of the environment in the form of air, water and land pollution. The role of private sector participation in solid waste management was noted to be positive.

The management of solid waste can be effectively addressed using a multi disciplinary approach, through an integrated solid waste management system in the country to accommodate the array of stakeholders' interests. The use of modelling in ground water pollution should be encouraged as it provides useful sensitisation facts on SWM.

LIST OF NOTATIONS

BOD	Biochemical Oxygen Demand
CBD	Central Business District
CBDA	Central Business District Association
CBO	Community Based Organization
CBP	Capacity Building Programme
CDS	City Development Strategy
COD	Chemical Oxygen Demand
DoE	Department of Environment - Nairobi City Council
EIC	Emerging Industrialised Countries
EMCA	Environmental Management and Coordination Act, 1999
EPHC	Environmental Protection and Heritage Council
FSDA	Foundation for Sustainable Development
GIS	Geographic Information System
GOK	Government of Kenya
GTZ	Deutsche Gesellschaft Techniche Zusammenarbeit
IDB	Inter-American Development Bank, Washingtonne DC
ILO	International Labour Organization
ISWA	International Solid Waste Association
ISWM	Integrated Solid Waste Management
JFA	Jobs for Africa
JICA	Japan International Cooperation Agency
KARA	Kenya Alliance of Residential Associations
LADP	Local Authority Development Plan
MENR	Ministry of Environment and Natural Resources
MOH	Ministry of Health
MOIC	Ministry of Industry and Commerce
MoLG	Ministry of Local Government
MSE	Micro and Small Enterprises
MSW	Municipal Solid Waste

MSWM	Municipal Solid Waste Management
NASWAMA	Nairobi Solid Waste Management Association
NCBDA	Nairobi Central Business District Association
NCC	Nairobi City Council
NCCK	National Council of Churches of Kenya
NCRR	National Center for Resource Recovery
NEAP	National Environmental Action Plan
NEMA	National Environment Management Authority
NEC	National Environment Council
NES	National Environmental Secretariat
NGO	Non-Governmental Organization
NISCC	Nairobi Informal Settlements Committee
PRSP	Poverty Reduction Strategy Paper
PSI	Private Sector Involvement
PSIA	Programme Support Implementation Arrangement
RA	Residents Associations
RDF	Refuse-derived fuel
r^2	Coefficient of determination
SIDI	Secretariat for Infrastructure Development and Investment
STDP	Small Towns Development Programme
SWM	Solid Waste Management
TDS	Total Dissolve Solids
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFPA	United Nations Fund for Population Activities
UNCHS	United Nations Centre for Human Settlements (Habitat)
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
WTE	Waste to Energy

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 General

Effective and sustainable management of solid waste is becoming a burgeoning problem for national and local governments due to rapid increase in volume and types of solid and hazardous waste as a result of continuous economic growth, urbanization and industrialization. The United Nations Environmental Program (UNEP) integrated solid waste management plan (UNEP, 2009a) estimated that in 2006 the total amount of municipal solid waste (MSW) generated globally reached 2.02 billion tonnes, representing a 7% annual increase since 2003. It further estimated that between 2007 and 2011, global generation of municipal solid waste will rise by 37.3%, equivalent to roughly 8% increase per year. Based on incomplete reports from its participants, the Basel Convention estimated that about 318 and 338 million tonnes of hazardous and other waste were generated in 2000 and 2001 respectively. Healthcare waste is classified as a sub-category of hazardous wastes in many countries.

The World Health Organisation (WHO) estimates that the total health-care waste per person per year in most low-income countries is anywhere from 0.5 kg to 3 kg (UNEP, 2009d). There is no estimate about global industrial wastes generation. The United States Environmental Protection Agency (USEPA, 2006) estimates that, American industrial facilities generate and dispose of approximately 7.6 billion tonnes of non-hazardous industrial solid waste each year. The EU estimated that its 25 member states produce 700 million tonnes of agricultural waste annually. Waste Electrical and Electronic Equipment (WEEE) or E-waste is also one of the fastest growing waste streams and it equals to 1% of total solid waste on an average in developing countries. It is expected to grow to 2% by 2010 (UNEP, 2009a). Although considerable efforts are being made by many Governments and other entities in tackling waste-related problems, there are still major gaps to be filled in this area.

The World Bank estimates that in developing countries, it is common for municipalities to spend 20-50 percent of their available budget on solid waste management (open dumping with open burning is the norm), even though 30-60 percent of all the urban solid wastes remain uncollected and less than 50 percent of the population is served. In low-income countries, collection alone drains up to 80-90 percent of municipal solid waste management budget.

In mid-income countries, collection costs 50-80 percent the total budget. In high-income countries, collection only accounts for less than 10 percent of the budget, which allows large funds to be allocated to waste treatment facilities. Upfront community participation in these advanced countries reduces the collection cost and facilitates waste recycling and recovery (World Bank, 2008).

Hence, developing countries face uphill challenges to properly manage their waste with most efforts being made to reduce the final volumes and to generate sufficient funds for waste management. If most of the waste could be diverted for material and resource recovery, then a substantial reduction in final volumes of waste could be achieved and the recovered material and resources could be utilized to generate revenue to fund waste management. This forms the premise for Integrated Solid Waste Management (ISWM) system, based on the 3R (reduce, reuse and recycle) principle. ISWM system has been pilot tested in a few locations (Wuxi, PR China; Pune, India; Maseru, Lesotho) and has been well received by local authorities. It has been shown that with appropriate segregation and recycling system a significant quantity of waste can be diverted from landfills and converted into a useful resource. Developing and implementing ISWM requires comprehensive data on present and anticipated waste situations, supportive policy frameworks, knowledge and capacity to develop plans/systems, proper use of environmentally sound technologies, and appropriate financial instruments to support its implementation (Scheinberg, 2001b).

1.2 Kenyan context

According to Rotich et al (2005), poor economic growth (1.1% in 1993 and less than 2% in 2001) has resulted in an increase in the poverty level which stood at 56% in 2001. Economic migration from the rural areas to the urban areas resulted in unplanned settlements in peri-urban areas, accommodating about 60% of the urban population on only 5% urban land area. This trend has lead to comparatively high urban growth rates with little infrastructure expansion to match it. This urbanization and accompanying industrialization in a situation of overstretched infrastructure is one of the major challenges facing the Kenya government.

The benefit of urbanization in Kenya has come along with environmental and social ills, some of staggering proportions. They include a diversity of problems ranging from lack of access to clean drinking water, illegal waste dumping and improper disposal of solid wastes and hazardous wastes. Urbanization also poses potential threats to the quantity and quality of water resources.

This scenario is a complex one and can be looked at in terms of water movement modes in built-up urban areas. Increases in impervious surface areas, due to urban and residential development increase surface runoff and reduce evaporation, infiltration, and ground water recharge (Dow and DeWalle, 2000). Sediment losses from urban areas are not generally significant because land surfaces are covered with impervious surface materials (Nelson and Booth, 2002). However, these impervious areas increase the amount and rate of runoff entering streams in an urbanized watershed. Increased stream flow rates often lead to more stream channel erosion, which can be the predominant source of sediment, and may result in the degradation of downstream water quality and destruction of properties along channel segments (Bledsoe and Watson, 2001). Nutrient runoff is also influenced by urbanization. While rapid surface flow is likely to enhance the transport of phosphorus, the decreased rates of infiltration may reduce the transport of nitrate into subsurface soils and ground water resources.

In many parts of the world, the urban poor live in life threatening conditions. At least 220 million urban dwellers lack access to clean drinking water and between one third and two thirds of solid waste generated is not collected (IDB, 2003). The uncollected waste undergoes oxidation and decomposition in the presence of oxygen, moisture and at temperature of between 32° and 60° C. The rate of decomposition is influenced by:

- Type of waste
- Ambient temperature
- Oxygen supply
- Water content

Water flowing through solid waste dumpsites also aids the natural degradation process. Depending on the nature of the wastes, water picks up various contaminants as it flows through (Lee, 1991). Leachate released from these wastes percolate through the unsaturated (vadose) zone and eventually the harmful non-degradable substances contained in the leachate contaminate ground water aquifers.

As leachate flows through the vadose zone, the organic pollutants in it degrade both aerobically and anaerobically, since the vadose zone is characterized by the presence of air and water. Down in the aquifer, flow is relatively slow and contamination travel time can be long, resulting in an equally long time to clear up pollution in the aquifers. The resulting impact on groundwater quality is thus dependent on a complex chemical, biological and physical process, which can be explored by a range of professionals.

1.3 Problem Statement

Groundwater has been assumed to be relatively free from contamination; numerous discoveries in recent years of toxic chemicals in well water have proved this assumption to be false. Groundwater contamination from chemical dumpsites tends to attract the greatest public attention, but a number of other sources including solid waste dumpsites, septic systems, pesticides, and underground storage tanks also can be significant (Lee, 1991).

Open dumpsites are still the primary means of managing solid waste. Open solid waste dumpsites pose a threat to human health and environment (Kim, 1998). The greatest concern is the potential of contaminants from a dumpsite to pollute valuable groundwater or surface water supplies. Water percolating through dumpsites produces leachate, which may contain undesirable or toxic chemicals. Rainwater seeps through the refuse and this water plus the original water content in the refuse will tend to move from within the boundaries of the dumpsite and eventually pollute surrounding soil.

When leachate seeps into underground aquifers (water bearing strata), the threat of water pollution becomes relevant for areas outside the immediate vicinity of the fill site. Therefore the seriousness of the pollution of soil and ground water surrounding a dumpsite becomes an area of increasing concern. Cases of water pollution from dumpsites usually involve surface waters, where the ability of the soil to purify waters is not involved, and where a direct link exists between the dumpsite and surface water. The pollution cases involving ground water occur when a well is placed downstream of a dumpsite (Haukohl et al, 2000).

1.4 Problem Justification

The management of solid waste in Kenyan Cities has been a major problem for decades. Solid waste goes uncollected for a long period of time thereby littering the streets and open fields in residential areas (Carl Bro, 2001). With passage of time and lack of proper disposal, these areas form sites for solid waste disposal. Open solid waste dumpsites are found in minor streets across the cities and in open fields, especially in middle and low-income residential areas. Due to the inefficiency of the solid waste collection system, most of the waste from domestic and commercial activities is dumped in these dumpsites.

Due to the unreliable water supply in the cities, many commercial enterprises have sunk boreholes to supplement their water requirements. Most of the office buildings and hotels in the cities have boreholes for this purpose. The unplanned settlements have shallow wells, which serve most of the households. However, with the lack of a proper solid waste collection system, the reliability of the boreholes as a source of safe drinking water is in doubt. The leachate generated from the dumpsites may find its way into the water table and pollute the water. Furthermore, when rain falls, the surface runoff washes away the leachate into rivers and streams passing through the cities. These streams and rivers are water supply sources for people living in low-income areas downstream.

Leachate which is one of the by-products of solid wastes disposal is given special considerations since it has been an important source of groundwater pollution in the past, in connection with the use of open dumps. The above scenario is very common in solid waste dump sites and sanitary landfills hence the need for the investigations of flow, to understand and be able to predict contaminant concentration as it flows through the unsaturated (vadose) zone and enable corrective measures to prevent pollution of underground water sources.

1.5 Objectives and Scope of Study

1.5.1 Overall Objective

To investigate the impact of poor solid waste management in Kenyan urban areas on ground water pollution.

1.5.2 Specific Objectives

(i) To review the state of solid waste management in urban centres in Kenya.
(ii) To identify shortcomings of current solid waste management practices.
(iii) To investigate the composition of leachate from a typical solid waste dumpsite.
(iv) To investigate groundwater pollution variation with time.
(v) To understand statistical modelling of leachate migration.

1.5.3 Scope of the Study

The scope of the study was to;

(i) Establish the pollution threat of leachate from a waste dump site.
(ii) Use the samples from the site to estimate the level of pollution transfer and understand the impact on the groundwater.
(iii) Recommend improvement on solid waste management in the selected urban centres in Kenya.

1.6 Study limitations

This study could not accurately simulate real time rainfall in terms of intensity and space. The time for the seasonal short and long rains is random and could not be simulated. Test equipment at the Institute for Nuclear Science broke down and thus the heavy metal content variation did not run for the whole period of the study. The level of engagement with respondents was below expectations due to their low awareness levels on solid waste management and poor data inventory.

1.7 Thesis Structure

This thesis has five chapters, a reference and five appendices. Chapter 1 has a general introduction to the problem of solid waste management; a specific context is made of the inefficiency in collection and springing of dumpsites in urban centres in Kenya. The consequence of the dump sites on groundwater is highlighted, leading to the objective and hypothesis of this study. Chapter 2 is presented in three sections. Section A reviews the global status of solid waste management in relation to the problems in the study towns of Nairobi, Mombasa, Kisumu, Nakuru and Eldoret. Section B reviews the leachate process. Section C reviews the theory of pollutant transport, leading to the methodology of this study in Chapter 4. The discussion of the results is then presented in Chapter 6 followed by the conclusions and recommendations in Chapter 5.

2. REVIEW OF LITERATURE

SECTION A: SOLID WASTE MANAGEMENT STATUS IN KENYA

2.1 Introduction

This chapter presents a review of the principles solid waste management globally. The concept of Integrated Solid Waste Management (ISWM) is outlined with a look at its possible application through case studies of different countries. The overview of global practices made in this chapter will be used to assess the status of solid waste management in Kenya through:

- comparing the current practice and trends in management,
- establishing the resources available, and
- understanding the consequences of poor solid waste management.

2.2 Solid waste management

Definition

The term 'waste' has a different meaning for different people. In general one can say that waste is 'unwanted' for the person who discards it; a product or material that does not have a value anymore for the first user and is therefore thrown away. But 'unwanted' is subjective and the waste could have value for another person in a different circumstance, or even in a different culture. There are many large industries that operate primarily or exclusively using waste materials – paper and metals are the commonest – as their industrial feed stocks (Scheinberg, 2001a).

In the context of Integrated Solid Waste Management (ISWM), waste is regarded both as a negative and as a useful material providing a potential source of income. It can in fact be the only free resource available to poor people, or urban dwellers, who cannot cut wood or use other common property resources available in the country. This real value of waste in many low-and middle-income countries in the South is confirmed by the huge informal sector that lives from waste collection and recovery. There are also formal sector examples, such as sugar cane factories that sell their fibres and cane waste to paper factories that produce paper out of it. Unfortunately not all wastes can be regarded as resources. Many hazardous and toxic materials cannot be safely recycled or reused. The category of waste can be divided into solid and liquid waste. Liquid waste is sometimes referred to as human waste or excreta. In this document we will look primarily at solid waste.

Most local governments and urban agencies have, time and again, identified solid waste as a major problem that has reached proportions requiring drastic measures. We can observe three key trends with respect to solid waste - increase in sheer *volume* of waste generated by urban residents; change in the *quality* or make-up of waste generated; and the *disposal* method of waste collected, by land-fill, incineration etc.

It is critical to adopt a broad approach in developing a working framework for solid waste management (SWM). This covers the social, economic, technological, political and administrative dimensions (UNEP, 2009). For example the social dimension of SWM involves waste minimization; the economic dimension of SWM involves waste recycling; the technological dimension of SWM involves waste disposal; and the political and administrative dimensions cuts across all the three issues of minimization, recycling and disposal as illustrated in figure 2.1. But SWM is not an isolated phenomenon that can be easily compartmentalized and solved with innovative technology or engineering. It is particularly an urban issue that is closely related, directly or indirectly, to a number of issues such as urban lifestyles, resource consumption patterns, jobs and income levels, and other socio-economic and socio-cultural issues. All these issues have to be brought together on a common platform in order to ensure a long-term solution to urban waste.

Figure 2.1 Solid Waste Management issues

There is a whole *culture* of waste management that needs to be put in place, as proposed by UNEP (2009) - from the micro-level of household and neighbourhood to the macro levels of city and state or nation. The general assumption is that SWM should be done at the city-level, and as a result, solutions tried out have been essentially end-of-pipe ('end-of-pipe' refers to finding solutions to a problem at the final stage of its cycle of causes and effects. In the case of urban waste, it means focusing on *waste disposal* rather than waste recycling or waste minimization). But this approach essentially misses the forest for the trees, in attempting piece-meal and ad hoc solutions to waste problems, instead of taking a long-term holistic approach.

In reality, there are a number of critical actions that need to be taken at each of the levels of household, neighbourhood, city and nation. Srinivas (2008) emphasises that action to be taken can have social, technological, economic, political or administrative dimensions. It is important that the right decision/action be taken/carried out at the right level. Thus, actions at the household level are predominantly social, technological and economic in nature. Similarly actions to be taken at the state and nation level are predominantly economic, political and administrative in nature. Action at the neighbourhood and city levels cuts across all five themes. The matrix (Table 2.1) that links the *dimensions* of decision-making (social, technological, economic, political and administrative) with the *levels* of decision-making (household, neighbourhood, city, and nation) - helps in categorizing the decisions, actions and related activities to be undertaken.

Table 2.1: The Solid Waste Management Matrix

Dimensions and Levels of decision-making	Household	Neighbourhood	City	Nation
Social	*	*	*	
Technological	*	*	*	
Economic	*	*	*	*
Political		*	*	*
Administrative		*	*	*

* *Focal areas for action* Source - Srinivas, 2008

The above matrix was 'field-tested' during a training session in SWM for city government officials. During the session, city officials from Nepal, China, Philippines and Japan categorized the various SWM activities and actions in their cities within the matrix - allowing them to identify weak areas - the lacks, gaps and mismatches, in their policies, programmes, plans and projects.

2.3 Solid waste production

The production of solid waste has always been associated with human settlement. When humans lived in small communities, the solid waste produced by these communities could easily be burned or buried. Chandran (1993), notes the potential environmental impact of this waste was minor because the material was rarely hazardous and was not being produced in large quantities. As towns and cities developed, people began to live in densely populated areas, and the production of waste became a health problem. In response to this threat, towns and cities designated dumping areas for solid waste, usually on the outskirts of the towns. All forms of solid waste were dumped, including industrial, medical, and household waste.

Solid waste disposal remained, for the most part, unregulated until the 20th Century. Dumps in most towns were left uncovered, and there was no attempt to treat the waste. Fires sometimes started spontaneously in these dumps; rodents and insects often became severe problems. Burning refuse in an uncontrolled manner resulted in severe air pollution and noxious odours. The adverse environmental impacts of these open dumps became apparent early in the 20th Century. Arntzen et al (2000) postulate that today, open dumps pose many risks to the environment and community health. In open dumps, rain water moves through the refuse and absorbs any organic and inorganic compounds (including metals, pesticides, and solvents) that are in the refuse. This liquid is known as leachate. This leachate then enters the soil below the dump and may eventually enter the ground water. For communities that depend on ground water to supply their drinking water, the formation and movement of leachate through the soil and into aquifers poses a risk to the environment and also to human health, especially if the leachate contains toxic chemicals.

Cointreau, (2004) highlights that open dumps also pose a risk to the environment in a different manner. Microorganisms present in the refuse use the refuse as a food source. Under the anaerobic (no oxygen) conditions typical in most dumps, these microorganisms convert the organic material in the refuse to methane and carbon dioxide. As the gas rises through the dump and escapes into the atmosphere, it sometimes picks up other organic compounds. The presence of large amounts of methane in this uncontrolled environment may result in explosions and fires. Additionally, this untreated gas may contain other compounds that pose a substantial health risk to nearby communities. As people learned more about what happens in dump sites, it became apparent that this initial attempt to manage solid waste disposal had created new problems. At some sites, these problems are still being addressed. It was obvious that an alternative method of disposal was essential.

2.4 Basic data on solid waste

The first significant data in solid waste management is the source. Knowing who is generating what type of waste, in what quantities and where enable formulation of the management framework. Households, commercial establishments, institutions such as schools, hospitals and government offices, factories and farms all generate different quantities and types of waste on different locations in the city. Scheinberg (2001a) reports that not more than 50% of waste generated by households in cities in the South reaches the collection vehicle and disposal site, because of extensive waste picking and reuse at household level.

Solid waste generation rates estimate the amount of waste created by residences or businesses over a certain period of time (in days, years, etc.). Waste generation includes all materials discarded, whether or not they are later recycled or disposed in a landfill. Waste generation rates for residential and commercial activities can be used to estimate the impact of new developments on the local waste stream. They may be useful in providing a general level of information for planning purposes. Measurement of waste generation rates in Emerging Industrialised Countries (EIC's) is both uncommon and difficult. Waste generation rates reported by Chandran (1993), are often quoted in the range 1 - 2 kg per capita per day in developed countries and 0.4 - 0.8 kg per capita per day in EIC's or developing countries. However, there is no substitute for local measurement.

In Karachi, Pakistan, the per capita solid waste generation rate was calculated in 1984 covering low, middle and high income areas and was found to be 0.26 kg/capita/day (Shamsi et al, 1996). The same was calculated again in 1991 and was found to be 0.34 kg/capita/day. The total solid waste generation in Karachi was calculated to be around 5588 tonnes per day. Approximately 4528 tonnes/ day (81%) of the solid waste generated was from residential areas while 522 tonnes/day (9%) was generated from commercial centres and industries, 359 tonnes/day (6%) was from street cleaning and 179 tonnes/day (4%) was miscellaneous waste. The generation rates of major cities reported by the participating member countries are listed in Table 2.2. EMC (2007) study of Asian cities revealed the amount of solid waste generated in the cities to be much higher than in rural areas. The generation rate in rural areas can be as low as 0.15 kg/capita/day, while in the urban areas the rate can be above 1.0 kg/capita/day.

Table 2.2: Solid-Waste Generation Rates of Major Asian Cities

City	Country	Generation rate (kg/day/person)
Delhi	India	0.47
Dhaka	Bangladesh	0.50
Urban	Islamic Republic of Iran	0.80
Penang	Malaysia	0.98
Kathmandu	Nepal	0.30
Manila	Philippines	0.66
Singapore	Singapore	0.94
Colombo	Sri Lanka	0.62
Taipei	Republic of China	0.95
Bangkok	Thailand	0.88
Hanoi	Vietnam	0.63

Source: EMC (2007)

Mufeed (2007) in his study revealed that Delhi generated 8567 tonnes of MSW every day at the rate of 0.5 Kg/capita/day approximately. MSW analysed contained high organic content (55-75%) and moisture content (40-60%), which indicated the possibility for composting and bio-methanation as best options for treatment. The study suggested that the waste from commercial, hotels and institutional areas could be used for Refuse Derived Fuel (RDF). Most of the treatment and disposal facilities of MSW were found to be in disorder except few one. All compost plants are working in low capacity because of the low market of compost and it needs regular maintenance, and two of the plants (MCD and NDMC composting plant at Okhla) are closed. Incineration is not successful because of high capital and operation costs, high moisture content, high organic material and low calorific value of MSW.

The predictive model developed in this study showed that the quantity of MSW generated and the per capita generation rate in Delhi expected to increase up to 18500 t/day and 0.77 kg/day/capita respectively in 2025. Using a system dynamics modelling, Mufeed (2007) showed the expected growth of population and the corresponding increase in MSW generation rate along with the electricity generation rate from MSW, projection of revenue produced and budget required for MSW treatment and disposal in 2001, 2006 and prediction for 2024. Furthermore, the physio-chemical characteristics of ground water samples in the proximity of Gazipur landfill site exceeded with the permissible limits of ground water standards, and it did not conform to the drinking water standard. It was noticed that the pollution of ground water was more in north and north-western areas of landfill, and the pollution was more in the areas near landfill and it reduced gradually with the distance in the north and west direction, which indicated that the landfill leachate affected negatively the ground water in the proximity of landfill.

2.5 Solid waste composition

The composition of household waste: this is determined among other things by eating and cooking habits (affluence, culture) and is subject to seasonal variations (agricultural production, religious feasts, presence of tourists). These differences in composition mean that different waste management systems may be considered for the various sources of waste (e.g. type and size of collection vehicles) to be able to diversify waste streams for reuse and recycling and to make use of small scale collection and recycling services. The composition also partly determines the suitability of the waste for certain types of treatment: the moisture content and calorific content (% of combustible material) for incineration and the organic content for composting.

The density or the weight per m^3: a high content of inorganic materials (e.g. paper, plastics in affluent or office areas) means the waste has a low density. Much dust, ashes and organic residues in the waste means it has a high density. Solid wastes in urban centres are by-products of a broad spectrum of domestic, industrial, service and manufacturing processes. The composition of solid waste varies significantly in the different cities in the region. Even within a city, the composition varies with location and time. In general, the solid waste contains more organic components than other materials. The average percentages of organic matter in the solid waste in major cities in Asian countries ranged from 50% to 70%. A presentation of the composition of solid waste in various cities is in Table 2.3.

The other components of waste of concern in towns are the Industrial and Medical Wastes. The Asian study report (EMC, 2007), estimated that about 200 tonnes of hospital and clinical wastes were generated in Dhaka City, Bangladesh. This includes toxic chemicals, radioactive material, and pathological elements.

Table 2.3 Urban refuse composition data (in percentage by weight)

	HIGHER INCOME					MIDDLE INCOME				LOWER INCOME				
TYPE OF MATERIAL	Brooklyn **New York**	London **United Kingdom**	Rome **Italy**	Singapore	Hong Kong	Medelin **Colombia**	Lagos **Nigeria**	Kano **Nigeria**	Manila **Philippines**	Jakarta **Indonesia**	Lahore **Pakistan**	Karachi **Pakistan**	Lucknow **India**	Calcutta **India**
Paper	35	37	18	43	32	22	14	17	17	2	4	1	2	3
Glass, Ceramics	9	8	4	1	10	2	3	2	5	1	3	1	6	8
Metals	13	8	3	3	2	1	4	5	2	4	4	1	3	1
Plastic	10	2	4	6	6	5	-	4-	4	3	2	-	4	1
Leather, Rubber	-	-	-	-	-	-	-	-	2	-	7	1	-	-
Textiles	4	2	-	9	10	4	-	7	4	1	5	1	3	4
Wood, bones, straw	4	-	-	-	-	-	-	-	6	4	2	1	1	5
Non-food Total	**74**	**57**	**29**	**63**	**60**	**34**	**21**	**35**	**40**	**15**	**27**	**4**	**18**	**22**
Food and putrescible	22	28	50	5	9	56	60	43	43	82	49	56	80	36
Miscellaneous inerts	4	15	21	32	31	10	19	22	17	3	24	40	2	42
Compostable Total	**26**	**38**	**71**	**37**	**40**	**66**	**79**	**65**	**60**	**85**	**73**	**96**	**82**	**78**
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Note: The above values have been rounded to the nearest whole number. (Source: Cointreau 1982)

According to the Directorate of Health inventory, the present average clinical-waste generation in the hospitals and clinics is 1 kg/bed/day, plus an extra 200 kg/ year. It is estimated that 20% of this waste is highly infectious and hazardous to human life. This waste was dumped with other municipal waste into surface drains, sewer systems, storm sewer systems, and Dhaka City Council (DCC) bins. Only one hospital authority claimed to have a pre-treatment system. It reported that the newly formed Solid-Waste Management Cell (SWMC) of the DCC is planning to choose one of the two modern mechanisms for medical-waste disposal—incinerator or autoclave sterilizer. Of the two, the latter was preferred due to its eco-friendliness and cost effectiveness.

In India, the total hazardous waste generated by the country was 4,415,954 tonnes/year (EMC, 2007). This was generated by 13,011 hazardous-waste generating units. Authorization to 11,138 units was granted by the pollution control boards. Out of the total amount of waste generated, 1,685,130 tonnes (38%) was recyclable, 188,097 tonnes (4%) was incinerable, and 2,529,947 tonnes (58%) was disposable. There were 116 incineration plants and 11 landfills for the disposal of hazardous wastes. The authorization and monitoring of hazardous wastes was the responsibility of the state pollution boards. Biomedical Wastes from major hospitals and nursing homes complied with the provisions of the Biomedical Waste (Management and Handling) Rules, namely the segregation/collection of waste in colour-coded plastic bags and final disposal of the waste as per the provisions of the rules, including autoclave, hydroclave, or incineration. However no data concerning the biomedical waste generated in the country was available. Monitoring compliance of the rules was done by the state pollution control boards.

2.6 Resources available

The equipment and resources available for solid waste management will determine what options are feasible for the collection and disposal of waste. Resources and equipment include people, machinery and services (World Bank 2008).

People

Staff involved in the management of solid waste need an appropriate qualification. Training of personnel in aspects of solid waste management such as proper landfill procedures, special waste identification and handling etc; is an important consideration. There will likely be a need to send staff on courses. Good short courses (one week duration) on waste management are available in New Zealand and elsewhere.

Machinery

Numerous types of collection vehicles and optional features are available. Manufacturers are continually refining and redesigning collection equipment to meet changing needs and to apply advances in technology. Trends in the collection vehicle industry include increased use of computer-aided equipment and electronic controls. Now, some trucks even have onboard computers for monitoring truck performance and collection operations. Running a sanitary landfill and covering waste requires heavy earthmoving plant to be regularly available. Obtaining suitable plant may be the first priority in any plan to upgrade landfill activities. The operation and maintenance requirements of machinery are also vital considerations. What could be achieved with collection services will depend largely on the vehicles available. Ideally a refuse compactor truck should be used. The type of machinery can also define the level of efficiency as illustrated by the combination in Figure 2.2.

Figure 2.2: Equipment for manual and automated collection

Services

Analytical laboratory facilities are usually limited in the small island states, with capability to undertake basic tests such as pH, conductivity, faecal coliform, available chlorine and possibly a few metals only. This poses a problem for assessing the impact of waste disposal sites on the environment. Samples are usually which has sent offshore, with cost and logistical difficulty.

A recommended minimum laboratory capacity for monitoring of leachate would be: pH, Electrical conductivity, Chloride ion, Ammoniacal nitrogen, Nitrate nitrogen, Total Phosphorus, Zinc (acid soluble), BOD5 (Biochemical oxygen demand) and heavy metals including Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Lead (Pb), Iron (Fe), Magnesium (Mg), Manganese (Mn) and Nickel (Ni).

Many solid waste planning efforts in urban areas in Kenya have emphasised technology at the expense of management support systems. This has unfortunately been due to lack of understanding of the policy issues related to effective waste management strategies and lack of experience in implementing programmes. This in turn has been due to institutional weakness and unfortunately the involvement of politics. An acceptable level of service for waste management depends critically on well planned management, operating within an adequate institutional arrangement and capable of generating the financial resources required to meet operation, maintenance and investment costs.

Among the common weaknesses in existing institutional systems are untrained staff, poor pay scales, the lack of incentives to do a good job, and corruption. Related to these are two key problem areas, namely inadequate supervision of workers and inadequate maintenance of facilities. In industrialised countries, one would expect one supervisor for every five to seven collection vehicles, whereas one per 10 - 30 vehicles is more common in Kenya. In addition, supervisors in Kenya often have no means of moving about within their service area, so that effective supervision is very difficult *(JICA, 1998)*. In Kenya, the solid waste management service is by far the largest employer of labour and possibly user of transport, and takes a huge portion of revenue budget of towns, and yet it is relatively uncommon to find at senior management level an individual officer with direct line management responsibility for all aspects of solid waste management operations.

There is often a small Cleansing Department at the town councils, with all labourers and supervisors managed on a decentralised basis in city districts. Often there is no planning unit, and the operational records which are essential to monitor and improve performance of the service are often poor or even non-existent. The provision of adequate funding for solid waste management on an ongoing basis is a major problem in many of the towns. As the proportion of total city budget which is spent on cleansing may be quite large, this implies an effort to improve the overall municipal administration system. This is because the money for running the service most commonly comes from the general municipal revenue. Direct user charges for refuse services are relatively uncommon, and where they do exist, collection rates are often very low. Three particular problems with direct charges are that those who can afford to pay live in the better income areas, while the problem is often that of providing an adequate service in the poorer areas; there is usually no viable means of shutting off service to a resident who doesn't pay his/her bills; and a direct charge provides an incentive for indiscriminate dumping, which is the opposite effect to that intended (Klundert et al, 1995).

2.7 Solid waste handling

Solid waste planning efforts in urban areas in Kenya have emphasised on acquiring of equipments and technology at the expense of management support systems. This has unfortunately been due to lack of understanding of the policy issues related to effective waste management strategies and lack of experience in implementing programmes (Moyo, 1999). This in turn has been due to institutional weakness and unfortunately the involvement of politics. An acceptable level of service for waste management depends critically on well planned management, operating within an adequate institutional arrangement and capable of generating the financial resources required to meet operating maintenance and investment costs.

The study councils had common challenges that included weaknesses in existing institutional systems, poorly trained staff, poor pay scales, the lack of incentives to do a good job, and corruption. Related to these were two key problem areas, namely inadequate supervision of workers and inadequate maintenance of facilities. In industrialised countries, one would expect one supervisor for every five to seven collection vehicles (Rushbrook 2000), whereas one per 10 - 30 vehicles is more common in Kenya. In addition, supervisors in Kenya often have no means of moving about within their service area, so that effective supervision is very difficult (JICA, 1998). In Kenya, the solid waste management service is by far the largest employer of labour and possibly user of transport, and takes a huge portion of revenue budget of the towns (Rotich et al, 2005), and yet it is relatively uncommon to find at senior management level an individual officer with direct line management responsibility for all aspects of solid waste management operations.

The Cleansing Department at the councils mainly consists of labourers and supervisors managed on a decentralised basis in city districts. Often there is no planning unit, and the operational records which are essential to monitor and improve performance of the service are often poor or even non-existent. The provision of adequate funding for solid waste management on an ongoing basis is a major problem in many of the towns (UNCHS 2009). As the proportion of total city budget which is spent on cleansing may be quite large, this implies an effort to improve the overall municipal administration system. This is because the money for running the service most commonly comes from the general municipal revenue. Direct user charges for refuse services are relatively uncommon, and where they do exist, collection rates are often very low. Three particular problems with direct charges are that those who can afford to pay live in the better income areas, while the problem is often providing an adequate service in the poorer areas; there is usually no viable means of shutting off service to a resident who doesn't pay his/her bills; and a direct charge provides an incentive for indiscriminate dumping, which is the opposite effect to that intended (Klundert et al, 1995).

Pfammatter et al (1996) stated that solid wastes in most developing countries are typically high and low value recyclables. They can be recovered and reused, though they make up only a small proportion of the total waste stream. The great majority of the waste (~70 percent) is organic. In theory, this waste could be converted to compost or used to generate biogas, but in situations where rudimentary solid waste management systems barely function, it is difficult to promote innovation, even when it is potentially cost-effective to do so. In addition, hazardous and infectious materials are discarded along with general waste throughout the continent. This is a dangerous condition that complicates the waste management problem.

Throughout most of sub-Saharan Africa solid waste generation exceeds collection capacity. This is in part due to rapid urban population growth: while only 35 percent of the sub-Saharan Africa population lives in urban areas, the urban population grew by 150 percent between 1970 and 1990. But the problem of growing demand is compounded by broken-down collection trucks and poor program management and design. Arntzen (2000) report on West African cities, had as many as 70 percent of trucks being always out of service at any one time, and in 1999 the City of Harare, Zimbabwe failed to collect refuse from nearly all of its residents because only 7 of its 90 trucks were operational.

Waste handling efficiency also depends on the status of the road network for access. Thus, the collection vehicle selected must be appropriate to the terrain, the type and density of generation points, the roads and ways it must travel, the type of waste or the kinds of materials it will be used to collect; capability of the crew that will work with it; and the point and manner of discharge of its load. Non-compactor trucks generally need to be covered in order to prevent residues flying off the truck and/or rain soaking the wastes. The municipal council when purchasing vehicles should select vehicles which use the minimum amount of energy and technical complexity necessary to collect the targeted materials efficiently. High-energy prices and vehicles that are difficult to repair raise the cost of collection. The trade-offs here depend significantly on the relative cost of capital and labour. According to JICA (1998), only about 25 per cent of the estimated 1,500 tonnes of solid waste generated daily in Nairobi was collected. Yet, until the mid-1970s the Nairobi City Council singly collected over 90 per cent of the waste. In the mid -1980s, the appalling NCC performance and demand for municipal solid waste management services attracted private sector providers. It was estimated then that there were at least 60 private companies engaged in solid waste collection services in Nairobi (JICA 1998).

In the Carl Bro (2001) report on the "Study of the Environmental Situation in Three Urban Centres", the total amount of solid waste produced was estimated at 1850, 260 and 400 tonnes/day and quantity delivered to the dumpsite was estimated at 35%, 60% and 20% respectively for Nairobi, Eldoret and Kisumu. There is limited literature on the Kenyan solid waste management (SWM) sector with the exception of Nairobi. Even for Nairobi, the available literature dwells largely on performance description and its causes, household waste generation behaviour, and waste characteristics (Ikiara et al., 2004). They cited poor management of solid waste as a general problem in Kenya with Nairobi being the worst hit.

The Kisumu City Development Strategy (CDS) (2004 – 2009), a UN-habitat document, contains a presentation on Lake Victoria Region city development strategy for improved urban environment and poverty reduction. It highlights some of the solid waste management problems in Nairobi, Mombasa and Kisumu. The solid waste management scenario in Kisumu was widely reflective of the situation in the majority of towns in the lake region. Like most urban centres in the region, Kisumu was faced with problems of lack of collection facilities and low efficiencies in operation of existing facilities as well as the design, capacity and location of final disposal sites. The poor management of solid waste resulted in generation of leachate which polluted the ground water and soil, the spread of infectious diseases (such as eyesores), blockage of sewers and drainage systems, spread of foul smoke from private burning of waste as well as pollution of Lake Victoria through run-off. Furthermore, scavengers and others were exposed to health risks as no separation of hazardous waste fractions was practiced.

Most of the solid waste generated in Kisumu remained uncollected with a collection efficiency estimated at 20%. The collection that took place was shared between the City Authority and a few un-authorised private collectors mainly concentrated in the high income areas, leaving the poor peri-urban neighbourhoods largely unattended. Waste transported to the dumpsite for disposal was not properly managed. In many instances open burning was employed to reduce the waste volume at the dumpsite. The other factor of sound solid waste management is the collection efficiency, as it is the main determinant of collection cost in all types of collection systems. Collection should take place at a time when streets are not crowded with bicycles or market booths, since the ability of the vehicle to travel to its appointed route will be diminished. The vehicle should have a volume to handle the waste that is generated on the defined collection route, and must make minimal trips to dump the accumulated waste or materials, so that the amount of time available for collection decreases.

Many households, particularly in the peri-urban and extended areas did not have the privilege of any mode of collection, and have resorted to private burning of waste or digging their own pits to bury the waste on site. However, some common dumping grounds had developed in city service lanes and open grounds within the neighbourhoods, presenting unsightly scenes that generally offend the public and inhabitants alike. Plastic waste used in most packaging was the most conspicuous nuisance, often littering many parts of the city and the residential neighbourhoods, and sometimes blamed for livestock death and blockage of storm water drains.

It was also notable that of the total amount of waste generated in Kisumu, approximately 60-65% was organic in character presenting enormous potential for recycling for farm use. Most clinical waste from the hospitals was incinerated, reducing the health related risks from exposure.

In the process of developing the City Development Strategy (CDS), it emerged that some very positive reuse and recycling initiatives exist in Kisumu. These small-scale initiatives included reuse and recycling of paper, plastic, organic waste, metals and water hyacinth, all providing micro-enterprise engagement for a significant number of city inhabitants. A further initiative had been undertaken to bring the recyclers under an umbrella body, the Kisumu Recyclers and Collectors Association, to provide common platform for negotiation and market access. Despite this presenting a useful opportunity for complimenting solid waste management of the city, a challenge still existed on how to effectively integrate it into the overall solid waste management system in the city. Awareness campaigns were recommended for sensitization of the general population on the unfolding events in the city. The extent and nature of the solid waste management problem in Kenya towns can be summarized as shown in Table 2.4.

Table 2.4: Relative Perceptions of Waste Collection Service in Nairobi.

Item	High Income Area	Medium Income Area	Low Income Area	Surrounding Areas
Existence of waste collection service	Yes: 74% No: 26%	Yes: 84% No: 16%	Yes: 25% No: 75%	Yes: 26% No: 74%
Collection by: - NCC - Private company	 27% 73%	 83% 17%	 64% 36%	 - -
Satisfaction with the waste collection service	Yes: 76% No.24%	Yes: 78% No: 22%	Yes: 39% No: 61%	-
Awareness of health risks from solid waste	Yes: 31% No: 69%	Yes: 89% No: 11%	Yes: 86% No: 14%	Yes: 69% No.31%
Willingness to pay for improved services	Yes: 76% No: 24%	Yes: 59% No: 41%	Yes: 58% No: 42%	Yes: 67% No: 33%

Source: JICA (1998).

The collection ratio, that is, the proportion of the solid waste generated that was collected, was low. As mentioned, this is estimated to be as low as 20-25 per cent. Marked inequality in the geographical service distribution characterizes the service in all cities. Broadly, the low income areas of the towns were hardly serviced. High-income and some middle-income residential areas together with commercial areas were well serviced by private companies and even the Councils. Small private firms are increasingly servicing some of the relatively better-off low-income areas. The core low-income areas (slums and other unplanned settlements) where 55-60 per cent of urban residents live, however, received no waste collection service from the councils. Some collection service was provided by localized community-based organizations (CBOs). The study of urban cities by JICA (1998) reported that 26 per cent of households in high-income areas, 16 per cent of those in middle-income areas, 75 per cent of those in low-income areas, and 74 per cent of the surrounding area do not receive any service in Nairobi. Residents in low-income areas are dissatisfied with waste collection services. They were aware of the health risks associated with the problem, and were willing to pay for improved services in spite of their low incomes.

There was widespread indiscriminate dumping in illegal dumpsites and waste pickers litter the cities with reusable waste materials without control. All the official dumpsites (Council owned and operated), were full and located in densely populated parts of the towns, far from the central business districts along roads with heavy traffic. Moreover, waste pickers and dealers 'control' the dumpsites, forcing the Councils and private companies to 'bribe' to access the dumps.

During the study carried out by *JICA (1998)* on the residents around the dumping site revealed serious complaints about smoke, smell, and broken glasses. Respiratory and stomach problems among children were common in the nearby clinics and were cited by the people interviewed. School children passing through the dumpsite often picked objects which were dangerous to their health. Solid wastes in the cities were not segregated with the exception of unstructured reuse of some waste materials at the household level. The private sector waste collectors, in addition, did not process waste in any way, which affected effective and efficient SWM. Consequently, the dumpsites were littered with all types of wastes from hospital wastes, manufacturing/industry wastes, paper and biodegradable materials.

2.8 Public-Private Partnerships

Privatization is the gradual process of disassociating state-owned enterprises or state-provided services from government control and subsidies, and replacing them with market-driven entities (Klundert, et al., 1995). In the context of municipal services, privatization generally implies reducing local government activity within a given sector by:

- involving participation from the private sector; or
- reducing government ownership, through divestiture of enterprises to unregulated private ownership, and commercialization of local government agencies.

Private sector participation leaves municipal resources available for urban infrastructure and equipment. Privatization of urban services also can reduce the cost of public services to consumers; relieve the financial and administrative burden on the government; increase productivity and efficiency by promoting competition; stimulate the adoption of innovation and new technology; improve the maintenance of equipment; and create greater responsiveness to cost control measures. There are five basic modes of privatization (Klundert, et al., 1995):

1. **Concessions:** a contractual arrangement whereby a private operator is selected and awarded a license to provide specified services over a discrete period of time in return for a negotiated fee. The concession agreement sets out the rights and obligations of the service provider, who generally retains ownership of the principle assets. This method is well suited to enterprises which provide services that are economically and socially important and need

significant improvement; are large and usually enjoy a monopoly position; are politically and/or practically difficult to sell; and are in need of investment capital, e.g., trucks and bins.

2. **Management contract:** a contract placing a municipal service under private management for a specified period of time, for which the contractor is paid a fee. The fee may be based partly on performance. The private manager has extensive autonomy, as set out in the contract.

3. **Commercialization:** a process in which the city authority forms a wholly owned subsidiary. Shares of the new company are restricted, and consumer representatives, the local government and other stakeholders make up the board of directors. The ownership of assets, regulation of tariffs and quality control remain at all times vested in the municipal authority. This method is suitable for managing water supplies.

4. **Franchise:** a process in which the city authority awards, through competition, a finite-term, zonal monopoly to a private firm for the delivery of service. The private firm pays a license fee to cover the government's costs of monitoring and recovers earned revenue through direct charges to households and the establishments served. The city authority provides control over the tariff charged to the consumer. This method is suitable for solid waste management.

5. **Private enterprise/entrepreneurship:** a mode whereby the city authority freely allows qualified private firms to compete for service delivery. Individual households and establishments make private arrangements with individual firms who compete for business. Under such arrangements, city councils license, monitor, and (as needed), sanction the private firms. Private firms bill their customers directly.

Criteria for Privatization

In deciding whether to privatize a specific aspect or portion of its service, a government needs to weigh the risks—political manipulation, changing environmental regulations, government tariff regulation, currency devaluation, inflation, and unclear taxation systems—against the economic benefits of private sector efficiency. The following criteria may be helpful in considering private sector involvement in solid waste management services (adapted from Cointreau-Levine, 1994):

Ease of defining outputs. Ensure that defined, measurable outputs of the proposed service are incorporated in written performance specifications to clearly establish public and private sector deliverables. The government must have the resources and capabilities to monitor service levels and enforce penalties for noncompliant behaviours.

Efficiency. Consider reasons for public and private sector inefficiencies, including cost accountability, labour tenure, government wage scales, restrictive labour practices, personnel benefits, inflexible work arrangements, bureaucratic procurement procedures, political limitations, and hiring and firing procedures. Assess options for reducing or removing these barriers. Give preference to plans offering economies of scale.

Capability. Ensure that adequate government capacity exists for planning, design, construction, operation, maintenance and oversight. Evaluate both the public and private sectors for technical and financial resources, including expertise, skills and access to capital. Private companies must possess required facilities and equipment, or have a business plan that covers them. Governments must have both the capability to monitor performance and the political will to enforce contractual or license agreements.

Competition. Ideally, a privatization plan will allow for competition between a number of private firms or between the government and a few private firms. Consider possible barriers to market entry and exit, as well as economies of scale that might limit competition. Determine if financial incentives or technical assistance would result in better performance from private firms. Ensure the government's ability and commitment to conducting a competitive procurement process.

Duplication. Ensure that the government has the political will to cut personnel and assets when services are privatized. Balance the cost savings from reduced staff with new monitoring and enforcement costs.

Risk. In some developing countries, commercial lenders and private companies do not want to risk their money on long-term or large-scale investments that rely on government payments. Regulatory framework must exist to protect the private sector against risks such as environmental damage, currency adjustments, inflation and political changes. Local governments must be able to generate enough revenue to meet contractual agreements with the private sector and protect against economic instabilities. Plans should include provisions for loss due to corruption (kickbacks, bribes and favours).

Accountability. Ensure that private sector participation will not disproportionally benefit wealthy classes. Market openings should be made available to small and medium-size enterprises, helping to redistribute income. Government must guarantee a fair minimum wage and safe working conditions. Government should also make provisions for displaced workers including job training and employment networking.

Costs. The costs for public waste collection services must be well understood. Cost factors should be analyzed separately for the different components of solid waste service—collection, cleansing, disposal and transfer.

Government must have detailed accounting information to determine whether private sector participation would be more cost-effective. A strategic planning and feasibility study should be conducted to know whether the technology offered by the private sector would result in lower costs. These criteria help to determine the extent to which a society is open or closed to competitive market forces, whether the procurement process is straightforward or opaque, how interrelated and transparent taxation and subsidies are, and the extent to which corruption skews the system. Moving public services to the private sector will be efficient only where competition, performance monitoring and accountability exist.

Ikiara (2004), reported emerging partnerships between local authorities and other agents (the private sector, NGOs and communities) to facilitate sharing of SWM responsibilities and financial burden in Nairobi. The same situation had taken root in other towns. There were hardly any deliberate and active processes of collaborative action between stakeholders and relationships were largely informal. Effective coordination among the numerous actors in the towns SWM sector was absent. Private garbage collection firms largely operate in an environment of open competition, with little or no cooperation from the municipal authority. Even the waste management activities of these firms were not geared in any way towards waste recycling, re-use or minimization. Due to limited public awareness and negative perception of informal actors, there was in fact little public support for source separation of waste, and waste recycling, re-use, and minimization. Support for partnerships was increasing, however, even within NCC, as is evident, for instance, in the city council's policy on private sector involvement (NCC, 2001).

The only formal public-private partnership in the city's SWM sector to date was the pilot one-year service contract awarded in 1997 to one of the private companies, the Kenya Refuse Handlers Limited (KRH), by NCC. The contract involved daily sweeping of streets, roads, lanes, pavements and markets in the city's Central Business District (CBD), solid waste collection and transportation from the same area, and disposal of the waste at the Dandora dumpsite, at an agreed monthly rate of Kshs 1, 312,500 ($ 20,275). The private company did very well initially and the CBD became noticeably clean. Payment problems led to poor performance, however, particularly due to sit-ins by unpaid workers. The contract, which ended in 1999, had been financed from NCC's general taxation, as revenue from waste charges was inadequate (JICA, 1998). The contract was renewed in 2000 but without clear indications that the problems that led to the failure of the first contract had been fully addressed.

The NCC also has some informal relationships with CBOs, aimed at helping people living in slums and other unplanned settlements, and promotion of composting activities and environmental cleanups.

Limitations of Privatization

To be successful, privatization of solid-waste management must contend with a variety of problems, including insufficient public awareness and little ability to generate the necessary public participation in planning, administering, or monitoring; managerial deficiencies and weaknesses in local authorities that make it hard to carry out policy reform measures; and lack of experienced and competent personnel to administer and manage the privatization process (see privatization story on the previous page). Municipal councils opting to privatize or commercialize their services often find that they need to upgrade all staff in accounting, auditing, information management, policy development and implementation to make these options work. Although private solid-waste entrepreneurs work all over a city, most activity is concentrated in residential neighbourhoods and biased towards middle and higher-income households who can be relied upon to pay for services.

Little or no private sector solid waste collection activity occurs in low income areas, due to inability to pay rather than the lack of access to these areas. Large firms usually serve wealthy areas, while small firms generally serve a single, middle or lower-middle income neighbourhood. Informal private sector waste entrepreneurs or "scavengers" operate in all areas. Although popular belief states that the private sector will field better maintained refuse collection vehicles, this is not usually the case. Unless contracts provide incentives for the private firms to invest in appropriate equipment, firms lease second-hand dump trucks that frequently break down.

Privatization: Beneficial But No Panacea

Solid-waste management (SWM) in Dar es Salaam is the responsibility of the Dar es Salaam City Council (DCC). An estimated total of 1,929 tonnes of waste is generated daily from households, businesses, institutions and market centres. Before the decision to privatize solid-waste collection and disposal, the City Council was only able to manage 2–4 percent of the waste generated daily.

The main reasons for this inability to manage waste collection were;

- Lack of equipment (trucks and machinery);
- Lack of funds to replace equipment, purchase spare parts, service existing equipment and fuel them. Historically, DCC has allocated less than 8 percent of its total budget for SWM. Out of the 30 trucks and machinery donated by the Japanese Government in 1987, only three were operational in 1992. In addition, the operational vehicles functioned at less than 20 percent of capacity;
- Lack of an official disposal site. The only "dump site" in the city was closed following an August 1991 court ruling in favour of residents of the Tabata area who complained of air pollution caused by burning waste dumped at the site; and
- Lack of involvement of other stakeholders.

- The DCC chose to try privatization to improve waste collection services. Privatization was accomplished in two phases, Phase I from 1992 to 1996, and Phase II from 1996 onwards. For Phase I, a single contractor was assigned to collect waste from 10 city wards and empowered to charge customers directly. For Phase II, four additional firms were given contracts through a process of open tendering, making a total of five contractors servicing 13 wards. The major achievements realized during the first phase of privatization included:
  - Establishment of a solid-waste management partnership advised by a multi-disciplinary stakeholder working group.
  - More efficient service and revenue collection. Households responded positively to the need to pay for refuse collection.
- Initially, collection of solid waste improved to 70 percent of waste generated. However, this rate started to decline six months after the engagement of the private contractor, for reasons outlined below.
  - 318 jobs were created for workers employed by the contractor. Also, human resources and stakeholders were used more efficiently; whereas 800 DCC workers collected only 30–60 tonnes per day, 318 workers under the private contractor collected 100 tonnes per day.

The problems identified in the first phase of privatization included:

Non-fulfilment of obligations by all parties. Under the contract, the contractor was supposed to pay the DCC the monthly costs of renting trucks, a leased depot, and the refuse disposal charges at the dump. DCC was obliged to pay revenue collection charges for the services provided by the contractor at DCC-owned premises like schools, hospitals, offices, etc. Unfortunately, neither party paid the other, and thus the DCC withdrew its facilities in September 1995.

Also, the DCC was responsible for the public awareness campaigns among residents of the privatized area, and for prosecuting customers who defaulted on refuse collection charges (RCCs). When the defaulters were not prosecuted, the contractor's ability to collect revenue was further limited.

Lack of competition. Using only a single contractor did not result in optimal pricing for the consumer or overall system efficiency.

Poor monitoring. Staffs of both the DCC and the contractor were unfamiliar with privatization of solid-waste collection and disposal, leading to poor monitoring and oversight.
Lack of well-functioning management information system (MIS) to track payment information.

Problems within the contract agreement. Some of the items within the contract were not well elaborated, such as the period when RCCs would be reviewed, how to deal with complaints by the refuse producers, how to monitor the daily operation of the contractors, and methods of arbitration.

During Phase II, the daily solid-waste collection increased in the newly contracted wards. Solid-waste heaps were reduced, especially in open spaces and market places. However, the constraints were similar to phase I, including inadequate payment of RCCs to the contractors. Preparations were insufficient to involve and raise awareness of people on the new strategies to clean the city and the responsibilities of individuals and stakeholders. Inadequate revenue collection prevented contractors from meeting financial targets. Contractors' equipment and facilities were inadequate, and they failed to meet promises to purchase replacements. DCC was unable to provide an enabling environment for the contractors (e.g., information on residents liable to pay RCCs, an effective public awareness campaign).

The contractors required close supervision, monitoring, support for planning, technical advice and financial assistance. All households were not treated equally in all wards.

2.9 Use of Economic Instruments (EI's)

Cities in both developed and developing countries generally do not spend more than 0.5 per cent of their per capita gross national product (GNP) on urban waste services, which covers only about one-third of overall cost (UNEP, 2005). The responsibility over solid waste collection and disposal is thus well beyond the capacity of municipal governments. More than 80 per cent of the total waste management costs in low-income countries are collection costs (UNEP, 2005). In Latin America, the cost of waste collection is about 46 per cent of the total municipal solid waste management cost. Cost recovery in SWM service is difficult because, even though there is some willingness to pay for waste collection service, there is little such willingness for waste disposal. Traditionally, therefore, municipal authorities have financed the services through general revenues or attempted to charge for the service through inefficient property tax. Owing to the existence of willingness to pay, however, private provision of waste collection has potential. In addition, limited economies of scale and ease of entry and exit in waste collection imply that competition can keep the price of the private service competitive.

Generally, economic instruments introduce more flexibility, efficiency and cost-effectiveness into solid waste management measures. Furthermore, they can stimulate development of pollution control technology and expertise in the private sector; provide government with a source of revenue to support waste management programs; and eliminate a government's requirements for larger amounts of detailed information needed to determine the feasible and appropriate level of control for each plant or product. Specifically, in solid waste management, EIs can be used as a tool to:

- reduce the amount of waste generated;
- reduce the proportion of hazardous waste in the waste generated;
- segregate hazardous waste for special handling and disposal;
- encourage recovery, reuse and recycling of wastes;
- support cost-effective solid waste collection, transport, treatment and disposal systems;

- minimize adverse environmental impacts related to solid waste collection, transport, treatment and disposal systems; and
- generate revenues to cover costs (IDB, 2003).

Command and control strategy involves direct regulation along with monitoring and enforcement systems. It generally requires the government to formulate the waste standards, to specify schedules for meeting the standards, permitting and enforcement procedures for facilities, liability assignment, and penalties for non-compliance. The major advantage of the command and control approach is that the regulator has a reasonable degree of predictability about how much pollution levels will be reduced. The definition of economic instruments varies in the literature. However, there appears to be some general consensus in the definition of an economic instrument as a policy, tool or action which has the purpose of affecting the behaviour of economic agents by changing their financial incentives in order to improve the cost-effectiveness of environmental and natural resource management. Economic instruments have various uses in the environmental and natural resource management arena, and according to UNEP (2004), EIs have at least six benefits over CACs. Economic instruments:

1. Provide flexibility in the overall cost of reducing emissions - EIs ensure that the overall economy wide cost of meeting specific emission targets are reduced by allowing the market to determine how much pollution each specific firm can reduce. In this way they encourage firms whose emission reduction is less costly to abate more rather than forcing every firm to meet a specific emissions level.
2. Act as incentives for the use of innovative abatement technologies - Since firms can trade in emissions, and because emission reductions have financial value, firms have a continued incentive to invest in abatement technology innovation since extra reductions can be sold to others.
3. Allocate environmental and natural resources to parties who value them most - Properly structured EIs ensure fair allocation of environmental and natural resources and encourage their sustainable utilization while at the same time raising revenues for the government in the form of resource rents.
4. Guarantee self-enforcement by aligning public and private interests - EIs create decentralized and self-enforcement systems for environmental policies by creating an incentive for agents with vested interests to ensure the proper use of

environmental and natural resources. Thus the burden of control is taken away from the state.

5. Increase transparency in resource use and allocation - Application of EIs in environmental and natural resource management is appealing in the sense of their openness as the costs and rights associated with many EIs are more visible through trading levels, prices, ownership patterns and fee receipts. This makes it easy to evaluate investment trade-offs and discourages practices such as lobbying for special privileges or exceptions.

6. Help in cost-recovery of publicly provided services in the provision of publicly owned or delivered resources such as drinking water or oil, market pricing is applied in many markets. In others, their prices are set at levels that recover the full cost of providing them. The revenues can then not only be used to finance continued provision of these services but also in activities that encourage increased conservation.

According to UNEP (2004), economic instruments are also considered in terms of their 'functional objectives', namely:

1. Establish, clarify or improve property rights

Property rights based EIs provide an incentive for owners of resources to invest in them and extract/harvest them sustainably. In other words, clear property rights add security and flexibility to the management of environmental and natural resources as they discourage "the tragedy of the commons" tendencies. It is worth noting that property rights need not be individualized, since even communal property rights can in some cases provide more secure tenure.

2. Ensure that resource users pay a fair price for what they consume

Environmental fees are charged to help clarify price signals and encourage efficient use of environmental and natural resources. Most of these fees first address the issue of recovering the cost of providing goods and services from the beneficiaries, as the most efficient solutions in an economic sense occur when fees are set to recover both the direct costs of goods and services plus the environmental costs associated with producing and using a particular product/service. However, political realities often eclipse this outcome.

3. Subsidize cleaner alternatives

Some EIs can be applied to change production or consumption behaviour to one that is more environmentally superior. Well-targeted and focused interventions, mostly in the form of subsidies, may be able to accelerate the development of these preferred alternatives.

4. Generate revenue

A number of EIs, for example permits, levies and taxes have immediate revenue generating implications to the government. This revenue can be potentially earmarked to help enforce, improve, and expand environmental and natural resource management.

Very few economic instruments are used in Kenya's current waste management practice, and even these are not used effectively. The instruments that have been used in a limited manner include user charges, financial instruments (fees, licenses), fiscal instruments, import duty waivers, deposit refund system, and property rights including institutional reforms.

With the exception of the 1996 privatisation experiment, and the memorandum of understanding between the NCC and the NCBDA, not much foresight is displayed by the councils. However, the NCC hires garbage collection and transport equipment from private companies. In the early 2000's there were plans to invite international bids from private companies to offer solid waste management services in the city. Controversies and policy issues derailed the process and seem to have been abandoned. Flaws with the application of the instruments in the country include;

- low rates devoid of incentive and do not change in tandem with the cost of service or the damage caused by wastes;
- use of uniform or flat rates;
- tipping charges based on vehicle type rather than actual loads;
- charges which do not recognise the different waste types and handling risks.

The low use and poor design of economic instruments in the country's solid waste management sector represents a missed opportunity considering the huge potential of these instruments.

2.10 Solid waste management shortfalls and their consequences

The poor SWM in most Kenyan urban centres can be attributed to many factors. Some of these factors are discussed in this section.

2.10.1 Inadequate political will and governance

Administrations of Urban councils are chaotic, with most of them often clashing or duplicating roles with the Central Government (particularly the Ministry of Local Government and the Provincial Administration in the Office of the President). Moreover, policymakers (councillors) are generally poorly educated and lack any power to discipline workers. The mayors, who are elected by the councillors, must facilitate their corrupt deals to keep the seats. Consequently, mismanagement, corruption, laziness, and general chaos have become the hallmark of the urban councils.

2.10.2 Enforcement of existing legislation

Council by-laws, prohibiting illegal disposal of waste, specifying storage and collection responsibilities for SW generators, and indicating the Council's right to collect SWM charges are not adequately implemented. The Central Government has also failed to play its oversight role effectively. This dysfunctional local administrative system has led to decline in the efficiency of council operations, unprecedented deterioration of physical infrastructure, lack of such critical facilities as transfer facilities, widespread indiscriminate waste dumping, lack of system-wide co-ordination and regulation of actors, absence of strong and effective partnerships between the NCC and other SWM actors, lack of policy and support for waste re-use and recycling, urban agriculture, and community involvement in SWM, and prevalence of casual littering due to lack of public education and non-enforcement of NCC bylaws (Ikiara et al., 2004).

2.10.3 Rapid population growth and urbanization

Nairobi, like other developing world cities, is characterized by rapid population growth and urbanization. The city has a population of about 3 million people who generate over 2000 tonnes of solid waste. In addition, the city is surrounded by four satellite towns that are also fast growing and do not have waste disposal facilities. The Nairobi City Council budgets enormous amount of funds on recurrent and development expenditures on solid waste management but the problem still persists. The same scenario exists in Mombasa, Kisumu, Nakuru and Eldoret, where the slums are fast linking up into the cities.

2.10.4 Lack of SWM policy and framework

Solid waste management problems in Nairobi are largely a result of lack of a waste management policy framework that would aim at improving the standards, efficiency and coverage of waste from "Cradle-to-Grave". Before enactment of Environmental Management and Coordination Act (EMCA) (1999), local authorities (LAs) had monopoly control over sanitation and solid waste management services in Kenya, largely under the Local Government Act (CAP 265) and Public Health Act (CAP 242). The former empowers LAs to establish and maintain MSW management services while the latter requires them to provide the services. The Acts, however, neither set standards for the service nor require waste reduction or recycling. In addition, the Acts do not classify waste into municipal, industrial and hazardous types or allocate responsibility over each type.

The community and CBOs play only a small role in SWM because they are not integrated into the formal system. Policies on community-based SWM service, in addition, have been lacking although the situation is changing. Current policy, for instance, emphasizes development of environmental partnerships with stakeholders, including promotion of environmental NGOs and CBOs.

Considerable progress has been made with respect to the policy and legal/regulatory framework for SWM over the last few years. Thus, EMCA (1999) allocates considerable property rights as far as various aspects of environmental management are concerned. The most important of these is the right to clean environment allocated to the citizens. The citizens can now compel polluters, including indiscriminate solid waste dumpers, to pay for the damage or nuisance caused. In reality, however, the cost of litigation (both in term of finances and time) makes it difficult for most of the citizens to exercise this right.

Other important rights are those allocated to National Environmental Management Authority (NEMA), for example, with respect to licensing (through lead agencies such as local authorities) of waste disposal facilities. Institutional weaknesses in NEMA and the lead agencies also affect the effectiveness with which this right has been exercised.

2.10.5 Un-regulated private sector participation

Private companies are operating in open competition and attract clients on a willing-buyer-willing-seller basis. They are issued with a business license and offer solid waste (SW) collection services, without vetting or regulation. For most of them service commences once a client completes (often name and address only) and signs a form prepared by them, which then becomes the only "contract". The forms specify the monthly charge, the frequency of the collection service, and the storage facilities to be supplied by the company. Because of increasing competition and cases of unsatisfactory service, some of the firms include (in the form) a promise to refund money for unsatisfactory service. Some of the "contracts", especially those involving small companies, are usually verbal and are short term.

There are no provisions for sanctions and legal framework for the companies to deal with payment defaulters or for clients to secure legal redress when service quality is unsatisfactory. In such a scenario the aggrieved party simply walks out of the relationship. Some of the private companies, however, retaliate for non-payment. There are no bylaws specifying the rights and obligations of the companies and their clients, or specifying the standards that must be observed. Encouragingly, the Nairobi City Council has developed a policy document that will involve private sector investors in solid waste management when it is implemented.

2.10.6 Low rate of waste recovery and recycling

Recycling of products such as papers, tyres, plastics, used clothes, and metals, is becoming increasingly popular. A kilogram of old newspapers sells for between Kshs.15 to Kshs.27 while old tyres go for Kshs.50-300 depending on the degree of wear, and size. Organic wastes are also increasingly being recycled to produce compost products. For example, community-based organizations (CBOs) managed by women are recycling organic waste from Korogocho Market to produce organic manure for sale.

Discussions with the municipal superintendents reveal a low level of solid waste recovered of 8 per cent of the recyclable and 5 per cent of the compostable. They recognise an unquantified recovery and recycling in the industries. Composting by community groups has potential but the groups are facing a number of constraints, the most important of which is procurement of land to conduct the business. Another problem is lack of a stable market for the recovered materials, especially for wastepaper and compost. Thus, for example, the self-help activities in a project in Mukuru earned Kshs 1.55 million in 1996 from the recovery of 1,018 tonnes of materials per year (Kim, 1998, Kwach, 2000). This income was not sufficient for the project's 60 members and for financing investments required to improve efficiency.

A survey carried out at the Dandora dumpsite, revealed scavengers recover recyclable materials from municipal solid waste. More than 30 different types of materials were recovered, with the major ones being ferrous metals (aluminium and copper).

While there is considerable potential in recycling, there is a problem of recyclables being contaminated with un-recyclable wastes. In addition, there is no policy on recycling in the country, which has led to the practice of some recycling companies importing waste materials and to the exploitation of waste pickers by middlemen and recycling firms. Industry operators encourage the setting up of recycling schemes (such as for aluminium cans, bottles, and polythene materials) to improve environmental conditions while also generating incomes to the poor.

2.10.7 Change of waste with society change

Plastic has changed the carrier bags industry around the world. In all urban centres in Kenya, plastic bags of all sizes and colours are found dotting the landscape. Besides this visual pollution, plastic bag wastes contribute to the blockage of drains, are consumed by livestock at great danger, and take many years to degrade. In a UNEP report (2004), Wangari Maathai, a Nobel Peace Prize winner, has linked plastic bag litter with malaria. The bags, when discarded, can fill with rainwater offering ideal and new breeding grounds for the malaria-carrying mosquitoes. It is the magnitude of this problem and the attention it is receiving in the country that motivated its choice as a pilot project. Top politicians, members of parliament, environmental lobbyists, and ordinary people have complained about the problem from time to time.

Bags made from plastic are durable, versatile and convenient, but also inexpensive, easily available and easy to store and transport on account of their thinness and lightness. Alternatives such as boxes and paper bags cannot handle liquids as well as plastic bags do. Simply put, plastic bags are popular with consumers because they are functional, lightweight, strong, inexpensive and hygienic. In addition, the environmental impact of plastic bags in landfills is low due to their inert (or un-reactive) nature. The Environmental Protection and Heritage Council (EPHC, 2002) of Australia reports that plastic bags may have some benefits to landfills; such as stabilizing qualities, leachate minimization, and minimization of greenhouse gas emissions. However, the very problem with plastic bag waste emanates from some of their advantages. First, because they are cheap there is excessive consumption and a tendency for misuse. In Australia, for example, an individual uses one new bag per day on average because they are free. While it is free to the customer, however, a plastic shopping bag costs the retail facility in that country about one cent (wholesale price), with a real average cost per household of $ 10-15 per year (EPHC, 2002).

Second, most of the plastic bags produced are too thin and fragile to be re-used. This characteristic of plastic bags lends them to inadvertent littering, which has become a serious problem in urban centres the world over. Littering of plastic bags is associated with numerous environmental problems:

- They cause visual pollution that affects such sectors as tourism.
- Plastic wastes block gutters and drains creating serious storm water problems. Bangladesh, for instance, imposed a ban on plastic bags in March, 2002 following flooding caused by blockage of drains (EPHC, 2002).
- Plastic wastes that find their way into the sea and other water bodies kill aquatic wildlife when the animals ingest the plastics mistaking them for food.
- Consumption of plastic bags by livestock can lead to death.
- Plastics take 20 to 1000 years to break down.

Thus, even though supermarkets and other market outlets give "free" plastic bags to customers, in reality they are very costly to the economy The real costs of the bags include production, consumption and disposal costs.

2.10.8 Status of the plastic bag problem in Kenya

As elsewhere in the world, the problem of overuse, misuse and indiscriminate and inadvertent littering of plastic bags is serious in Nairobi. Currently the plastic bags are either free or inexpensive making their use widespread. Most bags are thin and highly fragile, re-use is minimal. According to discussions with one of the leading supermarket chains in Kenya, approximately 8 million bags are given out by the supermarkets alone every month and two times as much in the informal sector in Kenya.

Many street children and other informal sector operators are found in markets and outside supermarkets selling the plastic bags at very low prices, ranging from Kshs 5 to 20 depending on size. There are also 'designer' plastic bags, mainly used to pack customer shopping in supermarkets and other wholesale and retail shops. While these are given to shoppers free, the cost of plastic bags is becoming a concern to the supermarkets for which the cost for an average sized 'designer' bag costs about Kshs 3 a piece (Klundert, et al.,1995).

2.11 Potential Environmental Impacts from Solid Waste Management Activities

The typical municipal solid waste stream (MSWS) will contain general wastes (organics and recyclables), special wastes (household hazardous, medical, and industrial waste), and construction and demolition debris. Most adverse environmental impacts of solid waste management are rooted in inadequate or incomplete collection, or in inappropriate siting, design, operation, or maintenance of dumps or landfills. Improper waste management activities can:

2.11.1 Impact on Land

The accumulation of uncollected waste in undesignated land may lead to:

- Reduction in flood retention areas due to a majority of disposal sites being located in low-lying areas such as marshy lands and abandoned paddy lands;
- Reduction and pollution of wetland habitats;
- Aesthetic impairment due to wind blown litter and waste left uncovered;
- Degradation of land due to leachate seepage from uncontrolled dumping with adverse effects on soil fertility and productivity; and
- Differential settlement in sites that are reclaimed for future development. With the decomposition of Municipal Solid Waste (MSW), settling is unpredictable with a possible risk of structural instability and collapse.

2.11.2 Impacts on Water Resources

In the absence of engineering methods to treat leachate generated from decomposing garbage, it enters groundwater and surface waters. The BOD (bio-chemical oxygen demand) of the leachate ranges from 2,000 - 30,000 mg/l (Tchobanoglous, et.al., 1993), while the environmental authorities require that wastewater discharged to surface waters be treated to reduce BOD concentrations to no more than 30 mg/l. This gives an indication of the level of pollution generated by leachate likely to enter watercourses. This is particularly significant in areas where groundwater is the only source of potable water.

The impact of ground water contamination is generally irreversible. It is reported by the Secretariat for Infrastructure Development and Investment of Colombo, Sri Lanka (SIDI, 1993) that the National Water Supply and Drainage Board (NWSDB) had considered the option of using groundwater to increase the supply of potable water to residents in the Greater Colombo area. However, due to the pollution of the ground water aquifers in the region, primarily caused by open dumping, the NWSDB was not able to proceed with this option. With Japanese funding amounting to Rs. 8.3 billion, the NWSDB has now initiated a project to tap the Kalu Ganga River (south of Colombo) as a source of water for the Greater Colombo Area (GCA).

Many Local Authorities dump MSW into or near rivers and streams with consequent contamination of potable water supply downstream. For example the Kelani River, which is the present source of potable water for the GCA, is polluted (SIDI, 1993) by leachate from a number of dumpsites along the banks of the river. In instances where clinical waste is co-disposed of with other waste, there is a possibility of pathogenic organisms entering water courses, resulting in health risks to water users.

2.11.3 Impacts on the Ecosystem

Leachate from poorly managed solid waste contaminates water bodies. When solid waste is dumped into rivers or streams it can alter aquatic habitats and harm native plants and animals. The high nutrient content in organic wastes can deplete dissolved oxygen in water bodies, denying oxygen to fish and other aquatic life form. Solids can cause sedimentation and change stream flow and bottom habitat. Siting dumps or landfills in sensitive ecosystems may destroy or significantly damage these valuable natural resources and the services they provide. The waste also attracts vermin and scavenging animals, resulting in change in the ecological balance of the area. The poorly managed waste is thus a threat to the native species.

2.11.4 Impacts on People and Property

In locations where shantytowns or slums exist near open dumps or near badly designed or operated landfills, landslides or fires can destroy homes and injure or kill residents. The accumulation of waste along streets may present physical hazards, clog drains and cause localized flooding.

2.11.5 Impacts on Tourism and Business

The unpleasant odor and unattractive appearance of piles of uncollected solid waste along streets and in fields, forests and other natural areas, can discourage tourism and the establishment and/or maintenance of businesses.

2.11.6 Impacts on Air Quality

When organic wastes are disposed of in deep dumps or landfills, they undergo anaerobic degradation and become significant sources of methane, a gas with 21 times the effect of carbon dioxide in trapping heat in the atmosphere. Garbage is often burned in residential areas and in landfills to reduce volume and uncover metals. Burning creates thick smoke that contains carbon monoxide, soot and nitrogen oxides, all of which are hazardous to human health and degrade urban air quality. Combustion of polyvinyl chlorides (PVCs) generates highly carcinogenic dioxins.

2.11.7 Impacts on Health

- Insect/mosquito breeding in stagnant water pools on waste sites and in canals and waterways blocked or constricted with waste resulting in the spread of disease.
- Health hazards to workers and neighbouring residents: There are significant health risks due to the existence of vermin, insects, flies and scavenging animals particularly to workers on site and waste pickers. They are exposed to health hazards primarily by coming into contact with syringes, contaminated needles, other hospital wastes, faecal matter and hazardous wastes. Partly burnt organic compounds could also result in serious health problems.
- Nuisance caused to the neighbourhood due to odour, flies and constant movement of refuse transporting vehicles delivering waste to the site.
- Hazards associated with collapse of slopes where MSW is dumped in an uncontrolled manner with side slopes not maintained at IV: 3H. The structural failure of slopes can cause property damage and injury or loss of life.

2.12 Solid Waste disposal

2.12.1 Guiding principle

The number one priority in waste management is to reduce the amount of waste we produce. The commitment is to reduce the waste that is disposed of by upto 60% per capita (Jones et al 2000). This target is consistent with worldwide trends and is underpinned by the philosophy of ecologically sustainable development (ESD), which requires us to use scarce natural resources more efficiently, and avoid the environmental impacts of waste disposal. The primary aim is to maximise conservation of resources through the effective avoidance and diversion of waste.

Although we recognise that waste is best reduced or avoided at the point of production or generation, we also recognise the need for strategies for reusing and recycling those wastes that are generated. Inevitably, some waste will need to be disposed of to landfill, but this is now viewed as a last resort which also needs to be carried out in an environmentally effective and efficient manner, consistent with ESD principles.

2.12.2 Land filling

For the last two decades, solid waste components in World Bank projects have focused on collection of solid wastes, with equipment provided to upgrade operations at existing open dumps (Cointreau et al., 2000). Since early 1990, the private sector has become increasingly been involved in the collection, disposal, and treatment of solid waste and World Bank projects have placed greater priority on implementation of new sanitary landfills. The basis of a good solid waste management system is the municipal solid waste (MSW) landfill. MSW landfills provide for the environmentally sound disposal of waste that cannot be reduced, recycled, composted, combusted, or processed in some other manner. A landfill is needed for disposing of residues from recycling, composting, combustion or other processing facilities and can be used if the alternative facilities break down. A properly designed MSW landfill includes provisions for leachate management and the possible collection of landfill gas and its potential use as an energy source. Innovative planning may also facilitate productive use of the landfill property after the landfill is closed.

Modern MSW landfills differ greatly from simple land disposal. Today's MSW landfills which have evolved in design and operating procedures over the last 20 years, are very different from landfills of even 5 or 10 years ago. Design improvements have reduced environmental impacts and improved the efficient use of resources.

Landfill Site Selection

This requires technical engineering competence, attention to economic, social and political aspects of land use and planning. It is necessary to obtain sufficient information about possible sites. Landfill area exclusion criteria applicable worldwide and the local interpretation are on Tables 2.5and 2.6 respectively (Rushbrook, 2000).

Table 2.5 Area Exclusion Criteria Applicable Worldwide.

Aspect	Criteria
Transport	T1. More than 2km from a suitable main road. T2. More than an economic travel distance from points of origin of waste collection vehicle.
Natural conditions	N1. Flood plains or other areas liable to flooding. N2. Extreme morphology (steep or over-steep slopes liable to landslides or avalanches.
Land use	L1. Designated groundwater recharge, sole source aquifer or surface water catchment areas for water supply scheme. L2. Incompatible future land use designations on or adjacent to the site, particularly hard (built) development or mineral extraction. L3. Within a military exclusion zone.
Public acceptability	P1. Within 200m of existing residential development (this minimum distance may be larger in some places due to political, geological or social requirements).
Safety	S1. Within 5km of an airport runway in the direction of approach and take-off. S2. Area of former military activity where buried ordinance may be Present. S3. Within a microwave transmitter exclusion zone. S4. Within a safer buffer distance (say 100m) from an existing or planned quarry, which will undertake blasting with explosives. S5. Areas known to contain collapsing soils (such as loess).

Source: Rushbrook, 2000

Factors to consider in landfill site selection

(a) Planning and land use
Land use plans and planning goals should be established by local and regional agencies to avoid future land use conflicts with the landfill.

(b) Climate, topography and natural features

Climatic characteristics such as prevailing winds, precipitation, evapotranspiration and temperature variations should be considered as they relate to odours, dust and leachate generation, blowing litter, cover soil, erosion etc. The topography of the site affects its capacity, drainage, ultimate land use, surface and ground water pollution, site access and related operating factors.

(c) Cost consideration

The cost of land and the cost per tonnenage of solid waste disposed should be compared to identify possible savings that may accrue.

(d) Public acceptance

A site with minimal potential for public opposition, all other things being equal, should be chosen over a site generating considerable local controversy.

***Table 2.6** Area Exclusion Criteria Subject to Local Interpretation.*

Aspect	**Criteria**
Natural conditions	N3. High or seasonally high water table. N4. Kerstin or geologically faulted areas, or areas containing mine workings, where leachate may migrate rapidly from the site to a potable aquifer. N5. Wetlands (swamps or marshes) or other areas of ecological significance.
Public acceptability	P2. Within an acceptable distance (desirable minimum distance 200m) from historical, religious or other important cultural site or heritage.

Source: Rushbrook, 2000

Site Planning and Design.

The optimum development plan should include comprehensive data, upon which the following facility plans would be developed:

- Detailed drainage facilities, all-weather roads, fencing, buildings, sanitation, water, lighting, telephone, scales, equipment, maintenance yard and all other site improvements;
- A series of cut and fill plans representing the landfill at various stages of completion;

- A detailed description of daily operating procedures;
- A phased analysis of equipment and manpower requirements for the life of the landfill.
- An ultimate land-use plan for the site. and
- An estimate of projected capital and operating costs;

The following is a list of key decisions to be made by municipalities, having identified the suitable site:

- Availability of technical resources to design, develops, and operates such a facility;
- The standard of land filling to be adopted, which is reflected in the design and realized in the construction, operation and subsequent restoration of, after-use;
- The possibility of using either mechanical equipment or manual operation; and
- Permitting waste scavenging.

Equipment and Manpower Requirement

A minimum of two persons is desirable to work at a sanitary landfill for safety reasons. Equipment requirement will however vary with landfill characteristics. They include crawler or rubber-tyre tractors with dozer blades, buckets, multipurpose buckets and landfill blade (ERM, 2000).

Other important matters to consider while planning and designing a landfill site include:

- Availability of access roads, which need to be all-weather roads;
- Availability of reception facilities for the supervisor at the entrance to the site to allow monitoring of vehicle movements;
- Availability of mobile plant maintenance facilities;
- Accommodation of scavengers; and
- Provision of ground water monitoring facilities for environmental monitoring.

Sanitary landfill methodology

United States Environmental Protection Agency (USEPA, 2006) defines three landfill methods as:

(a) Trench method

This is a long narrow excavation made in the earth, the soil removed from this excavation being stockpiled. Wastes are placed at one end of the trench, spread on a shallow inclination and then compacted.

(b) Area method

Refuse is dumped on undisturbed existing ground surface, spread over the ground surface in a uniform layer and then compacted to high density.

(c) The ramp method

This is a hybrid technique combining features of both trench and area methods of land filling

<u>Landfill operation</u>

During landfill operation, it is important to note the following general principles:

- Waste should be compacted into thin layers, each up to 300mm, and, in turn, these layers should build up into a total thickness of about 2m;
- Compacted waste should be covered with up to 15cm of soil or similar material at the end of each working day;
- Open burning of waste at the site should not be permitted;
- No biodegradable waste should be deposited in water;
- Inspections for vermin should be frequent and measures taken to prevent infestations;
- Litter should be collected regularly from the site;
- Drainage ditches should be kept free of any blockages;
- Site access road should be regularly inspected and repaired;
- A record should be kept of all waste deliveries to the site;
- Environmental monitoring should be performed routinely and records kept on site as evidence of the impact that the site has on the environment; and
- The public should be excluded from the site for their own safety.

The minimum level of staffing will vary depending on the quantity of waste received at the site and the method of filling in operation. A reasonable staffing would include:

- A landfill operations officer;
- A gate keeper;
- Security guards;
- Landfill and earthmoving equipment drivers;
- A maintenance mechanic; and
- Manual labourers.

2.13 Incineration

Process

This is a controlled combustion process for reducing solid, liquid or gaseous combustible wastes primarily to carbon dioxide, other gases, and relatively non-combustible residue. The residue is usually deposited in an accompanying landfill. To reduce waste volume, local governments or private operators can implement a controlled burning process called combustion or incineration. In addition to reducing volume, combustors, when properly equipped, can convert water into steam to fuel heating systems or generate electricity. Incineration facilities can also remove materials for recycling. Over one-fifth of the U.S. municipal solid waste incinerators use refuse derived fuel (RDF), (USEPA, 2006).

In contrast to mass burning, where the municipal solid waste is introduced without any sorting into the combustion chamber, RDF facilities are equipped to recover recyclables (e.g., metals, cans, and glass) first, and then shred the combustible fraction into fluff for incineration. Burning MSW can generate energy while reducing the amount of waste by up to 90 percent in volume and 75 percent in weight. A variety of pollution control technologies significantly reduce the gases emitted into the air, including:

- Scrubbers—devices that use a liquid spray to neutralize acid gases;and
- Filters—remove tiny ash particles.

Burning waste at extremely high temperatures also destroys chemical compounds and disease-causing bacteria. Regular testing ensures that residual ash is non-hazardous before being land filled. About ten percent of the total ash formed in the combustion process is used for beneficial use such as daily cover in landfills and road construction.

Waste to Energy (WTE) technology options.

During the incineration process the energy generated can be harnessed for use in power generation. Some of the waste to energy technology units (Boley, 1991) for solid waste incineration includes:

- Modular incinerators (15-100 tonnes-per-day) - These are usually factory assembled units consisting of a refractory-lined furnace and waste heat boiler, both of which can be preassembled and shipped to the construction site. Capacity is increased by adding units.

- Mass-burning systems (200-750 tonnes-per-day per unit) - Mass-burn systems usually consist of a reciprocating grate combustion system, refractory-lining on the bottom four feet, and water-walled steam generator. These systems produce a higher quality of steam (pressure and temperature) than modular systems.
- Refuse-derived fuel (RDF) systems - Two types of RDF systems are currently used. Shred-and-burn systems require minimal processing and removal of non-combustibles; and simplified process systems, which remove a significant portion of the non-combustible.

Merits of incineration

Incinerators reduce the volume of the original waste by 95-96 %, depending upon composition and degree of recovery of materials such as metals from the ash for recycling. This means that while incineration does not completely replace landfilling, it reduces the necessary volume for disposal significantly. Incineration has particularly strong benefits for the treatment of certain waste types in niche areas such as clinical wastes and certain hazardous wastes where pathogens and toxins can be destroyed by high temperatures. Waste combustion is particularly popular in countries such as Japan where land is a scarce resource (IWSA, 1993).

Denmark and Sweden have been leaders in using the energy generated from incineration for more than a century, in localised combined heat and power facilities supporting district heating schemes. In 2005, waste incineration produced 4.8 % of the electricity consumption and 13.7 % of the total domestic heat consumption in Denmark (Kleis et al., 2004). A number of other European Countries rely heavily on incineration for handling municipal waste, in particular Luxemburg, The Netherlands, Germany and France.

Technology / Types of incinerators

Incinerator plants can also be defined according to their designs. USEPA (2006) list some of the plants as:

- **Moving grate incinerators**. This enables the movement of waste over grates through the combustion chamber to be optimised, to allow a more efficient and complete combustion. A single moving grate boiler can handle up to 35 metric tonnes of waste per hour, and can operate 8,000 hours per year with only one scheduled stop for inspection and maintenance of about one month's duration. Moving grate incinerators are sometimes referred to as Municipal Solid Waste Incinerators (MSWIs). The waste is introduced by a waste crane through the "throat" at one end of the grate, from where it moves down over the descending grate to the ash pit in the other end. Here the ash is removed through a water lock. Municipal solid waste in the furnace of a moving grate incinerator capable of handling 15 short tonnes (14 metric tonnes) of waste per hour. The holes in the grate elements supplying the primary combustion air are visible. Figure 2.3 shows a typical moving grate incineration process.

Figure 2.3: A Moving Grate Incinerator

- **Fixed grate incinerator**: The older and simpler kind of incinerator was a brick-lined cell with a fixed metal grate over a lower ash pit, with one opening in the top or side for loading and another opening in the side for removing incombustible solids called clinkers. Many small incinerators formerly found in apartment houses have now been replaced by waste compactors.

- **Rotary-kiln:** Incinerator is used by municipalities and by large industrial plants. This design of the incinerator has 2 chambers a primary chamber and secondary chamber. The primary chamber in a rotary kiln incinerator consists of an inclined refractory lined cylindrical tube. Movement of the cylinder on its axis facilitates movement of waste. In the primary chamber, there is conversion of solid fraction to gases, through volatilization, destructive distillation and partial combustion reactions. The secondary chamber is necessary to complete gas phase combustion reactions. The clinkers spill out at the end of the cylinder. A tall flue gas stack, fan, or steam jet supplies the needed draft. Ash drops through the grate, but many particles are carried along with the hot gases. The particles and any combustible gases may be combusted in an "afterburner". Figure 2.4 shows an installed rotary kiln (Ramboll, 2006).

Figure 2.4: Rotary Kiln Incinerator with Vertical Afterburner for Hazardous Waste

- **Fluidised bed:** consists of fluid-solid mixture that exhibits fluid-like properties. As such, the upper surface of the bed is relatively horizontal, which is analogous to hydrostatic behaviour. The bed can be considered to be an inhomogeneous mixture of fluid and solid that can be represented by a single bulk density. Furthermore, an object with a higher density than the bed will sink, whereas an object with a lower density than the bed will float, thus the bed can be considered to exhibit the fluid behaviour expected of Archimedes' principle. As the "density", (actually the solid volume fraction of the suspension), of the bed can be altered by changing the fluid fraction, objects with different densities comparative to the bed can, by altering either the fluid or solid fraction, be caused to sink or float (Kleis et al, 2004).

In fluidized beds, the contact of the solid particles with the fluidization medium (a gas or a liquid) is greatly enhanced when compared to packed beds. This behaviour in fluidized combustion beds enables good thermal transport inside the system and good heat transfer between the bed and its container. Similarly to the good heat transfer, which enables thermal uniformity analogous to that of a well mixed gas, the bed can have a significant heat-capacity whilst maintaining a homogeneous temperature field.

- **Small scale incinerators**, as in figure 2.5, exist for special purposes. For example, the small scale incinerators are aimed for hygienically safe destruction of medical waste in developing countries. Simple, mobile incinerators are becoming more widely used in developing countries where the threat of avian influenza is high. Small incinerators can be quickly deployed to remote areas where an outbreak has occurred to dispose of infected animals quickly and without the risk of cross contamination, (Knox 2005).

Figure 2.5: An example of a low capacity, mobile incinerator.

2.14 Composting

The decision to implement biological valorisation of waste through composting must be accompanied by a reflection regarding the final objective of the project, i.e, whether the purpose was to treat waste or produce compost. Composting is the controlled biological decomposition of organic matter, such as food and yard wastes, into sanitary, nuisance free, human-like material (humus). Composting is nature's way of recycling organic waste into new soil, which can be used in vegetable and flower gardens, landscaping, and many other applications (USEPA, 2006.). The benefits of composting include:

- Keeps organic wastes out of landfills;
- Provides nutrients to the soil;
- Increases beneficial soil organisms (e.g., worms and centipedes);
- Suppresses certain plant diseases;
- Reduces the need for fertilizers and pesticides;
- Protects soils from erosion;
- increases overall waste diversion from final disposal, especially since as much as 80% of the waste stream in low and middle income countries is compostable;
- enhances recycling and incineration operations by removing organic matter from the waste stream;
- produces a valuable soil amendment—integral to sustainable agriculture;

- promotes environmentally sound practices, such as the reduction of methane generation at landfills;
- enhances the effectiveness of fertilizer application;
- can reduce waste transportation requirements;
- flexible for implementation at different levels, from household efforts to large-scale centralized facilities;
- can be started with very little capital and operating costs;
- the climate of many developing countries is optimum for composting,
- addresses significant health effects resulting from organic waste, such as reducing Dengue Fever;
- provides an excellent opportunity to improve a city's overall waste collection program;
- accommodates seasonal waste fluctuations, such as leaves and crop residue; and
- can integrate existing informal sectors involved in the collection, separation and recycling of wastes.

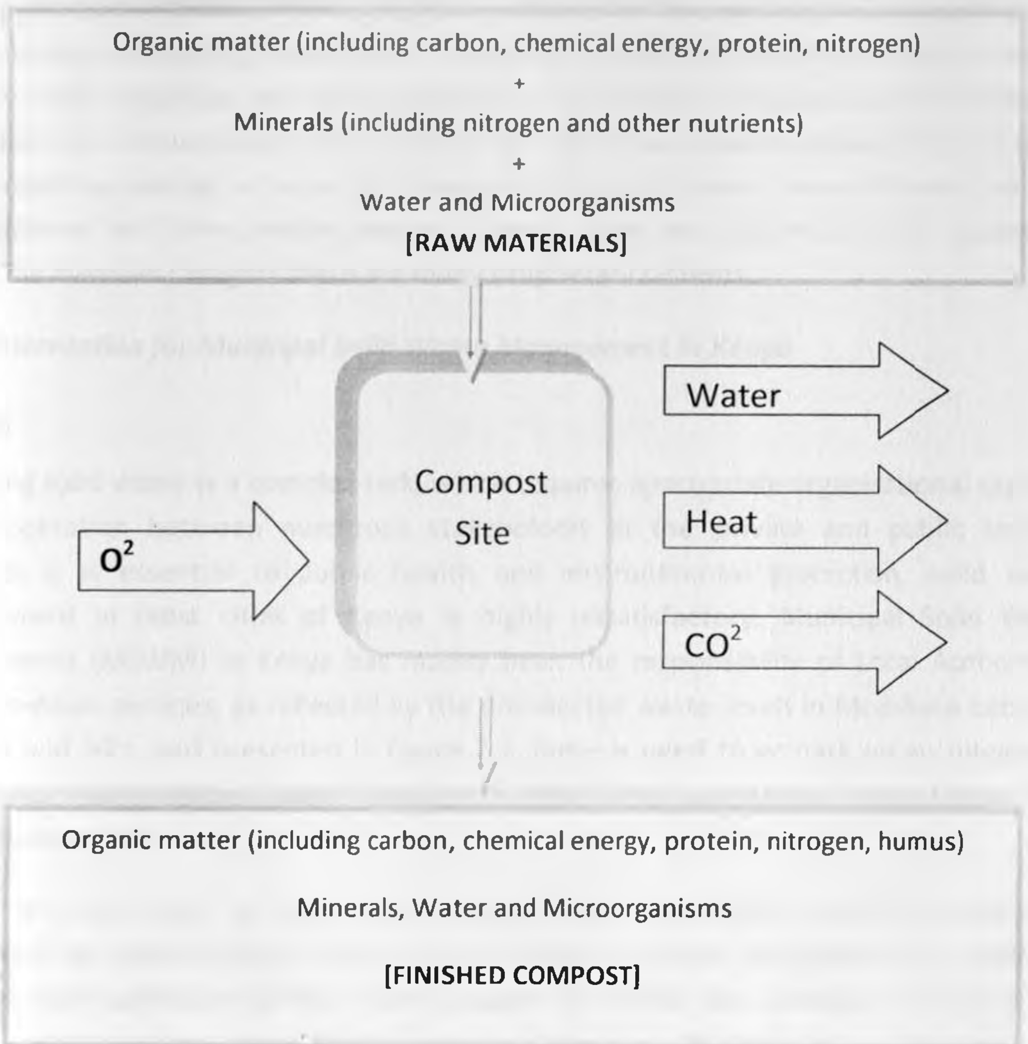
There are four principal categories of composting systems:

- turned windrows;
- static piles;
- covered-aerated static piles; and
- in-vessel composting.

The choice of system selected depends on, the type and amount of organic material to be composted, the land area available and the sensitivity of the site to odours, the financial resources available, the desired end product and the time in which the material can remain in process(USEPA, 2006). For turned windrow composting, the material to be composted is arranged in long rows (windrows) that are aerated by convective air movement, diffusion, and periodic mechanical turning that exposes the material to oxygen. The raw materials are mixed and aerated with front-end loaders or windrow turners. They are turned frequently during the initial period of high oxygen demand and heat generation and may be turned less frequently as the composting process proceeds. They may need to be turned as frequently as several times per week, depending on the material being composted. The compost process is illustrated in Figure 2.6.

Static piles are also formed in the shape of windrows but may be higher and wider since they do not need to conform to the size of a windrow turner. The term static piles refers to the fact that these piles are not turned or are turned infrequently (several times per year), generally with a front end loader.

Static systems tend to be less expensive in terms of manpower and equipment than windrows, but require more land area because the material decomposes more slowly and stays on the site longer (Perla, 1997).



The carbon, chemical energy, protein, and water in the finished compost is less than that in the raw materials. The volume of the finished compost is 50% or less of the volume of raw material.

USEPA, 2006.

Figure 2.6: The composting Process

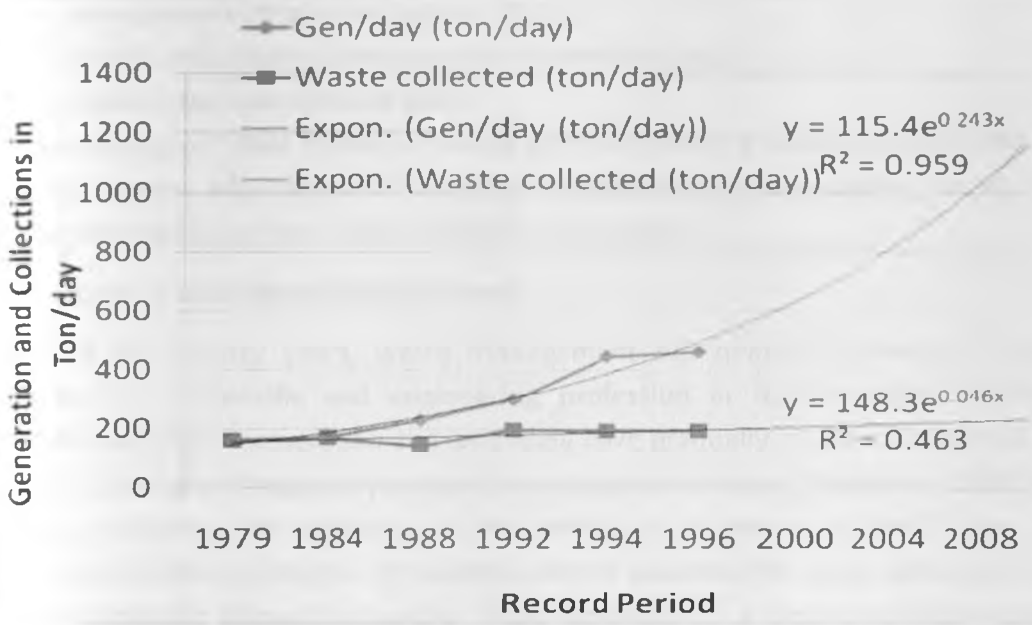
Covered-aerated, static-pile composting is useful for co-composting yard waste with sludge or manures. A forced aeration system is placed under the piles to maintain a minimum oxygen level throughout the composting mass. This aeration system usually consists of a series of perforated pipes or floors running underneath the pile connected to a pump that draws (negative pressure) or blows (positive pressure) air through the pile. In-vessel, bin or closed-reactor composting takes place in partially or wholly enclosed containers in which environmental conditions are closely controlled. The principles of operation are essentially the same as for windrow and static pile systems in that the material is piled (in a container) and aerated by turning or forced air. In-vessel systems are more space efficient than the other options and have greater process controls. They are also much more expensive. Within the in-vessel category there are many proprietary systems.

2.15 Intervention for Municipal Solid Waste Management in Kenya

General

Managing solid waste is a complex task, which requires appropriate organisational capacity and cooperation between numerous stakeholders in the private and public sectors. Although it is essential to public health and environmental protection, solid waste management in most cities of Kenya is highly unsatisfactory. Municipal Solid Waste Management (MSWM) in Kenya has mainly been the responsibility of Local Authorities. With run-down services, as reflected by the uncollected waste levels in Mombasa between the 80's and 90's, and presented in figure 2.7, there is need to embark on an Integrated Solid Waste Management (ISWM) strategy to avoid falling back to the state of poor solid waste management.

Among the key issues of discussion floated in the late 1990's was the Conceptual Framework for Municipal Solid Waste in low-income Countries (Schubeler et al., 1996). It provides brief definitions of the main concepts of MSWM and identifies the goals and principles that normally guide MSWM system development. It discusses key objectives and issues, which should be addressed by MSWM strategies with regard to political, institutional, social, financial, economic and technical aspects. The Framework paper suggests MSWM as an important entry point for integrated urban management support. It concludes by outlining possible directions for development cooperation.



Source: cleansing superintendent annual reports - Projections by Norconsult

Figure 2.7: The solid waste generation and collection for Mombasa over time.

Like all Countries worldwide, Kenya must embrace the key goals of MSWM, namely to:

- Protect the health of the population, particularly that of low-income groups;
- Promote environmental quality and sustainability; and
- Support economic productivity and employment generation.

In order to achieve the MSWM goals Schubeler (1996) recommends adoption of an Integrated Solid Waste Management (ISWM). ISWM must be all inclusive and participatory. This can assure sustainable solid waste management systems, which are adapted to and carried by the municipality, private sector and the local communities. Integrated Solid Waste Management (ISWM) encompasses planning and management systems, waste generation processes and organisations and procedures and facilities for waste handling. The approach considers and brings on board the specific interests, roles and responsibilities of numerous actors, including:

- Households through encouraged waste separation education;
- Community-based organisations (CBO) and other service users, to facilitate SWM in low income and unplanned settlements;
- Local and national government authorities;

- Non-governmental organisations (NGO);
- Formal and informal private sector enterprises; and
- External support agencies (ESAs).

The functioning of ISWM systems in Kenya and the impact of related development activities depends on their adaptation to particular characteristics of the political, social, economic and environmental context of the respective city or town.

2.16 Trends in Solid Waste Management

Over the last twenty years, waste management has begun to emerge in developed countries as a scientific and engineering profession in its own right. Environmental standards of refuse incineration and landfilling have gradually improved, and new methods of refuse sorting and resource recovery have begun to emerge (Chandran, 1993). Research has been directed, for example, at the behaviour of waste in landfill sites, focusing particularly on the production of leachate and its potential for water pollution. Industrial, and in particular hazardous wastes, have emerged as a priority concern, leading to introduction of legislation and control systems, and development of networks of sophisticated treatment and disposal facilities. The political priority given to waste management has increased sharply, largely due to public concern over well publicised incidents.

In the developing world, individual countries are at various stages in this gradual evolution towards "modern" standards of waste management. In many of the poorest countries, and in the low income areas of major cities such as Bangkok and Manila, the first priority is still to get the refuse out from under the roof. The standards of waste disposal are still almost universally low, with open dumping as the standard method in most countries. Hazardous wastes are beginning to be recognised as a priority problem, but most countries are at a relatively early stage in developing and implementing action programs (Chandran, 1993).

The experience of the last fifty years in developed countries is highly relevant to Kenya as it continues to tackle solid waste management problems. By examining both the successes and failures of past programs in developed countries, it should be possible to benefit from the experiences of others. However, it must be recognised that the priorities of the 1990's in emerging industrialised countries (EIC) are likely to be very different from those in developed countries. Whereas their level of control has reached, say 90%, they aim to approach 99%; whereas in Kenya the level of control is only 20 - 30%, then it would be fairly ambitious to adopt 90% as our goal. In addition, technologies and management systems from developed countries will not necessarily achieve their purpose in Kenya, on the contrary they will almost always require adapting to become more appropriate to the specific problems and needs of each city.

Current trends in Solid Waste Management involve the use of GIS to Improve Solid Waste Management and Recycling Programs. As populations grow in Nairobi, Mombasa, Kisumu, Eldoret and Nakuru, there is need for incorporating GIS as a decision support tool for solid waste management. GIS can be effectively used to improve the services provided with respect to waste prevention and reduction and recycling program implementation. Case studies can be done on the following:

- Analyzing participation rates at Household Hazardous Waste Facilities;
- Assisting haulers with routing collection vehicles;
- Evaluating service levels of yard debris programs;
- Developing travel time models for transfer stations;
- Inventory of multifamily complexes and recycling levels;
- Calculating recycling participation rates; and
- Distributing compost bins and evaluating the overall management efficiency.

Factors for Positive Change in the Near Term:

The United Nations Development Programme (UNDP) was involved in bringing a number of stakeholder groups together including waste haulers, Community Based Organizations (CBOs), Non-Governmental Organizations (NGOs), and Local Government officials to form stakeholder meetings with the objective of formulating a public/private action plan for solid waste disposal. Concurrently, the Nairobi Solid Waste Management Association (NASWAMA) was launched, with an inaugural meeting on November 7, 2002. The association intended to bring together all organizations involved in garbage collection and recycling in Nairobi. Amongst its objectives are:

- To liaise with the Government and Local Authorities on matters concerning solid waste management;
- To encourage the enforcement of existing laws and advocate for new legislation where none exist;

- To formulate and enforce minimum operating standards to be abided by the members. Their hope is to enhance the best practices in the collection and disposal of solid waste; and
- A long-term action plan of NASWAMA is to convert the Dandora dumpsite into a state of the art recycling and waste disposal facility.

Best Prospects in the Long Term:

The National Environmental Management Agency (NEMA) brought a wide range of stakeholders together in the form of a consultative stakeholder committee on plastic waste management (NEMA 2001). The stakeholders include NEMA itself, the Kenya Association of Manufacturers (KAM); KAM's plastics sector group, the Ministry of Environment and Natural Resources, the Ministry of Local Government, the Ministry of Trade and Industry, the Kenya Industrial Research and Development Institute (KIRDI), plastics retailers, and plastics consumers. The committee had, moreover, drawn up a road map for plastic management in the country (Table 2.7) with focus being on banning of plastics thinner than 30 microns, encouragement of recycling, collection of plastics already in the environment, reduction of littering through legal instruments, development of disposal guidelines, and design of economic instruments to improve the management of plastics.

Viewed from this roadmap, the policy package being designed was seen as elaborate and would improve on the activities agreed upon, and fast track the economic instruments activity. Currently, a committee to oversee implementation of the road map is already in place and a Kenyan Standard (KS-1794) for polythene bags has been approved. The committee set up a contributory fund to raise resources for awareness creation and public campaigns against littering and improper disposal of plastics. It recognized the value of establishing linkages with best practice globally for efforts towards effective and efficient management of plastics. The process of stakeholder consultation has not been perfect, however. The Ministry of Health then announced its plan to table in parliament a policy paper aimed at banning plastic packaging in the Kenya. The motion was passed in Parliament on 8th December 2004 calling for the use of sisal bags as opposed to polythene bags.

Table 2.7 Stakeholder Negotiated Road Map for Plastics Management in Kenya

Activity	Target	Implementation date
Ban very thin or flimsy plastics through a standard on thickness (minimum of 30 microns)	Complete and immediate phase out; complete enforcement within a year	By July 2005. Kenya Bureau of Standards to publish the standard by end of 2004
Encourage recycling of plastics through incentives such as differential power tariffs and investment tax allowances (140%) for recycling machinery	Plastic manufacturers to recycle 15% of their output; Local authorities and outlets to recover 75% of plastics used	By 2006; incentives to be included in the 2005 Finance Bill
Collection of plastics already in the environment	No plastic wastes in the country's major cities	By July 2005
Put in place legal measures on littering	Each city and municipal council to have by-laws on plastics	By July 2005
Development of better plastic disposal methods	Develop plastic disposal guidelines	By July 2005
Study the possibility of introducing appropriate economic instruments	Politically, socially and economically acceptable instruments	By 2006

Source: NEMA (2001)

During the debate, some members of Parliament recommended a ban on polythene bags. There is, thus, considerable support for measures aimed at minimizing the use of plastic bags. This project was to ride on this support, the on-going stakeholder initiatives, and the efforts being made to operationalize the Environmental Management and Control Act (EMCA 1999).

2.17 Strategic Aspects of Solid Waste Management in Kenya

To achieve sustainable and effective waste management, development strategies the ISWM must go beyond purely technical considerations to formulate specific objectives and implement appropriate measures with regard to political, institutional, social, financial, economic and technical aspects of MSWM. The aspects for consideration are outlined herein.

1. **Political aspects**

In Kenya, MSWM operates within highly charged political councils. This aspect is pivotal in a successful ISWM system. The ISWM thus should encompass formulation of country goals and priorities, determination of roles and jurisdiction of key institutions, and the legal and regulatory framework for effective management. Key elements in the Kenyan community include:

- Setting society's goals and priorities regarding environmental protection and equitable service access for all urban, unplanned settlements and rural residents, clearly articulated in order to mobilise popular support and resources required for their realisation;
- A clear definition of jurisdiction and roles of the stakeholder institutions essential to the political sustainability of ISWM systems. The strategic plan for an ISWM system should have explicitly defined roles of government authorities and other actors; and
- Bylaws, ordinances and regulations for ISWM should be few in number, transparent, unambiguous and equitable.

2. **Institutional aspects**

Kenya can benefit immensely from an ISWM system giving due concern to distribution of functions and responsibilities and correspond to organisational structures, procedures, methods, institutional capacities and private sector involvement. This can be realised through:

- An appropriate distribution of responsibilities, authority and revenues between national, provincial and local governments. In the larger metropolitan areas of Nairobi, Mombasa and Kisumu, where SWM tasks extend across several local government units, inter-municipal cooperation is essential;

- Decentralisation of responsibility for SWM requires a corresponding distribution of powers and capacities. It normally calls for revised organisational structures, staffing plans and job descriptions of the local agencies within each town or City;
- Most stakeholders need to institute capacity-building measures for ISWM, giving primary attention to strategic planning and financial management. Discrepancies have been recorded to exist between MSWM job requirements and the actual staff qualifications in all the towns studied. Training and human resource development is thus an important component;
- Cases reported of Private sector involvement in MSWM imply a shift in the role of government institutions from service provision to regulation and should be taken on board. Essential conditions for successful private sector involvement include competitive bidding, technical and organisational capacity, regulatory instruments and monitoring and control systems; and
- The contribution of informal waste collection workers in any form has been and will remain significant and thus the need to be improved through appropriate organisational measures.

3. Social aspects

The patterns of waste generation and handling of households and other users, community-based waste management and the social conditions of waste workers are key to an effective ISWM system:

- Waste generation patterns in all the study areas were determined by people's attitudes as well as their socio-economic characteristics. Peoples' attitudes towards waste may be positively influenced by awareness-building campaigns and educational measures;
- In all the study Cities many low-income residential areas, community-based solid waste management is the only feasible solution. Functional links between community-based activities and the municipal system would thus be very important;
- Even where municipal waste collection services were provided, user cooperation is essential for an efficient ISWM operation. Cooperation may be promoted through general awareness building programs as well as focused ISWM information campaigns; and

- Waste workers especially those in the informal private sector live and work under socially precarious conditions and are subject to serious health risks. Support should aim to improve their working conditions, earnings, and access to social services.

4. Financial aspects

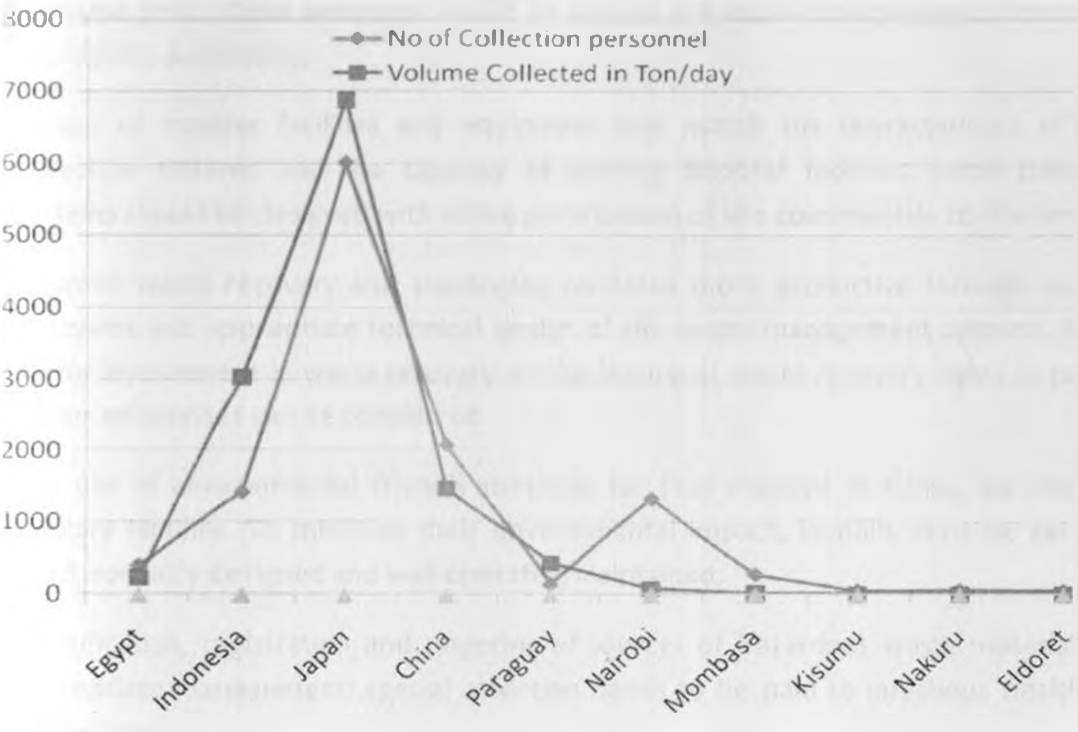
The Kenyan situation requires an ISWM with studious budgeting and cost accounting, capital investment, cost recovery and cost reduction. There is a variety of options to draw from and they include:

- Practical methods of budgeting, cost accounting, financial monitoring and financial evaluation are too seldom employed in urban waste departments in Kenya. Their application should be actively promoted within institutional development programs;
- Options for financing capital investment for SWM include; local budget resources, loans from financial intermediaries; and special central government loans or grants. While central financing is often needed, investment authority should be devolved to local governments;
- Options employed world over for financing recurrent SWM costs are: user charges; local taxes and intergovernmental transfers; and clear preference should be given to user charges, especially hazardous waste generators. To achieve equitable service access. In Kenya there may be a need for some degree of cross-subsidisation and/or financing of the sector (Kwach, 2000);
- The MSWM fee collection performance in Kenya has been poor. But improvement can be achieved by attaching solid waste fees to the billing for another service, such as water supply for low income areas, while direct charges for services should be adopted for middle and upmarket areas;
- Devolving solid waste service revenues from a general municipal account, where they tend to be consumed by other expenditures can also be considered where possible. Clear political decisions and autonomous accounting procedures are required to ensure that MSWM revenues are employed for the intended purpose; and
- The potential for increasing MSWM revenues is usually limited and a cost reduction approach adopted where, "Doing more with less" is almost always the best way to improve financial sustainability.

5. Economic aspects

The impact of solid waste services on economic activities, cost-effectiveness of ISWM systems, macro-economic dimensions of resource use and conservation, and income generation in Kenya cannot be over emphasized. Some of the key economic aspects include:

- Solid waste generation and the demand for waste collection services in all the study areas generally show an increase with economic development;
- The efficient human resources management can contribute substantially to the economics of an ISWM. Figure 2.8 shows the global comparative collection efficiency of the study cities, all of which performed the least. This low collection efficiency can be looked at as a reflection of an opportunity which can be harnessed for economic gain in the solid waste management in the towns;
- A trade-off is thus required between the objectives of low-cost collection service and environmental protection;
- The economic effectiveness of ISWM systems depends upon the life-cycle costs of facilities and equipment and the long-term economic impact of services provided; The situation in Kenya portrays total dilapidation in equipment, and where they exist most are obsolete;
- Economic evaluation of the SWM planning and investment would constitute an important input to strategy for the ISWM;
- Encouraging and sensitising on measures which discourage wasteful use of materials and encourage waste minimisation should be done. The best way to promote efficient use and conservation of materials is to internalize the costs of waste management as far as possible in the production, distribution and consumption phases;



Source: ADB (2002)

Figure 2.8: Global Comparative Collection Efficiency of the Study Towns.

- Kenya should encourage Private sector involvement in waste management to actually improve efficiency in the sector. Economic strategies should seek, firstly, to increase effectiveness and labour productivity of MSWM and, secondly, to generate employment by expanding service coverage; and
- Provide for recognition of industries that practice in-house waste reduction/reuse, through appropriate incentives.

6. Technical aspects

The planning, implementation and maintenance of collection and transfer systems, waste recovery, final disposal and hazardous waste management in the study areas is key to an effective ISWM system. This can be done by the incorporation of:

- Technical facilities and equipment designed and selected with careful regard to their operating characteristics, performance, and maintenance requirements and expected life-cycle costs. Close attention should be paid to preventive maintenance, repair and spare parts availability;

- Design of transfer facilities and equipment that match the characteristics of local collection systems and the capacity of existing disposal facilities. Local collection systems should be designed with active participation of the communities concerned;
- Informal waste recovery and scavenging rendered more productive through support measures and appropriate technical design of the waste management systems. Public sector involvement in waste recovery and/or leasing of waste recovery rights to private sector enterprises can be considered.
- The use of environmental friendly methods for final disposal in Kenya, be they the sanitary landfills. To minimise their environmental impact, landfills must be carefully sited, correctly designed and well operated/maintained;
- Identification, registration and targeting of sources of hazardous waste materials for appropriate management; special attention needs to be paid to infectious healthcare wastes; and
- Encouraging appropriate disposal of households' organic or recyclables. Education of the need for and recognition of the monetary value of recycling, through the use of abundant, ready, inexpensive labour. This in turn will guarantee the viability and sustainability of the recycling industry.

SECTION B: THE LEACHATE PROCESS

2.18 Introduction

The inefficiency in solid waste management is impacting negatively on the environment. UNEP, International Environment Technology Centre (IETC, 2004) suggests guides to sound solid waste management. Making these management decisions must be from an informed position to enhance the service provision. Zurbrugg (2003) in his publication highlights the importance of minimisation of the health, environmental and aesthetic impacts of solid waste. One contributor to these impacts is the leachate from solid waste. This chapter presents the concept of leachate formation, through the understanding of the process, the flow in the ground and potential contamination. It also presents the risk and mobility of pollutants in groundwater.

2.19 Formation of leachate

Oweis and Khera (1990) observed that refuse placed in a landfill or open dumpsite, undergoes oxidation and decomposition in the presence of oxygen, moisture and appropriate temperature. Water, which is essential for decomposition is derived from the waste itself and it is about 10 to 20% by volume or 100-200mm sq for each 1m sq of refuse. The type of refuse, ambient temperature, oxygen supply and water content influences the rate of decomposition. When infiltration exceeds the total evapo-infiltration plus the moisture retention capacity of the refuse in the gravitational field, the water percolates through the refuse removing dissolved and or suspended products of biological and chemical decomposition, as illustrated in Figure 2.9. Subsequently, the effluent from the landfill or open dumpsites is enriched in many hazardous constituents. The composition of solid waste controls the composition of the leachate produced from a Municipal solid waste disposal site.

Ground water pollution by a landfill depends on the kind of leaching process and the character of transport. The leaching process is controlled by rainfall infiltration that dissolves substances from the waste matrix.

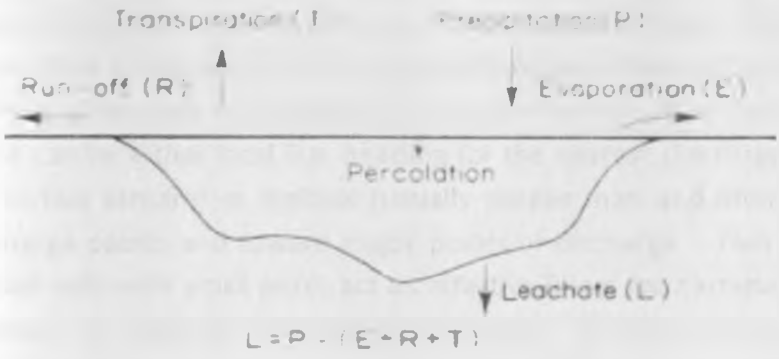


Figure 2.9: Formation of Leachate (Source: Holmes, 1983)

In case studies conducted in California, by the National Center for Resource Recovery (NCRR, 1974) USA, it was demonstrated that within a year after initiation of one test dumpsite, continuous leaching of one acre of fill would result in the leaching of 1.5 tonnes of sodium and potassium, 1.0 tonne of calcium and magnesium, 0.91 tonne of chloride, 0.23 tonnes of sulphate, and 3.9 tonnes of bicarbonates. Thus it is apparent that substantial amounts of pollutants may be removed from solid waste dumpsites and transported to the surrounding soil or water systems.

Subsurface water usually occurs in either a zone of aeration or a zone of saturation. The zone of aeration is a condition where the pores of soil and rock are filled with both air and water; while in a zone of saturation, pores are entirely filled with water. The upper surface of saturation is frequently referred to as a water table. Some water is held in the zone of aeration by the attractive force that exists between soil particles and water, but water in excess of the amount that can be held by these forces moves downwards under the influence of gravity. The amount of water in the zone of aeration depends on:

- Precipitation;
- Vegetation cover;
- Depth of water table; and
- Soil conditions.

The ease with which water moves through a zone of saturation depends on the permeability of the soil. Sand and gravel strata allow more rapid movement than those of silt or clay. Joints or fractures in rigid rock structures (such as limestone, shale, sandstone, and granite) also usually provide easy movement of ground water. Water from precipitation or leachate from a dumpsite tends to move downward through the zone of aeration, but once it reaches the zone of saturation, it moves with the ground water. This ground water movement can be either local (i.e. heading for the nearest discharge point into a swamp, pond or surface stream) or regional (usually deeper than and often running underneath local discharge points and toward major points of discharge – rivers, lakes, and oceans). Fine-grained soils with small pores act as effective filters for bacteria, but such filtration is not effective for removal of dissolved chemicals. Therefore special caution must be exercised when dumpsites are located in abandoned quarries and strip mines to make sure refuse does not come into contact with exposed aquifer. Special caution should also be exercised at dumpsites located where leachates have direct access to surface water.

Experimental results on landfill leaching conducted by South Dakota State University, USA, have indicated that the parameters which best serve to describe chemical pollution of ground water from landfill leaching are: pH; specific conductance; total hardness; calcium hardness; chloride and nitrate content (NCRR Inc, 1974). In these experiments, tests were conducted to determine the presence of sodium, potassium and iron. It was determined that chemical pollutants were removed from underground water 400 meters downstream from the fill. This was established by drilling thirty-one test wells of varying depth and distance from the fill area. Leachate samples drawn adjacent to the downstream side of the fill, indicated chloride content fifty times more than that of upstream control wells. Hardness and alkalinity were nearly twice as great in the downstream well samples, sodium and potassium content was over twenty times as great, and iron content was sixty times as great.

As mentioned by the report by the Centre for Policy and Implementation Studies (CPIS) (1993) microorganisms have been found in significant numbers of leachate from sanitary dumpsites. The most commonly found are various strains of mesophilic aerobes, thermophilic anaerobes, actinomycetes and fungi. The health significance of the microorganism content is that pathogens buried with refuse can be transported out of the fill into underground water supplies. However, biological contaminants are usually filtered by surrounding soil more quickly than chemical contaminants.

2.20 Mechanism for Leachate Flow Control

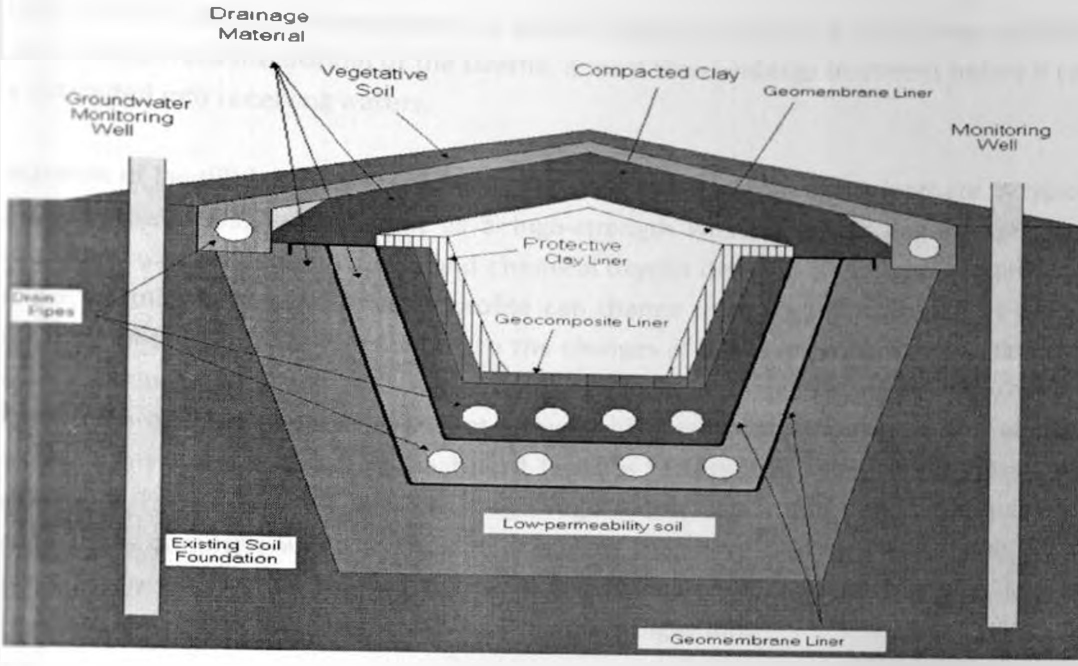
Rutherford, et al, (2000) recognise sanitary landfills as indispensable aspects for maintaining sanitary living conditions. A landfill is defined as an engineered land burial facility for the disposal of solid waste which is so located, designed, constructed and operated to contain and isolate the solid waste so that it does not pose substantial present or potential hazard to human health or environment (Lagerkvist 1997*)*.

In an effort to ensure that there is no leakage of leachate from sanitary landfills, an adequate lining system is provided. The liner is designed (Figure 2.10) as barrier to intercept leachate and to direct it to a collection system. Collection and treatment of this leachate must occur to prevent contamination of local ground water.

There are several types of liners that may be used in a sanitary landfill. The major considerations when deciding on the material for the liner are:

- Permeability of the material; and
- Type of leachate.

Rutherford, et al., (2000) contend that high clay content material is considered useful not only for low permeability but also for potential contaminant retardation. According to studies done, clay has an ability to attenuate many of the chemical constituents in leachate With the increase in solid waste that municipalities are generating (almost 200 million tonnes/ year) the solid waste collection and disposal constituents are growing fast. In the United States, the most popular method for solid waste disposal is sanitary landfills (Qasim and Chiang, 1994). Many of the solid waste landfills that were developed before 1988 had to either be shut down or be reconstructed due to Subtitle D of the Resource Conservation and Recovery Act (RCRA) that went into effect in the later part of 1993 in the US. Under Subtitle D, leachate management must be properly implemented. The landfill lining system prevents the leachate from seeping into the groundwater. The Subtitle D allows for the treatment of the leachate collected to be mandated by the states. One rule that must be followed by all states is that the leachate collected must be treated as industrial waste. Publicly owned treatment works have to be sure the leachate does not interfere with other treatment processes or sludge quality.



Source: Qasim and Chiang, 1994

Figure 2.10: Schematic of a Liner System

Production of leachate from sanitary landfills is an environmental hazard. There are several factors that influence the generation of leachate. Some of these are: precipitation; runoff; evaporation; waste density and depth of the landfill. Not much leachate is produced until the landfill is fully saturated. The leachate that is generated comes from the decomposition of the landfill waste (Lee et al, 2003). This occurs in three possible stages: In the first aerobic decomposition dominates, in this phase the temperatures rise well above ambient temperatures and produce leachates mainly of soluble salts; and the second stage is believed to be anaerobic decomposition. The first part of this decomposition produces large amounts of volatile fatty acids and carbon dioxide. The facultative bacteria then get taken over by the methane producing bacteria. These methane producing bacteria, which require a neutral pH, convert the volatile fatty acids into methane and carbon dioxide.

The decomposition process eventually decreases with landfill age due to substrate depletion. Through all the decomposition processes, the water that percolates through from precipitation carries these contaminants to the bottom of the landfill producing the leachate. The liquid state leachate is not the only contaminant that must be regulated. Over time the decomposition process produces gases that may be emitted to the atmosphere.

These gases also have to be regulated. As for the liquid leachate once it has been collected into the sump from the bottom of the landfill, it must then undergo treatment before it can be distributed into receiving waters.

Treatment of landfill leachate is a difficult task due to the nature of the leachate. A typical landfill leachate usually starts out as a high-strength wastewater, having low pH, high biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and the presence of toxic chemicals. This wastewater profile can change from landfill to landfill as well as within the same landfill as it ages. Due to the changes of the wastewater composition over time, sometimes 30 years, the conventional biological waste treatment and chemical treatment processes separately do not achieve high removal efficiency in the effluent. When it comes to the design of treatment facilities factors that influence the design are: leachate characteristics; effluent discharge regulations; costs; and permit requirements. Some of the common waste treatment processes that have been applied to the landfill leachates are: Activated Sludge, Waste Stabilization Ponds, Aerated Lagoons, Trickling Filters, Rotating Biological Contactor, and Anaerobic Digestion.

In examples in the US, Lee, (2003) envisages an emphasis on resource recovery and solid waste reduction. There will be less landfills and more innovative ways of disposing solid waste. One way will be through incineration with some sort of energy recovery system. Even though there will be less landfills in the future they will still play a major role in solid waste and residual disposal. Each year the design of the landfills and leachate control strategies will become stricter in order to protect the groundwater. So when the permit application is submitted by the municipality to the state, these applications will be looked at very closely to be sure the design engineer has properly designed the landfill. Designing a landfill is not just the application of the liner system, there are issues of proper slopes for runoff, there has to be a sophisticated monitoring well system around the landfill, and most important the leachate must receive proper treatment before discharge. All of these regulations are mandated and enforced through each state to ensure the safety of the soil and groundwater to be free from any solid waste contaminants.

2.21 Ground Water Quality

Groundwater qualities are determined by diverse natural and human influences. Negative effects on groundwater quality arising from impurities and pollution of groundwater result from:

- Small business and industrial production processes, including storage and disposal of waste materials;
- Contamination of soils by accidents and improper storage of water-endangering materials;
- Agricultural and forestry activities (input of nutrients and pesticides); and
- Use of sewage for irrigation in farms.

Lagerkvist (1997) defines Water pollution as "contamination of water by undesirable foreign matter." It impacts our oceans, our surface water, and our underground water. Pollution comes in many forms, some conventional and others toxic.

Other forms of water pollution include:

- Sewage effluents;
- Thermal pollution;
- Eutrophication;
- Petroleum;
- Faecal pollution;
- Acid precipitation;
- Storm sewage discharges;
- Urban surface water runoff;
- Farm fertilizer and pesticide runoff;
- Acid mine drainage;
- Radioactive substances;
- Indicator of Surface Water Pollutants;
- Suspended Sediment;
- Faecal coliform;
- Total phosphorous;
- Nitrate;
- Dissolved solids;
- Dissolved Oxygen;
- Sulphates; and
- Chlorides.

Table 2.8: Forms of pollution

Toxic Pollutants	Conventional Pollutants
Cadmium	Ammonia
Copper	BOD
Lead	Nitrogen (and nitrate)
Mercury	Pathogens
Phenol	Phosphorus
Total residual chloride	Suspended solids

(Source: Lee, 1991)

2.22 Factors of Vulnerability

The groundwater aquifer is protected to varying degrees from contaminants by a geologic mantle of surface strata (natural protective effect). Cohesive soils are capable of absorbing a certain amount of pollutants (Lee et al., 1991) by incorporating metals into their layer lattice of argillaceous minerals. These complexly bound pollutants in soils pose a relatively low danger to groundwater, but pollutants, which are not bound, can percolate (seep) into the groundwater.

Decomposition of pollutants in soil can occur by microbiological processes, but decomposition is substance-specific, and dependent on the nature, temperature, and oxygen content of the soil. But this self-purification, as well as the filtering effect, is relatively insignificant. Every further contamination presents a danger for the first groundwater aquifer. Sand and gravel without cohesive components bind only very small amounts of pollutants, and hardly protect groundwater. A "certain" protection is afforded only by a greater thickness (> 10 m), which prolongs percolation time. The vulnerability of groundwater to pollution depends on a range of factors summarised in Table 2.9.

2.23 Impact of landfill leachate on groundwater quality

Leachate whether still acetogenic or older and methanogenic is in general quite capable of causing oxygen deprived conditions in watercourses which put at risk the natural ecology. The ammoniacal nitrogen concentrations vary massively from site to site, but also rise during the later stages of the acetogenic stage, and at concentrations which vary according to the pH, but always by the time 100 mg/l ammoniacal nitrogen is reached will be toxic to fish and many other higher aquatic organisms.

Table 2.9: Factors of Vulnerability

Geological-lithilogical	- Formation of infiltration and percolation zones
Morphological	- Surface form
Geo-chemical	-Binding conditions of soil - composition of pollutants
Physical	- Adhesive and cohesive forces in soils
Hydro geological	- Surface and subterranean flows - Flow direction and speed

(Source: http://www.scisoftware.com/publications/publications/publications.html)

In groundwater, the risk arises from the migration of leachate contamination into water supplies where the presence of ammoniacal nitrogen is and even its breakdown product nitrate will render the groundwater unsuitable for drinking. Nevertheless, the toxicity is not generally (in fact almost never) due to the presence of the sorts of chemicals thought of as "poisons", while some of the more highly poisonous chemicals are occasionally found, they are seen at minutely low concentrations, and the risk at these low levels is far lower than generally perceived by the public. Unfortunately, even dilute leachates which enter watercourses can cause the growth of "sewage fungus", and this can be the case on occasions where the leachate would not otherwise be significantly damaging. Sewage fungus grows to cover every surface, in the bed and all plant life. It is grey/white in colour and builds up to become a matted covering of fungal growth quite soon smothering the natural bed ecology.

Fatta et al (1999) reported on the characterisation of the leachate originating from the Ano Liosia landfill (situated in Attica region, Greece) as well as assessment on the quality of the local aquifer. The experimental results showed that most of the parameters examined in the leachate samples such as colour, conductivity, TS, COD, NH_3–N, PO_4–P, SO_4^{2-}, Cl^-, K^+, Fe and Pb were found in high levels. The organic load was quite high since the COD concentrations were in the range of 3250–6125 mg/L. In addition, the low BOD/COD ratio (0.096–0.195), confirmed that the majority of this organic matter is not easily biodegradable. The groundwater near the landfill site was characterised as not potable and not suitable for irrigation water, since most of the physical and chemical parameters examined – such as colour, conductivity, DS, hardness, Cl^-, NH_3–N, COD, K^+, Na^+, Ca^{2+}, Fe, Ni and Pb exceeded the permissible limits given by EU, EPA and the Greek Ministry of Agriculture. In addition, this study presented the application of the hydrologic evaluation of landfill performance (HELP) model for the determination of the yearly leakage from the base of the landfill after the final capping.

2.24 Distribution of Pollutants

Factors of importance for the temporal and spatial distribution of pollutants in groundwater are:

- Overland flow and flow direction;
- Rate of infiltration and percolation; and
- The horizontal flow velocity in the aquifer.

Pollutants deposited in argillaceous soil cannot infiltrate so quickly, but pollutants can be transported by rainwater into hollows with a sandy under soil, and are also a great danger for the first groundwater aquifer (Fatta et al., 1999).

Distribution rate

The percolation rate or the water depth per unit of time is one of the critical criteria for groundwater vulnerability to pollution. This vulnerability derives primarily from the geologic structure of the mantle covering the groundwater (permeability, porosity) and its thickness (flow and percolation routes). An increase in argillaceous material is related to a decrease of the permeability co-efficient and thus the percolation rate. Greater depth increases the time needed for percolation. The lithological (rock) structure of the groundwater aquifer and the groundwater flow gradient determine the horizontal flow rate and thus the temporal and spatial dispersion of pollutants within groundwater. A groundwater aquifer is not a homogeneous structure. Fine sand, coarse sand, or silt can alternate. For this reason, a horizontal coefficient of permeability must be included to calculate flow velocity.

2.25 Choice of Indicators

Standard parameters chosen as indicators for the quality of near-surface groundwater are: chlorides; sulphates; ammonium; nitrates; oxidability; conductivity; and levels of AOX and pesticides. Ammonium and nitrates are considered parameters for pollution of near-surface groundwater by sewage water and faeces. The oxidability gives indications for organic pollution. Electrical conductivity, a sum parameter for dissolved substances in groundwater, is a parameter for contaminations of inorganic matter and a standard for general pollution of salts. The same applies for chlorides. 'Chemically stable', chlorides do not transform and can thus be followed over long distances. Groundwater deterioration from high sulphate impacts indicates debris underground or waste disposal sites with large amounts of building rubble. AOX stands for adsorbable halogenated hydrocarbons and serves as indicator for intensive industrial use (Fatta et al., 1999). The presence of AOX is also characteristic for pollution from the storage of industrial waste (old contaminated sites).

Limits

These are internationally accepted values for the physical, chemical and biological characteristics of water as shown in Table 2.10 for drinking. The limit values are valid in a strict sense only for drinking water (pure water). They are used here as critical parameters for groundwater because other criteria are lacking. Basically, ground water quality without anthropogenic influences should be attained.

Oxidability

Causes are waste disposal sites and old contaminated sites, as well as the influence of operations of sewage farms and wastewater processing areas. The influence of inflows from wastewater processing areas and settlement areas without sewage treatment facilities is apparent.

Conductivity

Electrical conductivity is considered a parameter for impacts of inorganic matter. The subsurface shows the effects of inputs containing salts such as nitrates, phosphates, chlorides and sulphates.

Ammonium

Ammonium is produced as a decomposition product from animal and plant protein. Only traces of ammonium are generally present in unpolluted groundwater. Its presence in near-surface groundwater usually indicates pollution from wastewater and faeces. Health dangers from ammonium ions are not currently known, but their presence in groundwater is hygienically disturbing, because of their usual origins in faeces. Causes for the relatively high ammonium concentrations in groundwater are primarily due to sewage farms, which discharged large amounts, wastewaters into the groundwater for decades. Further impacts followed from percolation of effluents in settled areas without sewer systems and from leaking sewage pipelines. High ammonium values can also appear under natural conditions in low-oxygen groundwater, such as under moors, because ammonium impacts cannot be oxidized there.

Table 2.10: Drinking water standards

Parameter	Kenya Bureau Standard (KEBS) Drinking Water Standards
PH	6.5-8.5
Specific Conductivity	2000µs/cm
Total Hardness	150 mg/l
Chlorides	250 mg/L
Sulphates	240 mg/l
Oxidibility (K MnO_4 Consumption as O_2)	5 mg/l
Bacterial Count per ml	500 bacterial colonies per millilitre
Turbidity	1 NTU
Nitrates	50 ppm
Ammonium	0.5 mg/l
BOD	4mg/l
AOX*	0.01 mg/l
Total Dissolved Solids	500 mg/l (0.05%)

(Source: Ministry of Water Resources Management and Development, 1996)

Nitrates

Nitrates in higher concentrations are considered toxic. It can be reduced to nitrite in the intestinal tract. Nitrite then binds with haemoglobin in the blood and restricts the transport of oxygen in the blood circulatory system. This leads to oxygen deficiency manifestations (methemoglobinemia), which can be deadly for children, especially infants. The transformation of nitrates can also release nitro amines, which are carcinogenic.

Sulphates

The cause is the underground distribution of building rubble - especially debris - over large areas (most of it war damage). Building rubble and debris contain sulphurous plasters, which are washed-out by precipitation waters Thus there is a tendency for higher values in the city centre than in outlying areas. High local values are also found in the sphere of influence of waste disposal sites, which have a large proportion of building rubble and debris

Chlorides

Chlorides are not toxicologically alarming, but they can be considered a measure for general pollution. Groundwater containing salts sometimes climbs from deeper layers to the surface. Other exceeded limit values can be found in the vicinity of waste disposal sites.

AOX

The presence of AOX (adsorb able halogenated hydrocarbons; **AOX** = adsorbierbare halogenierte Kohlenwasserstoffe) in groundwater is always due to anthropogenic activity - the effects of small industrial business discharging waste on the ground within their premises or pollution from old contaminated sites. A particular problem is presented by the group of highly volatile chlorinated hydrocarbons (CHC = LCKW). This material is detected along with other materials in the determination of AOX. Studies indicate that the boulder marl overlying the groundwater aquifer may not be an effective protective barrier against this material group. In fact, the highly volatile CHCs penetrate boulder marl overlapping relatively easily.

Cadmium

Cadmium is considered a representative indicator for heavy metal impacts in groundwater, because of its environmental behaviour. It has a high accumulation rate in soils. Even the bare possibility of remobilization and washout is a considerable point of danger for groundwater. Cadmium is severely toxic to the human organism. Liver, kidneys and bone marrow are the most susceptible organs or accumulation points in chronic or acute cadmium exposure. Most cadmium absorption proceeds above the digestive tract.

Biochemical Oxygen Demand

The biochemical oxygen demand is defined as the amount of oxygen required by bacteria while breaking down decomposable organic matter under aerobic conditions. It is the estimate of the amount of oxygen required to stabilize biodegradable organic materials by heterogeneous microbial population.

Chemical Oxygen Demand

The chemical oxygen demand (COD) is a measure if the oxygen equivalent of the organic fraction in the sample which is susceptible to permanganate or dichromate oxidation in an acid solution. The parameter is used in estimating the organic content of waters and wastewaters.

Acidity

The acidity of water or its capacity to donate protonnes is attributed to the unionised portions of weakly ionising acids, hydrolysing salts, and free mineral acids. Microbial systems may reduce acidity in some instances through biological degradation of organic acids.

Ammonia- Nitrogen

Ammonia nitrogen is present in many natural streams in relatively low concentrations (< 100 mg/l), although industrial streams contain exceedingly high concentrations. The presence of ammonia nitrogen in excess of 1,600 mg/l has been proved inhibitory to many microorganisms

Turbidity

Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhoea, and associated headaches.

2.26 Risk of Water Contamination

The risk of groundwater contamination by leachate as outlined by Rutherford et al (2000) is to be determined by the following factors:

- Depth of the water table - If the water table is low (far below the ground surface), water will become partially filtered as it percolates downward through the soil. If the water table is high (close to the ground surface), contaminants can enter the groundwater directly, without filtration by soil;

- Concentration of contaminants - A high concentration of contaminants in leachate will make groundwater pollution more likely;
- Permeability of the geologic strata - Highly permeable geologic strata allow water to percolate through, receiving little filtration along the way. Strata consisting of relatively impermeable materials such as silt and clay impede the downward percolation of water;
- Type of geologic strata - Some earth materials, such as clay, are more effective at filtering out contaminants, not just because they are impermeable but also because chemicals can bind to their particle's surfaces;
- The toxicity of the contaminants - Leachate is produced when water filters downward through a dumpsite, picking up dissolved materials from the decomposing wastes. Depending on characteristics of the dumpsite and the wastes it contains, the leachate may be relatively harmless or extremely toxic. Generally leachate has a high biochemical oxygen demand (BOD) and high concentrations of organic carbon, nitrogen, chloride, iron, manganese, and phenols. Many other chemicals may be present, including pesticides, solvents, and heavy metals; and
- The direction of groundwater flow - Groundwater moves slowly and continuously through the open spaces in soil and rock. If a dumpsite contaminates groundwater, a plume of contamination will occur. Wells in that plume will be contaminated, but other wells, even those close to the dumpsite, may be unaffected if they are not in the plume.

Characteristics of contaminants in landfill leachate

Lee (2002) defines three broad types of contaminants present in municipal landfill leachate that need to be considered in evaluating the public health and ground water quality impacts of sanitary landfills. The three groups are:

- Toxic pollutants;
- Conventional pollutants; and
- Non-conventional pollutants.

Toxic pollutants

Toxic pollutants such as heavy metals (chromium, lead), inorganic chemicals (salts, acids), and organic chemicals (pesticides, solvents) can damage human health, aquatic organisms, and the overall health of the ecosystem. Toxic effects can be acute, causing immediate death or impairment, or chronic, causing subtle damage that may not emerge until years after exposure. Leachate may possess toxics that often persist in the environment and collecting in water. Toxics can bio-accumulate in the tissues of organisms after repeated intake or exposure. Toxic concentrations can increase at higher levels in the food chain, called biomagnifications

Conventional pollutants

Conventional contaminants include parameters such as dissolved solids, hardness, alkalinity chloride, sulphate, iron, manganese hydrogen sulphide and a variety of non- differentiated organics measured as chemical oxygen demand (COD), Biochemical oxygen Demand (BOD) and Total Organic Carbon (TOC). These are typical components present in elevated concentrations in landfill leachate and can thus indicate the presence of leachate in unsaturated or saturated ground waters. However, if present in sufficient amounts conventional contaminants can cause severe degradation of ground water quality and preclude its uses for domestic water supply purposes.

Non-conventional pollutants

These are largely organic chemicals that have not been defined and whose potential hazards to the public health and ground water quality are not known. Typically the organic pollutants, those organics that are identified and quantified represent a very small fraction of the total matter present in leachate as measured by chemical oxygen demand (COD) and Total Organic Carbon (TOC). It is estimated that from 90 to 95% of the organic material in municipal landfill leachate is of unknown composition. Those chemicals have not been identified and obviously, their potential impacts on public health and ground water quality are unknown (Lee et al., 1991). Table 2.11 shows concentrations of some leachate constituents from typical municipal waste landfills.

2.27 Mobility of Contaminants

The flow of leachate through a porous medium is a very complex process. The best-understood components of the process are physical processes involving ground flow, dispersion and diffusion. The geochemical and biological processes are significant in attenuating the contaminants or changing their mobility.

The Geochemical Process

This process involves primarily:

- Adsorption or desorption

- Precipitation or dissolution

Table 2.11: Leachate constituents from typical municipal waste landfills

Constituent	Concentration (mg/l)
Chemical oxygen demand	50-90,000
Biological oxygen demand	5-75,000
Total organic carbon	50-45,000
Total solids	1-75,000
Total dissolved solids	775-55,000
Total suspended solids	10-45,000
Volatile suspended solids	20-750
Fixed solids	90-50,000
Alkalinity as $CaCO_3$	0.1-20,350
Total coliform bacteria (CFU/100ml)	0-10
Iron	200-500
Zinc	0.6-220
Sulphate	25-500
Sodium	0.2-79
Hardness	0.1-36000
Total phosphorus	0.1- 150
Organic phosphorus	0.4 –100
Nitrate (Nitrogen)	0.1 –45
Phosphate (inorganic)	0.4 –150
Acidity	2700- 6000
Turbidity (Jackson Turbidity units)	30-450
Chloride	30- 5000
Copper	0.1- 90
Lead	0.001-1.44
Constituent	**Concentration (mg/l)**
Magnesium	3- 15000
Potassium	35- 2300

Table 2.11 (cont): Leachate Constituents from Typical Municipal Waste Landfills

Constituent	Concentration (mg/l)
Calcium	0- 0.375
Mercury	0- 0.16
Chromium	0.02-18

(Source: Tchobanoglous, G., et al., 1993)

Adsorption refers to the mechanism of ion exchange or chemical elements in aqueous solution binding strongly with the solid surface of soil. For example:

1. Potassium ion in solution may be exchanged with a hydrogen ion on the solid soil surface and potassium in this case is retained.
2. An element in solution (e.g. Copper) reacts with surface hydroxyl group (OH) and forms a complex leading to retention of some metals. The hydrogen ion concentration characterised by the pH value affects the adsorption process. The total capacity of soils to exchange ions characterizes their ability to selectively retain certain elements in the leachate. Fine-grained soils have higher cation exchange capacity because of larger availability of exchange surfaces. Major cations in leachate (e.g. Magnesium, Potassium and Sodium) attenuate primarily through cation exchange. Precipitation occurs when the soluble concentration of a contaminant in leachate is higher than that of an equilibrium state.

Physical Processes

Contaminants dissolved in water (solutes) could migrate through the underlying soils in three identifiable ways:

1. Transport by Advection - Under a given hydraulic gradient, the ground water and solute move with a certain advective velocity depending on the hydraulic conductivity and variations of hydraulic head.
2. Diffusion – This is caused by molecular motion of a solute because of a difference of molecular concentrations. This results in the spread of solute into an increasing larger volume in the aquifer.
3. Hydraulic dispersion – Dispersion of solute is caused by variation of fluid velocity within pore space.

The relative importance of various modes of transport depends on the advective velocity and the hydraulic conductivity.

Oweis and Khera, (1990), in an analytical study of flow through a liner mechanical dispersion appeared to be insignificant for an advective velocity less than 0.1m/year. For advective velocities greater than 0.02m/year, advection dominates over diffusion. For advective velocities less than 0.0001m/year, diffusion dominates over advection. For velocities between 0.02m/year and 0.0001m/year both advection and diffusion occur.

SECTION C: THEORY OF POLLUTANT TRANSPORT

2.28 Introduction

With few exceptions, the pollution of groundwater is associated with vadose zone (unsaturated zone) transport of pollutants from the soil surface/root zone to the water table. There are a variety of factors that influence the rate of transport of pollutants through the vadose zone, including the moisture content of the unsaturated part of the aquifer, and preferential pathways (Lee et al., 2007). Problems exist with regulatory agencies allowing inappropriate assumptions in modelling vadose zone transport of pollutants, in which average annual moisture content is sometimes used rather than the potential for wetted front transport following rainfall events. Also, this modelling typically ignores preferential pathways for rapid transport of pollutants through the vadose zone. The net result is that models based on average moisture content and the lack of preferential pathways can greatly underestimate the rate of movement of pollutants through the vadose zone to the water table.

There is need to evaluate the potential for properly conducted vadose zone monitoring to assist in evaluating whether pollutants in the root zone are being transported in sufficient quantities to cause groundwater pollution. Consideration will need to be given to wetted-front and preferential pathway transport in assessing the magnitude of transport of pollutants through the vadose zone to the water table, as well as the mixing of the percolating water with the upper area of the saturated part of the aquifer. Containing the leachate released from the solid waste is a significant step in solid waste management. Moyo (1998) reports most waste dump sites in Kenyan urban centres as not being sanitary managed. The quality and quantity of leachate released by these sites pose a long term danger to ground water as presented by Jones-Lee (2000). The chapter also covers examples of models which have been used to understand the problem of leachate contamination in different conditions.

2.29 Estimating Leachate Volume

Oweis and Khera, (1990) reported the water holding capacity of refuse as presented in Table 2.12. The amount of Leachate generated from a sanitary landfill or open dumpsites to be dependent on the following factors:

- The available water;
- Landfill constituents; and

- Surface and foundations soils.

They also reported that the available water in the landfill is influenced by:

- Moisture in the refuse itself;
- Precipitation;
- Surface runoff;
- Groundwater moving through the landfill where the ground water table is high; and
- Water generated from the decomposition process.

Table 2.12: Water holding capacity of refuse

Point in time	% by volume	Equivalent mm of water per metre of refuse
At placement time	10-20	150
At field capacity	30-35	300
At saturation (porosity 0.4)		550

(Source: Oweis and Khera, 1990)

The water reaching the dumpsite is affected by the:

- Evapotranspiration;
- Surface runoff; and
- The field capacity of the soil cover.

The field capacity is the maximum amount of water a soil or refuse can retain in a gravitational field without percolation. Table 4.1 highlights the water holding capacity of refuse (Oweis and Khera, 1990).

Water balance method

The water balance method allows the estimation of the rate of percolation and commonly used *(Oweis and Khera, 1990)* to predict the amount of leachate generated from a landfill. The method assumes a one-dimensional flow, conservation of mass and known retention and transmission characteristics of the soil cover and refuse.

Accordingly, the basic equation is

$$P + S_R + I_R = I + R_O$$

Where,

P is the input of water from precipitation.

S_R is the input of water from irrigation.

I_R is the infiltration.

R_O is the surface runoff.

The portion of infiltrating liquid I that will percolate in the soil cover P_{ERS} is given by

$$P_{ERS} = I - A_{ET} - \Delta ST_c$$

Where,

A_{ET} is the actual evapotranspiration and

ΔST_c is the change in moisture storage in soil cover.

Also the portion of I percolating in the refuse P_{ERR} which represents the leachate volume is given by

$$P_{ERR} = I - E_{AT} - \Delta S_c + W_D - \Delta STR$$

Where,

W_D is the water from decomposition of solid waste

Δ STR is the moisture content in refuse.

If there is ground water intrusion, the amount of leachate generated L is modified and is given by the expression:

$$L = P_{ERR} + W_{Gw}$$

Where,

W_{Gw} is the input water from ground water underflow.

2.30 Leachate Flow in Vadose Zone

Seepage can be defined as the flow of water from one point to the other due to difference in pressure head or pore pressure. Seepage is concerned with the flow of fluids through porous media.

In saturated flow, hydraulic conductivity is dependent on the soil water suction and hence water content since the two are directly related by capillarity. The flow of water in porous media is based on Darcy's law, which states that the flux of water through soil is proportional to the gradient of the soil water potential.

Calculation of flow velocity and flux.

Flow velocity and flux are two important transmission parameters determined in the vadose zone. According to Holmes (1983) three major approaches to evaluating flux are possible. These include:

- Calculating flux from mathematical formulae and empirical relationships between soil- suction, soil water content and hydraulic conductivity;
- Measurements of changes in the water content of the soil profile over time; and
- Direct measurements using flow meters.

Darcy's Law

The easiest method available for calculating saturated flow from infiltrometer data is the use of Darcy's Law. This method is conservative because it assumes the soil is saturated. In simple terms, solving for average linear velocity (V), Darcy's Law is written as

$$V = Q / nA$$

Where,

Q - is the discharge
n - is the effective porosity of the formation
A - is the cross sectional area of flow.
Q/A - is the measured steady state infiltration rate per unit area.
For use of Darcy's law, Q/A is negative because the flow is down wards.

In summary Darcy's law is a generalized relationship for flow in porous media *(Nielsen, 1993)*. It gives the volume flow rate as a function of flow area, elevation, fluid pressure and a proportionality constant known as permeability. The fluid velocity is the result of gravity, pressure forces and viscous resistance. The equation therefore allows development of the analysis of ground water flow in the context of potential flow by considering the fluid as frictionless.

General hydraulic equation

The solution of a flow problem through a porous medium requires the aspects listed below to be considered:

- Equilibrium of porous body;
- Strain compatibility;
- Interaction between pore water and soil skeleton;
- Conservation of the mass of the water;
- State relationship for pore water; and
- Dynamic equilibrium of pore water.

Multiple phase components of the vadose zone

The vadose zone can be considered as being composed of two phases namely:

- Solid phase; and
- Non solid (liquid) phase.

Solid phase

The solid phase of the vadose zone is characterized predominantly by the permanent skeletal structure through which the fluid phase may pass or be retained. Fluids through the interstices of porous media can transport small solid particles. Due to the relative magnitude of velocities in the vadose zone, the portion of the solid phase that is mobile is extremely small and can be ignored. The physical mechanisms used to describe the inert solids in the solid phase include:

- Grain size distribution;
- Porosity;
- Angularity;
- Specific surface; and
- Uniformity.

Porosity affects the amount of water that can exit the voids. The lower the porosity the lower the capacity of the water content in the vadose zone. In addition, for a given pore size distribution, lower porosity means fewer pores and lowers capability for transmission of fluids through the vadose zone.

Particle shape or angularity can also have a bearing on porosity and fluid transmission. The shape of the individual particles can range from spherical to very angular to flat plates. Depending on the packing and mixing of these particles, a wide range of porosities is likely.

Specific surface is the ratio of grain surface area to its volume. Grains with the largest specific surface are flat plates (clay) and those with the smallest specific surface area are spheres (weathered silicate grains). Due to the importance of surface chemistry in contaminant transport studies clay content of the medium is important particularly because of the high specific surface clay (Nielsen, 1993).

Non-solid (liquid) phase.

A given molecule of water may reside in the vadose zone for a time ranging from a few minutes to several years depending on the size of a particular vadose zone and transport characteristics (Nielsen, 1993).

Water in the vadose zone may enter from above in form of precipitation and recharge, which include rainfall, infiltration, spreading basin, septic system etc. Water may also flow from the saturated zone to the vadose zone through capillarity action. Lastly water may enter the vadose zone from within due to any of the numerous biological and chemical reactions that have water as an end product.

Water in the vadose zone can either exit due to evapotranspiration process or drain into the saturated zone. Vadose water may also be consumed by certain biological or chemical reactions within the vadose zone.

The fluid properties, which are important in describing vadose water, include:

- Density;
- Specific weight;
- Kinematic viscosity;
- Bulk modulus of elasticity;
- Vapour pressure;
- Surface tension;
- Dynamic viscosity; and
- Wet ability in the presence of air.

2.31 Soil Moisture and Hydrodynamic Dispersion

These two parameters must be specified in order to solve the equations governing the flow. The soil moisture is either given as a function of the volumetric water content of the soil or the soil water pressure and is necessary for the solution of the water flow equation.

Two processes; mechanical dispersion and molecular diffusion account for hydraulic dispersion in porous media. The mechanical dispersion depends on both the flow of the fluid and the nature of the pore system through which the flow takes place. The molecular and ionic diffusion depends on time and is more significant at low velocity (Bear, 1972).

Monitoring vadose zone transmission properties

Vadose zone properties are generally of greater interest in ground water monitoring studies than are storage properties. No direct in situ methods exist for measuring the unsaturated hydraulic conductivity of a geological material because the hydraulic conductivity is a function of moisture content. However, the flux can be measured and used in calculation of the transmission rates.

The rate of moisture movement is determined indirectly from infiltration rates or measurements of unsaturated flow. Field data can also be used in estimation of transmission properties of the vadose zone however, when doing so it is important to remember that large variations in these parameters can occur because of soil heterogeneities (Nielsen, 1993).

Field measurements of infiltration rates

Field measurements of infiltration rates are appropriate for estimating downward fluid transmission during the wetting cycle. The infiltration rates are affected by:

- Soil texture and structure including soil layers;
- Initial moisture content;
- Entrapped air; and
- Water salinity.

Infiltration is determined using infiltrometers. Since infiltration is the rate at which water enters a permeable material, infiltrometers do not directly measure hydraulic conductivity.

In order to calculate saturated hydraulic conductivity from infiltration data, the hydraulic gradient and extent of lateral flow must be known. Saturated hydraulic conductivity is of interest in vadose zone because it is the upper boundary for unsaturated hydraulic conductivity. Use of this value provides a conservative estimate of fluid transmission time (Nielsen, 1993).

Measurement of trace movement

Traces are matter or energy that is carried by ground water, which can provide information on the rate and direction of ground water movement. Traces can be:

- Natural, such as heat carried by hot springs;
- Intentionally added such as dyes; and
- Accidentally introduced such as oil from underground storage tanks.

The main difference between uses of traces under unsaturated conditions as opposed to saturated conditions is the practical problem of sampling a tracer at increasing depths under unsaturated conditions; and this may define the regime of leachate flow from dump sites.

2.32 Contaminant Transport Process

Solute contaminant processes are first developed in the saturated zone and then extended to apply under unsaturated conditions. According to Fatta et al (1999), the simplest approach describing contaminant transport in sub surface horizon assumes the total one-dimensional flux is due to advection, diffusion and hydrodynamic dispersion.

By combining the flux equation with conservation of mass, the fundamental mass transport equation in the unsaturated zone can be derived.

Characteristics and environmental significance of colloids

Colloids can be classified as non-settleable particles having nominal diameter between 1 and 1000nm (Fatta et al., 1999). Their extremely high surface area to mass ratio provides a high specific concentration of contaminant binding sites, which could result in significant contaminant scavenging in competition with immobile solids.

In addition to this repulsive forces, most commonly electrostatic between colloidal particles are often greater than both gravitational and attractive forces acting on the particles preventing both their sedimentation from solution or coagulation to form settleable floc. Their stability in suspension allows them to be readily transported as a result of their inability to be immobilized by conventional means that require transport of the particle to a collective surface, such as physical or chemical sorption. Studies have shown that stable dispersion is less susceptible to physical and chemical retardation mechanisms such as an accumulation at immobile surfaces and precipitation.

Colloids have been known to be transported faster than non-reactive contaminants as a result of size exclusion from pores smaller than those of the colloid. Extensive research has shown that like any reactive constituent colloids are also susceptible to retardation by sorption, precipitation complexation and other mechanisms.

Sub Surface interaction chemistry relevant to metals attenuation

Chemical reactions of solutes such as metals play key role in determining the solutes' speciation bioavailability (Fatta et al, 1999) at sub surface horizons. Several processes affect the solute movement in soils. These processes include:

- Adsorption;
- Complex formation; and
- Precipitation or distribution.

Sorption refers to the removal of solute (sorbate) from the solution phase by the solid phase (sorbent). The two categories of sorption; absorption and adsorption are distinguished by the extent to which the sorbate interacts with the sorbent. In adsorption, the solute is restricted to the sorbent surface or interface between the sorbate and sorbent.

Research has shown that distribution of the solute between phases is due to the relative affinity it has for solvent and sorbent phases. This affinity is directly related to physical, chemical and electrostatic forces that exist between the phases. Ion exchange is also an important process responsible for sorption. The negative change on the soil colloids, clay and organic matter and soil surfaces make ion exchange one of the most important reactions influencing transport of cations and anions in soils.

2.33 Theory of Solute Transport

The theory of solute transport in porous and fractured hydrological systems underground is discussed by Bear et al. (1993). The term "solute" indicates a chemical substance dissolved in fluid. The following are the principal modes of transport:

- advection and convection, i.e. through movement of the fluid involved;
- mechanical dispersion, this is reflected in variations in actual fluid particle velocities; and

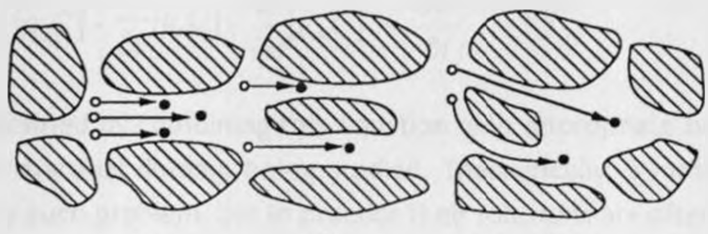
- molecular diffusion, this causes the solute to diffuse from regions of high concentration to regions with lower concentration.

If the transport were only through constant velocity fluid movement, tracer test analysis/interpretation would be simple. But because of the other modes of transport, in particular mechanical dispersion, their analysis/interpretation is much more involved. Fig. 2.11 illustrates the main causes of mechanical dispersion, which are through:

(a) The effect of pore/fracture walls;

(b) The effect of pore/fracture width; and

(c) The effect of flow-path tortuosity.



(a) the effect of pore/fracture walls. (b) the effect of pore/fracture width. (c) the effect of flow path tortuosity.

Fig.2.11: Illustration of the Main Causes of Mechanical Dispersion

The basic equations describing the solute flow are the following:

$$F_x = F_{x,advection} + F_{x,dispersion} \quad (1)$$

where F_x denotes the mass flow rate of the solute (kg/m^2s) in the x-direction, and

$$F_{x,advection} = u_x \phi C \quad (2)$$

$$F_{x,dispersion} = -\phi D_x \partial C/\partial x \quad (3)$$

Equation (3) is Fick's law. In addition u_x denotes the fluid particle velocity (m/s), ϕ the material porosity (-), C the solute concentration (kg/m^3) and D_x the dispersion coefficient (m^2/s):

$$D_x = \alpha_x u_x + D^* \quad (4)$$

where α_x is the dispersivity of the material (m) and D* is the coefficient of molecular diffusion (m^2/s). Comparable equations apply for the y- and z-directions.

The differential equation for solute transport is derived by combining the above flow-equations and the conservation of mass of the solute involved. For a homogeneous, isotropic and saturated medium (Shamrukh et al., 2001). the differential equation is:

$$\frac{\partial}{\partial x}\left[D_x \frac{\partial C}{\partial x}\right] + \frac{\partial}{\partial y}\left[D_y \frac{\partial C}{\partial y}\right] + \frac{\partial}{\partial z}\left[D_z \frac{\partial C}{\partial z}\right]$$

$$- \frac{\partial}{\partial x}[u_x C] - \frac{\partial}{\partial y}[u_x C] - \frac{\partial}{\partial z}[u_{zx} C] = \frac{\partial C}{\partial t} \qquad (5)$$

A model may be defined by combining this equation with appropriate boundary and initial conditions for the material domain being studied. Theoretically, a mathematical solution should exist for any such problem, but in practice their solutions are often very complicated (Shamrukh et al., 2001). Such complicated problems may, of course, be solved numerically with the aid of powerful computers. Some simpler analytical solutions are possible after highly simplifying assumptions have been made on geometry, dispersion, etc. One such model, and the associated solution, forms the basis of the method of tracer test analysis/interpretation presented below.

Another example of an analytical solution to equation (5) is available for a model of a homogeneous, infinite, confined hydrological reservoir with constant reservoir thickness b and two-dimensional radial flow. This solution is normally not suitable for analysing tracer test data, but can be used in reinjection studies. Fluid with solute concentration, C_0 is injected at a rate Q (m^3/s) at time t = 0 through an injection well at the centre of the reservoir, while the initial concentration is C = 0. By neglecting molecular diffusion, the following approximate solution may be obtained:

$$\frac{C}{C_0} \approx \frac{1}{2}\,\mathrm{erfc}\left[\left(\frac{r_D^{1/2}}{2} - t_D\right)\left(\frac{4}{3}r_D^3\right)^{-1/2}\right] \qquad (6)$$

with $r_D = r/\alpha_L$, where r is the radial distance from the injection well, α_L is the longitudinal (radial) dispersivity, $t_D = \frac{Qt}{2\pi b\phi\alpha_L^2}$ and erfc is the complimentary error function.

2.34 Tracer Test in a one-dimensional flow-channel model

Tracer tests involve injecting a chemical tracer into a hydrological system and monitoring its' recovery, through time, at various observation points. Results were used to study flow-paths and quantify fluid-flow in hydrological system. They may also be used in surface and groundwater hydrology, pollution and nuclear-waste storage studies, as well as in petroleum reservoir engineering. The theoretical basis of tracer interpretation models is the theory of solute transport in porous/permeable media, which incorporates transport by advection, mechanical dispersion and molecular diffusion. This will be reviewed very briefly below. A method of tracer test analysis/interpretation, which is conveniently based on the assumption of specific flow channels connecting injection and production wells, will consequently be presented. The *ICEBOX* software package includes several programs that may be used for tracer test analysis, namely; *TRINV*, which is an interactive program for inversion of tracer test data, and *TRCOOL*, which is a program used to predict cooling of production wells during long-term reinjection. A few other programs can be of use in tracer work (*DATE2SEC, TRMASS* and *TRCURV*).

These programs are used in geothermal studies to predict possible cooling of production wells due to long-term reinjection of colder fluid. Thermal breakthrough time are about 2 - 3 orders of magnitude greater than chemical (tracer) breakthrough time. Many models developed, often adopted from groundwater/nuclear-waste storage studies, applying tracer tests yield volume of flow paths. Cooling is determined by surface area involved. The studies are used extensively in geothermal applications, yet comprehensive interpretation of geothermal tracer test data, and consequent modelling for management purposes (production well cooling predictions), has been rather limited. The interpretation has mostly been qualitative rather than quantitative.

Before radioactive tracer test data is interpreted some steps must be taken to correct and prepare the return data collected. These are:

Correct the data for radioactive decay by the following equation:

(1) $C_{corr} = C_{meas} \exp(0.693t/t_{1/2})$

where C is the activity of the tracer (cps), t is the time since the tracer was at full initial activity, $t_{1/2}$ is the half life of the radioactive isotope being used as tracer and exp is the exponential function. The half-lives of iodide-131 and iodide-125 are 8.5 and 60 days, respectively.

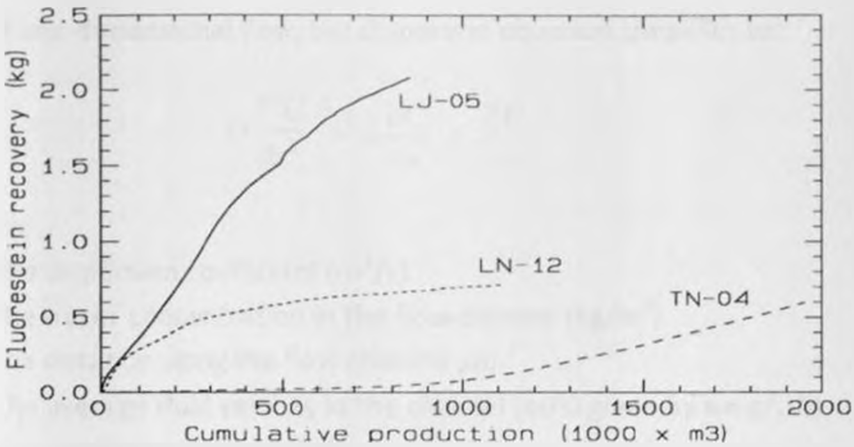
2) Also correct by multiplying by 1/(sample volume·measurement efficiency), which results in concentration-, or activity values, in units cps/L or cps/m^3.

3) It should be noted that following these steps radioactive tracer data are fully comparable to mass, one may simply interchange "kg" and "cps". The return data are then compared with the initial activity (0.5 - 2 Ci, 1 Ci = $37 \cdot 10^9$cps), just as conventional tracer test data are compared with the mass of tracer injected (kg).

When analysing tracer test data one must keep in mind that some of the tracers recovered through the production wells is injected back into the reservoir. If this is a significant amount it will interfere with the data interpretation and must be corrected. This is seldom the case, however. Bjornsson et al. (1994) presented a method for doing such a correction. The program TRCORRC in the ICEBOX-package may be used for this purpose. In addition, the program TRCORRQ may be used to correct for small variations in production and/or injection rates. The first step in analysing tracer test data involves estimating the mass (activity) of tracer recovered throughout a test. This is done on the basis of the following equation:

$$m_i(t) = \int_0^t C_i(s)Q_i(s)\,ds$$

where $m_i(t)$ indicates the cumulative mass recovered in production well number i (kg), as a function of time, C_i indicates the tracer concentration (kg/L or kg/kg) and Q_i is the production rate of the well in question (L/s or kg/s, respectively). The program TRMASS in the ICEBOX-package may be used for this purpose. An example of such mass recovery calculations is presented in Fig. 2.12. The figure shows the cumulative tracer recovery in three production wells as a function of cumulative production from each well during a two-year period from late 1997 through most of 1999. A simple one-dimensional flow-channel tracer transport model has turned out to be quite powerful in simulating return data from tracer tests in geothermal systems (Bjornsson et al., 1994).



The Laugaland Geothermal Field in N-Iceland during a tracer test, where 10 kg of sodium-fluorescein were injected

Figure 2.12. An Example of the results of tracer mass recovery calculations.

It assumes the flow between injection and production wells may be approximated by one-dimensional flow-channels, as shown in Fig. 2.13.

These flow-channels may, in fact, be parts of near-vertical fracture-zones or parts of horizontal interbeds or layers. These channels may be envisioned as being delineated by the boundaries of these structures, on one hand, and flow-field stream-lines, on the other hand. In other cases these channels may be larger volumes involved in the flow between wells. In some cases more than one channel may be assumed to connect an injection and a production well, for example connecting different feed-zones in the wells involved.

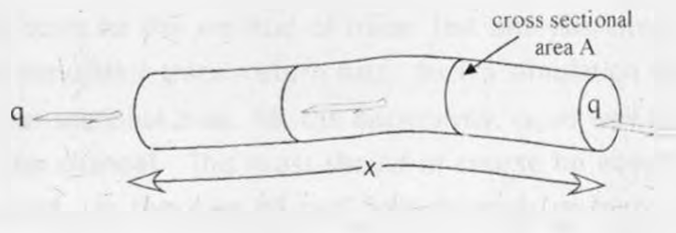


Figure 2.13 A schematic figure of a flow-channel with one-dimensional flow connecting an injection well and a production well.

In the case of one-dimensional flow, the dispersion equation simplifies to:

$$D\frac{\partial^2 C}{\partial x^2} = u\frac{\partial C}{\partial x} + \frac{\partial C}{\partial t}$$

Where;

D, is the dispersion coefficient (m^2/s).

C, is the tracer concentration in the flow-channel (kg/m^3).

X, is the distance along the flow channel (m).

U, is the average fluid velocity in the channel (m/s) given by $u = q/\rho A\phi$ with q the injection rate (kg/s).

ρ, is the water density (kg/m^3).

A, is the average cross-sectional area of the flow-cannel (m^2).

ϕ, is the flow-channel porosity.

Molecular diffusion may be neglected such that $D = \alpha_L u$ with α_L the longitudinal dispersivity of the channel (m). Assuming instantaneous injection of a mass, M (kg) of tracer at time t = 0 the solution is given by:

$$c(t) = \frac{uM}{Q}\frac{1}{2\sqrt{\pi Dt}}e^{-(x-ut)^2/4Dt}$$

where

c(t), is actually the tracer concentration in the production well fluid.

Q, is the production rate (kg/s).

X, is the distance between the wells involved.

Conservation of the tracer according to $c \cdot Q = C \cdot q$, has been assumed.

This equation is the basis for the method of tracer test analysis/interpretation presented here, which involves simulating tracer return data. Such a simulation yields information on the flow channel cross-sectional area, Aϕ, the dispersivity, α_L as well as the mass of tracer recovered through the channel. This mass should of course be equal to or less than the mass of tracer injected. In the case of two flow-channels or more, the analysis yields estimates of these parameters for each channel. It should be pointed out that through the estimate for Aϕ, the flow channel pore space volume, Axϕ, has in fact been estimated.

The tracer interpretation software TRINV, included in the ICEBOX software package is used for this simulation or interpretation. It is an interactive DOS-mode program, which automatically simulates the data through inversion. The user defines a model with one or more flow-channels and defines a first guess for the model parameters. TRINV, consequently, uses non-linear least-squares fitting to simulate the data and obtain the model properties, i.e. the flow channel volumes ($Ax\phi$) and dispersivity (α_L). The software may also be used to plot the results.

This method of analysis should not be looked upon to yield unique solutions, even though it often results in solutions that are considered to be the most likely ones. Numerous other models have been developed to simulate the transport of contaminants in ground-water systems, and in relation to underground disposal, or storage of nuclear waste. Many of these models are in fact applicable in the interpretation of tracer tests in geothermal systems. It is often possible to simulate a given data-set by more than one model; therefore, a specific model may not be uniquely validated. The transport of dissolved solids through fractured rocks and the analysis of tracer tests conducted in fractured geothermal systems are, discussed by Grisak and Pickens (1980).

In addition to the distance between wells and volume of flow-paths, mechanical dispersion is the only factor assumed to control the tracer return curves in the interpretation presented above. Retardation of the tracers by diffusion into the rock matrix is neglected (Bjornsson et al., 1994). Through this effect, the chemical used as a tracer diffuses into the rock matrix when the tracer concentration in the flow path is high. As the concentration in the flow-path decreases, the concentration gradient eventually reverses, causing diffusion from the rock-matrix back into the fracture. This will of course affect the shapes of the tracer return curves obtained. In particular, it may cause the flow, through the mode A flow channels discussed above, to be underestimated. Robinson and Tester (1984), postulated that matrix diffusion should be negligible in fractured rock. Grisak and Pickens (1980), pointed out that it may be significant when fracture apertures are small, flow velocities are low and rock porosity is high.

2.35 Geographic information system in groundwater modelling

Geographic information systems have emerged as effective tools in decision-making in many areas, such as engineering and environmental fields. Example applications in the water resources area include studies in watershed analysis and modelling that have been attracted by the ability of the GIS to handle large-scale areas and a vast amount of data (El-

Kadi et al., 1994). GIS has also been applied in assessing contamination by agricultural pollution. Rifai et al. (1993) developed a GIS user interface for delineating wellhead protection areas.

The El-Kadi study (1994) introduced a combined or integrated GIS/modelling system that is suitable for site-specific analysis for ground-water modelling. The paper describes the proposed system and its implementation for a specific ground-water model. Next, an example application to a specific modelling study is presented. Finally, mesh generation is generalized to include cases of irregular and nonuniform meshes.

Such modelling requires, in general, a numerical solution of the governing partial differential equation(s). The formulation necessitates the creation of a spatial mesh with parameter values that are assigned to each element (or node) of the mesh. The aquifer parameters are usually known at a limited number of sampling or measuring points. The values assigned to elements (or nodes) are estimated by interpolation from point measurements. Solutions also require availability of initial and boundary conditions. Initial conditions can be either field-measured or mathematically obtained by solving an appropriate governing equation. The hydraulic boundaries can coincide with the physical boundaries but in many cases do not, due to the limited portion of the aquifer that can be covered by the numerical model. In this case, an iterative procedure is usually needed to identify the appropriate conditions. Decisions regarding suitability and accuracy of spatial model data are an essential part of modelling. Hence, the process can be laborious in requiring intensive modeller interaction with the system.

Attempts to reduce the effort required in modelling include the use of a pre-processor to generate the mesh and to prepare the data for the model, and a graphical post-processor to analyse the output from the model. El-Kadi (1994) facilitated modelling further by using the graphical and data handling capabilities of the GIS. The use of a GIS as the shell for modelling is appealing because of its ability to:

- make the information in the database available on the same screen during data preparation;
- provide graphical error checking on a continuous basis;
- save and analyse the spatial data and results as any GIS layer;

- overlay site map, spatial data, and results in a flexible manner; and
- prepare an additional GIS information layer, known as the cosmetic layer, for reporting purposes with a custom-made text.

Availability of a BASIC-like programming language in the GIS package facilitates automating most steps in data preparation and results presentation.

The geographic information/modelling system are generic in nature because no modifications are necessary in the numerical model. The pre and post processing routines are developed in a modular way to allow use with other models. The integrated system facilitates modelling efforts by automating many of the modelling steps within an interactive scheme that provides the means for error checking and results evaluation. It is also suitable for use on a regular basis and is only limited by the nature of the specific model used.

The integrated system is suitable for extracting and interpolating point measurements from maps. The data can be imported to the system as block or cell averages that are suitable for numerical modelling. A drawback, however, is the relative difficulty in extracting spatially distributed data, owing to the vectorized nature of the GIS. An approach was introduced here that allows defining cell properties based on the geographic location of its centroid. This approach is acceptable because spatial maps of parameters are not generally reliable. For example, using various degrees of spatial-correlation data in interpolating point measurements can lead to different data distribution. In addition, some of the parameters, such as dispersivity, are merely fitting parameters and are scale, and possibly, time-dependent. Hence, their values cannot be tabulated or mapped for general modelling use.

Also, much of the information needed, such as boundary conditions, is site-dependent, and in many cases, their location does not coincide with the physical boundaries. Therefore, a complete automation of data preparation, although possible if extensive data exist, might not be feasible in all cases. The programming language MapBasic, although suitable for many of the procedures needed, is not appropriate for intensive calculations. It is recommended that calculations be made in independent routines and results be imported to GIS. Examples of extensive calculations include data interpolation (including kriging), contouring, and irregular mesh design. Creating two ASCII files for coordinates and descriptive data can easily do data importation. Flexibility in mesh design as described here may increase versatility and usefulness of the approach.

2.36 Simulating Hydrologic and Water Quality Impacts in an Urbanizing Watershed

Sangjun et-al., (2003) investigated the water quality of the Polecat Creek watershed in Caroline County, Virginia, USA. A Hydrologic Simulation Program-Fortran (HSPF) was calibrated and used to assess the future effects of various land development scenarios on water quality in the Polecat Creek. Model parameters related to hydrology and water quality were calibrated and validated using observed stream flow and water quality data collected at the watershed outlet and the outlets of two sub watersheds. Using the county's Comprehensive Plan, land use scenarios were developed by taking into account the trends and spatial distributions of future development. The simulation results for the various land use scenarios showed that runoff volume and peak rate increased as urban areas increased. Urbanization also increased sediment loads mainly due to increases in channel erosion. Constituent loads of total Kjeldal nitrogen, orthophosphorus, and total phosphorous for Polecat Creek watershed slightly decreased under future development scenarios. These reductions were due to increases in urban areas that typically contribute smaller quantities of nitrogen and phosphorous, as compared to agricultural areas. However, nitrate loads increased for the future land use scenarios, as compared to the existing land use. The increases in nitrate loads may result from increases in residential land and associated fertilizer use and concurrent decreases in forested land.

The procedures used could assist local, state, and regional policy makers in developing land management strategies that minimize environmental impacts while allowing for future development (Sangjun et-al., 2003). The hydrologic and water quality components of HSPF were calibrated and validated using 61 months of observed data collected at the watershed outlet and two sub watershed outlets. Long term water balance, seasonal rainfall variability, and storm hydrographs were analysed to calibrate and validate the hydrologic parameters. The errors in total runoff for the calibration period were;

- 0.5 percent at the outlet of Lake Caroline (QPB);
- percent at one of the upland sub watersheds (QPC); and
- 0.4 percent at the watershed outlet (QPE).

There was a good correlation for the 10 percent highest and 50 percent lowest flow between the measured and simulated values as well for all three monitoring stations. Errors in total runoff ranged from 0.4 percent to 6.7 percent during the validation period. The simulated and measured sediment loads were compared for both storm flow and non-storm flow conditions. The simulated total sediment load at the outlet of the Polecat Creek Watershed for the calibration period was 179.8 kg/ha/yr, while the measured load was 197.1 kg/ha/yr. For the validation period, the simulated and observed total sediment loads were 38.6 kg/ha/yr and 36.0 kg/ha/yr, respectively. Correlation coefficients of total sediment load for various sub watersheds ranged from 0.32 to 0.70 for calibration and from 0.46 to 0.81 for validation. Nutrient loads were also simulated by considering land use inputs such as chemical fertilizer and manure applications. The error in NO_3 load for QPE was 5.1 percent for the calibration period, while a value of 42.1 percent was obtained for the validation period.

The simulated and observed TKN for QPE were 1.09 kg/ha/yr and 2.79 kg/ha/yr for the calibration period and 0.8 kg/ha/yr and 1.35 kg/ha/yr for the validation period. TKN loads for QPB and QPC were overestimated for the validation period but considered acceptable. The correlation coefficients between simulated and observed monthly loads for PO_4 were 0.70 for QPB and 0.64 for QPC for the calibration period. In the calibration period, HSPF underestimated TP loads for three sub watersheds, QPB, QPC, and QPE. The model simulated TP loads well for the validation period but overestimated PO_4 loads (Sangjun et-al., 2003).

Six land use scenarios were developed based on the Comprehensive Plan of Caroline County. The future land use scenarios represent different patterns of urban development for the Ladysmith and Carmel Church areas. Hydrology and water quality of six scenarios were simulated and compared to those of baseline conditions to assess the possible impacts of future urbanization. Simulation results of the future land use changes suggest that streamflow volume and peak rate would dramatically increase. The commercial development of the Carmel Church area could result in increases in impervious areas of up to 20.2 percent for sub watershed QPC, which may lead to increases of 31.3 percent in streamflow volume, and 50.7 percent in peak rate compared with the baseline conditions. Increases in runoff volume and peak flow may result in increased channel erosion within the QPC sub watershed and immediately downstream.

Simulated future development of residential area within Ladysmith results in an increase in nitrogen loads due to fertilizer use in residential areas. The future development of both the Ladysmith and Carmel Church areas may result in increased stream flow volumes and sediment loads of approximately 8.7 percent and 9.9 percent, respectively, at the outlet of the Polecat Creek Watershed. Urbanization was found to have a very slight impact on phosphorus loadings from the Watershed. Simulated phosphorus loads for future development slightly decreased, as compared with the baseline simulation, due to a reduction in agricultural area. The results could be used to recognize potential impacts due to urbanization, assess alternative strategies, and select the strategies that reduce the adverse impacts on water quality while allowing for future development.

2.37 Modelling the effect of chemical fertilizers on ground water quality

Chemical fertilizer use in Egypt has increased significantly since the construction of the Aswan High Dam in 1968. Increased applications of chemical fertilizers in irrigated lands are likely to create non-point contamination sources of chemical fertilizer species. Shamrukh et-al (2001), investigated the pollution of ground water in the Nile Valley aquifer by chemical fertilizers. This study was conducted to investigate the contamination of ground water by nitrogen and phosphorus chemical fertilizers, as well as the availability of ground water for irrigation and public water supply for the next century. Future concentrations of NO_3, and PO_4 in shallow and deep ground water in the Nile Valley were assessed under realizable rates of fertilizer application. A ground water modelling system (GMS) was used to simulate the three-dimensional ground water flow and contaminant transport in the Tahta region of the Nile Valley Aquifer, and to predict the future concentrations of chemical fertilizer species.

Results of the transport simulation predict the occurrence of ground water contamination at shallow depths (750mm) due to the high rate and method of chemical fertilizer applications. Best management practices should be employed to control and reduce nitrate leaching and future impact of phosphorus and potassium fertilizer applications. At the same time, new deeper wells should be constructed. In addition, the use of hand pumps in zones close to croplands (375mm in depth) must be avoided due to susceptibility to fertilizer contamination. Ground water from existing deep wells can be used as an alternative water supply. Furthermore, a ground water quality monitoring system should be established for early detection of ground water contamination and to determine progress of the fertilizer contaminant plume. A properly designed system should monitor nitrate and phosphate composition in observation and water supply wells.

The study report concluded that excessive nitrogen fertilization rates in the Nile Valley flood plain will likely be the main cause of future ground water contamination. Best management practices should be employed to control and reduce nitrate leaching and future impact of P and K fertilizers. The study showed that current applications of P fertilizers are not the source of recent elevated detection of PO_4 concentrations in the Nile Valley Aquifer. Other sources of those elevated species may be redox reactions or dissolution of their minerals. The use of hand pumps to supply ground water from shallow depths of 15 m, in the Nile Aquifer must be avoided in the next two decades because of their vulnerability to pollution. Existing extraction wells can be used as an alternative to supply water. In addition, new water supply wells should be drilled deeper in the next decades to avoid ground water contamination by NO_3 in the upper layers.

The vulnerability of ground water contamination in reclaimed desert areas to is high due to the absence of the clay-silt cap. Fertilizer application in those reclaimed areas must be kept low since the deeper wells will not prevent ground water contamination in case of occurrence. Finally, there is a strong need to establish a ground water quality monitoring system in the Nile Valley to monitor the quality of ground water in the desert fringes and flood plain areas. Such a monitoring program should include periodical sampling of observation and water supply wells for nitrate, phosphate, potassium, and total dissolved solids.

3. RESEARCH METHODOLOGY

3.1 Introduction

The purpose of this chapter is to describe the methodology employed for this thesis. The chapter contains a discussion on the issues centred upon the research design. First, a discussion of study sites is given followed by a discussion of the issues focused upon in the conduct of the research and ethical issues of the research. This is followed by a discussion of the justification for the selection of a qualitative case study research approach. The next section details the methods on data collection and the chapter concludes with a discussion of the data analysis techniques used.

3.2 Description of the study sites

To estimate the extent, effectiveness and shortfalls in solid waste management, the five major towns, namely Nairobi, Mombasa, Kisumu, Nakuru and Eldoret, in Kenya were selected for this study. To establish the composition of the solid waste, an audit of waste reaching the towns' dump sites, was carried out over a 9-day period. The main components identified were the food, paper, metal, glass, plastics and the rest lumped as others.

An audit of the public health departments, charged with the solid waste management, was carried out to help identify personnel, equipment and resources use. Most of the uncollected wastes witnessed in the study towns were in residential areas and small commercial areas. This research, in an effort to sample the typical solid waste indentified an existing waste dumpsite located in a commercial/residential area next to the university.

3.3 Objective of the study

The objective of the study was to investigate the impact of poor solid waste management in Kenyan urban areas on ground water resources. The specific objectives were,

(i) To review the state of solid waste management in urban centres in Kenya.
(ii) To identify shortcomings of current solid waste management practices.
(iii) To investigate the composition of leachate from a typical solid waste dumpsite.
(iv) To investigate groundwater pollution variation with time.
(v) To understand statistical modelling of leachate migration.

3.4 Research approach

The research employed a multi-faceted approach in order to cater for all the requirements of the assignment. It comprised a number of stages which were complementary in sourcing data and information required. These included:

- Initial Consultations - The researcher held initial consultations with the supervisors for the purposes of building consensus on the objectives of the research and harmonizing the researcher's understanding and approach to the project and the research expectations.

- Literature Review – In order to understand the state of solid waste management in urban centres in Kenya, comparison with practice elsewhere was necessary. This was based on literature sourced in the library and internet. These included reviewing background documents (journals and texts) on solid waste management. This then formed the basis for highlighting the shortcomings of the current practice.

3.5 Field Interviews and Visits

In order to satisfy the requirements of this research, data/information on solid waste management was collected from the Nairobi, Mombasa, Kisumu, Nakuru and Eldoret council staff and reports. Key informant interviews in the respective councils formed a very important component of the process. They included:

- Environment officer, Department of Environment at the Nairobi City Council;
- Superintendents in charge of the cleansing sections in the Municipal councils;
- Bins Services Ltd. Managing Director;
- Domestic Refuse and Disposal Services (DRDS);
- Bulk Refuse Handlers Ltd; and
- Key stakeholders were interviewed to provide crucial information and guidance to the research in their towns.

3.6 Field Sampling

The field sampling was done in two forms:

Sampling of the solid waste from the dump site was used to set up the leachate model in the laboratory. This is the sample which was analysed for basic properties and filled in the model shown in Figure 3.6. The determinations of the leachate movement into the soil strata was investigated by the sample taken from pits within the waste dump site as shown in Figures 3.1 to 3.4.

Figure 3.1. Mamlaka dumping site on the day of sampling

Figure 3.2. Sampling soil from a hole at the site at Mamlaka, Nairobi

Figure 3.3: One of the sampling holes at the site at Mamlaka, Nairobi

Figure 3.4. Some samples of soil at the dumping site at Mamlaka, Nairobi

3.7 The solid waste sampling point

The sampling site is located along Dorobo road, near Nairobi Primary School, before the lecturers' quarters. A check with the NCC confirmed that they were not aware the dumping site existed. The site provided a composite waste since it is near a primary school, residential houses, business premises and a main road passing nearby. It also represents a typical risk spectrum at risk to the pollution due to uncollected solid waste. The area utilised as a dumping site is approximately 64 square metres. The dumping site was initially about 1.5m deep at excavation but currently stands at an average height of 1.6m above the ground level.

The waste dumped at the site is purely domestic as it is collected from the Halls of Residence on a daily basis. In the Halls of Residence, the wastes generated from the environs are temporarily kept in plastic buckets for 1-2 days before they are transferred to the site. Once at the site, the waste is subjected to incineration. The study reveals that the waste is lit after every 1-2 days on the surface and left to burn. The effectiveness of the burning process is determined by the prevailing weather conditions at that time and the moisture content of the waste.

3.8 Type of wastes

A study of the site revealed no evidence of any form of separation/selection or processing on the wastes. Figure 3.5 shows a typical sample of waste brought into the laboratory. They range from paper, cardboard, plastics, wood, tin, cans, and human wastes. Most of the wastes are wrapped in polythene bags and dumped at the site. It takes even longer foe the waste to decompose in such wrappings.

Fig 3.5: A dry sample for sieve analysis

3.9 Laboratory tests

3.9.1 Basic tests

These basic tests are important in trying to arrive at the properties of solid wastes. Information on properties of solid wastes are important in evaluating alternative equipment needs, systems, and management programs and plans especially with respect to implementation of disposal and resource and energy recovery options (Shah, 2000). The tests included the determination of physical and chemical composition of solid waste. The physical composition tests were conducted in accordance with the BS 1377 procedures.

They included:

- moisture content;
- density of wastes; and
- analysis of particle size.

3.10 Pollutant concentration tests

3.10.1 Model concept

When infiltration exceeds the total evapo-infiltration plus the moisture retention capacity of the refuse in the gravitational field, the water percolates through the refuse removing dissolved and or suspended products of biological and chemical decomposition, as illustrated in Figure 3.6.

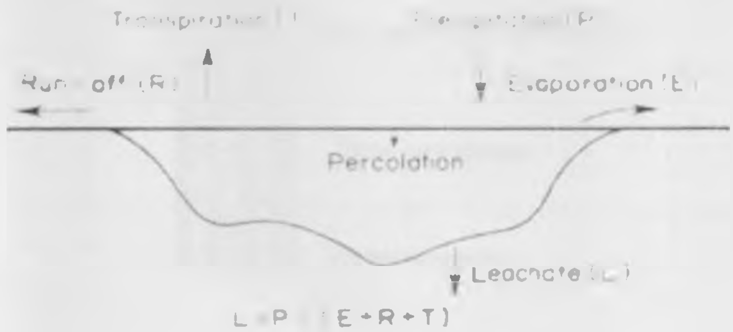


Figure 3.6. Concept for formation of leachate in a dump site

Subsequently, the effluent from open dumpsite is enriched in many hazardous constituents. The composition of solid waste controls the composition of the leachate produced from a Municipal solid waste disposal site.

Ground water pollution by a landfill depends on the kind of leaching process and the character of transport. The leaching process is controlled by rainfall infiltration that dissolves substances from the waste matrix.

3.10.2 Leachate sampling set-up

In order to generate the leachate for analysis a setup was designed as illustrated in Figure 3.7 and shown in Figure 3.8. The solid waste sample from the site was then placed in a column setup. The diameter of the sampling column was 112mm while its height was 1330mm. The packing in the column consisted of three layers:

- The solid waste sample from a local dumpsite (uppermost layer);
- Coarse aggregate filter material which was the middle layer (170mm); and
- Fine aggregate (sand) filter material which was the bottom layer (400mm).

The two points used for sampling were located within the sand layer and they were 150mm apart. The sampling points consisted of rubber pipes that could be opened and closed tightly using a screw mechanism.

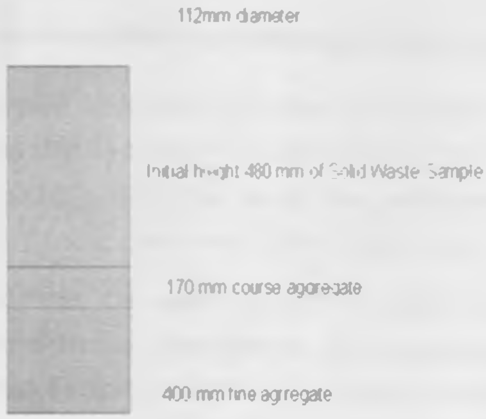


Figure 3.7. Layout of the extraction set-up

The set up had 3 sampling points namely A, B and C in ascending order. The leachate was drained through a filter media of aggregates and sand. The height of the cylinder was 1600mm and the diameter was 110mm.

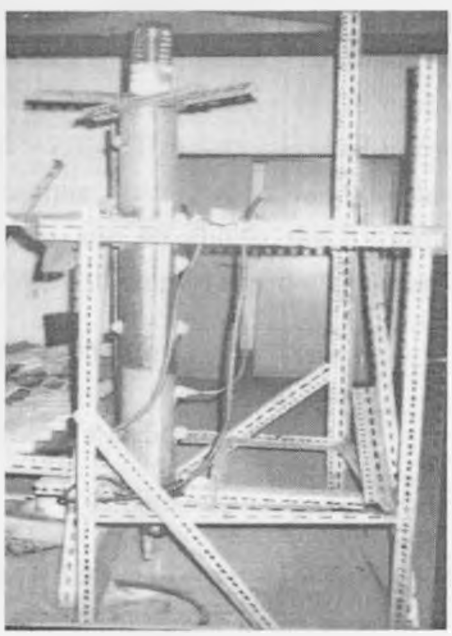


Figure 3.8: Sampling column set up with the dripping container at the mouth of the column.

3.10.3 Leachate Generation

Two different approaches were used for the leahate generation, namely:

- All the samples derived from the soil: The soil sample was transferred into the conical column. Then distilled water as calculated in 3.11 was applied uniformly on the surface of the sample with the aid of the perforated provision. The leachate generated was filtered using glass micro fibre filters; and
- The sample derived from the solid waste: The solid waste was arranged in the column. In the order of the particle sizes i.e. by placing sweepings, unclassified, food waste and paper from bottom to top of the column respectively. This reflected the arrangement that was observed in the field. Filtrates were then collected in different labelled bottles and kept in the refrigerator until the leachate generation process was completed.

3.11 Water Application Rate

The quantity and quality of leachate generated is highly dependent upon the amount and duration of rainfall. To simulate the true effect of rainfall on the uncollected waste dump sites, a water application rate for the laboratory setup had to be determined. In order to determine the water application rate onto the sample, rainfall data for Nairobi was obtained from the data centre at the Meteorological Department, Dagoretti, Nairobi. The rainfall data for the two rainy seasons (October to December and March to May) were obtained for four years (2001 – 2004). The data was used to compute the rate of addition of water into the solid waste sample which had to be equivalent to rainfall falling over any given rainfall season. This was also to enable the formation of adequate quantity of leachate for all the tests that were to be performed within a reasonable period of time.

Determination of water application rate

Diameter of the top of the column = 18.5cm

Height of the column = 35.0cm

Diameter of the column, 25cm from the bottom was calculated from;

$$\frac{25 \times 18.5}{35} = 13.2 \text{ cm}$$

25cm was the highest depth of the samples when they were placed in the column.

$$\text{Cross Sectional Area} = \frac{\Pi d^2}{4}$$

$$= \frac{\Pi \times 13.2^2 \times 10^{4}}{4}$$

$$= 1.368 \times 10^{2}\ m^2$$

Total amount of rainfall, from the rainfall data = 420.5 mm

$$\text{Average daily rainfall} = \frac{420.5}{26}$$

$$= 16.17\text{mm per day}$$

Volume of rain falling in the field area equivalent to the column cross sectional area per day was calculated as equal to the average daily rainfall depth (R_d) times thecross sectional area of the column (A_c)

$$R_d \times A_c = 1.368 \times 10^{2} \times 16.17 \times 10^{3}\ m^3$$

$$R_d \times A_c = 2.212 \times 10^{4}\ m^3$$

$$R_d \times A_c = 221.2\ ml$$

Assuming that the rain fell for an average duration of 3 hours per day, then the average hourly rainfall (R_h) is equal to:

$$R_h = \frac{221.2}{3}$$

$$R_h = 73.7\ ml \text{ per hour}$$

3.12 Data analysis

Much of the data/information derived from the research was quantitative in nature. However, a certain amount of qualitative data was also generated. Data analysis and plotting was done using MS-Excel to relate the variation of the measured parameters with time. The parameters were also subjected to a trend analysis, through statistical curve fitting. Additional information and data was also presented in Appendices of the reports.

4. RESULTS AND DISCUSSION

4.1 Introduction

The main findings of this study were in the solid waste management practice in the selected towns in Kenya and the impact of inefficient management on the environment. This chapter presents the status of solid waste management in Kenya with:

- Comparisons of the current practice and trends in management.
- Establishment of the resources availability.
- Understanding the consequences of poor solid waste management.

The results of the leachate quality and its variation with time and space is presented and discussed.

4.2 Solid Waste Management

The varying problems in management of solid waste in the study towns was a clear indication of the potential use of term 'waste' having a different meaning for different people. Due to the socio-economic disparity of the community, waste discards from the higher social class has found immediate reuse by the less endowed (economically) members of the community. The informal community participation in recovery and recycling was evident with cases the 'unwanted' products from some sectors of the community seen of much value for others persons in a different circumstance, or even in a different culture within the same town. This was in conformity with Scheinberg's (2001a) definition of solid waste.

Some large industries in Kenya have embraced the use of waste materials such as paper, glass and metals as inputs in their manufacturing In line with the World bank guidelines (Bernstein, 2004). The real value of waste was confirmed by the huge informal sector that lives from waste collection and recovery. The UNEP (2009d) recommendations on social, economic, technology, political and administrative dimensions are to some extent applied in the SWM in Kenya. An example of the social dimension of SWM is the waste minimization through adaptation of recommendations and guidelines for the use of plastics in packaging; the economic dimension is also in the waste recycling of soft drinks and beer bottles. The technology dimension of SWM is lagging the former two dimensions due to poor investment in the in the sector.

4.3 Solid waste production

Planning and management of solid waste in the study towns was dependent on the profile of the human settlement. In small communities and peri-urban middle income residential areas, the solid waste produced by these communities could easily be burned or buried. This was in conformity to observations by Chandran (1993), who noted that the potential environmental impact of this waste in such environs was minor because the material was rarely hazardous and was not being produced in large quantities. As the towns developed, people began to live in densely populated areas, and the production of waste became a health problem. In response to this threat, towns and cities designated dumping areas for solid waste, usually on the outskirts of the towns. All forms of solid waste were dumped, including industrial, medical, and household waste.

4.4 Basic data on solid waste

The estimates done for waste generation rates in the study towns were as presented in Table 4.1. Whereas industrialised Countries (EIC's) record (Chandran, 1993) solid waste generation rates in the range 1 - 2 kg per capita per day, in developed countries a range of 0.4 - 0.98 kg per capita per day was reported (Table 2.2).

Table **4.1:** Mean solid waste generation rates of the study towns in Kenya

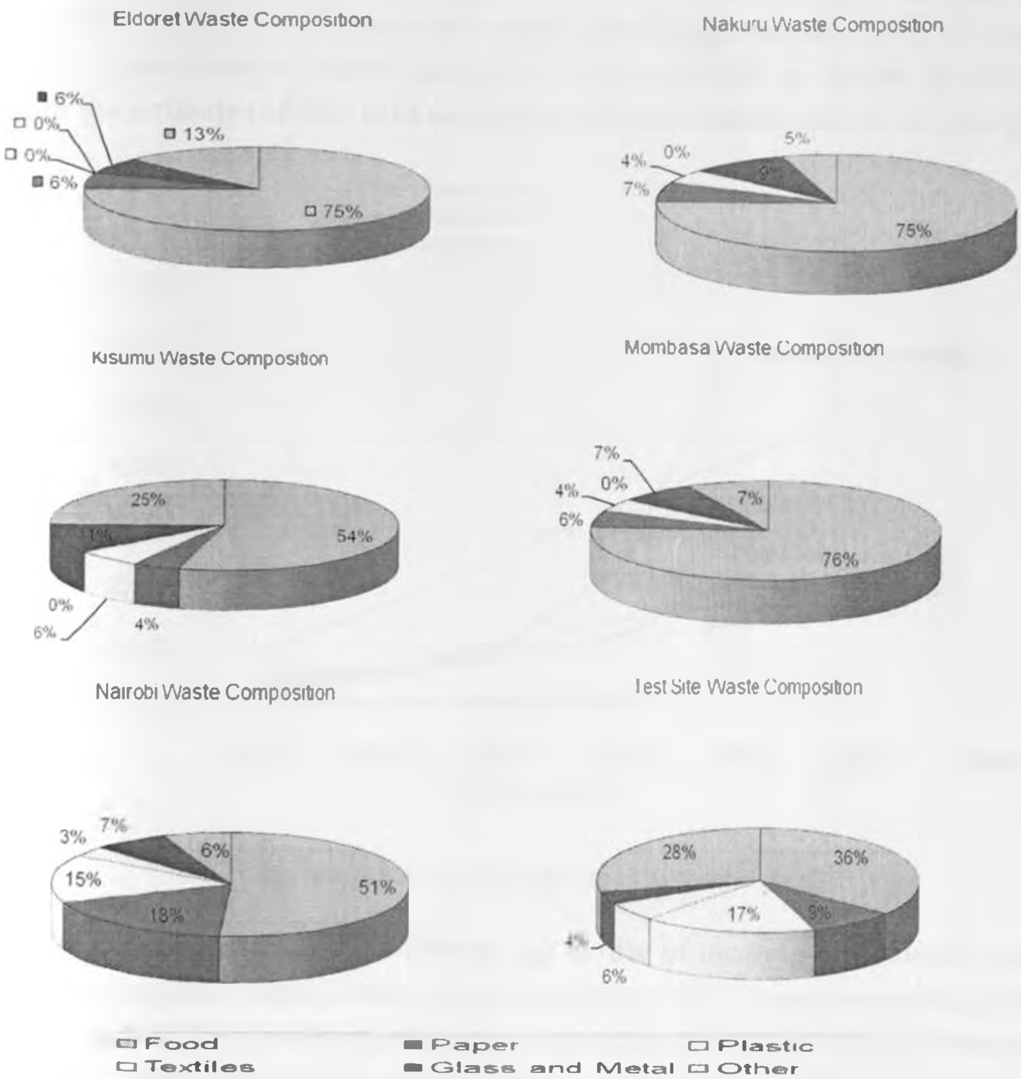
	Nairobi	Mombasa	Kisumu	Nakuru	Eldoret
Population [1] 1999	2,143,254	665,018	322,734	239,000	197,449
Generation rate [2] (kg/day/person)	0.67	0.65	0.8	0.4	1.6
Total generation/ day (tonne/day)	1436	432	258	96	316

[1] Population figures according to the 1999 National Housing and Population Census

[2] Generation rates, JICA 1997, Student field study 1996 to 2002

4.5 Solid waste composition

The evolving eating and cooking habits (affluence, culture) of the residents of the study towns determines the composition of the waste. In interviews with the staff at the town councils, different waste management systems were considered for the various sources of waste. In general, the solid wastes contain more organic components than other materials. The relative composition of solid wastes generated in the towns of Nairobi, Mombasa, Nakuru and Kisumu as shown in Figure 4.1 are within average percentages of organic matter in the solid waste in major cities in Asian countries (range from 50% to 70%) (EMC, 2007). The food waste content of the waste is substantial, with Mombasa, 76 %, Nakuru, 75 %, and Kisumu, 53 %. This is indicative of waste which can be subjected to composting in selected collection zones within various urban areas.



Source: field studies done from 1996 to 2002

Figure 4.1: Waste compositions in the study towns

These towns compare well with middle income country data in Table 2.3. Nairobi had 51 % food waste content, confirming the impact of urbanisation levels on waste composition. The composition for Nairobi tends to compare well with the higher income cities in Table 2.3. The other components of waste of concern in towns are the Industrial and Medical Wastes. The exposure to plastic packaging was evident in the case of Nairobi (15 %) against the smaller urban areas. Industrial wastes constitute about 23 per cent of the total solid wastes was reported by JICA (1998) was generated in Nairobi. The collection and disposal of industrial waste in Nairobi is done by industries themselves. The industries have the responsibility to collect and dispose the waste at the designated City Council dumping sites. The waste generation in Nairobi increased with population as shown in Figure 4.2. It presents the estimates of daily solid waste quantities for Nairobi over the 22 year period.

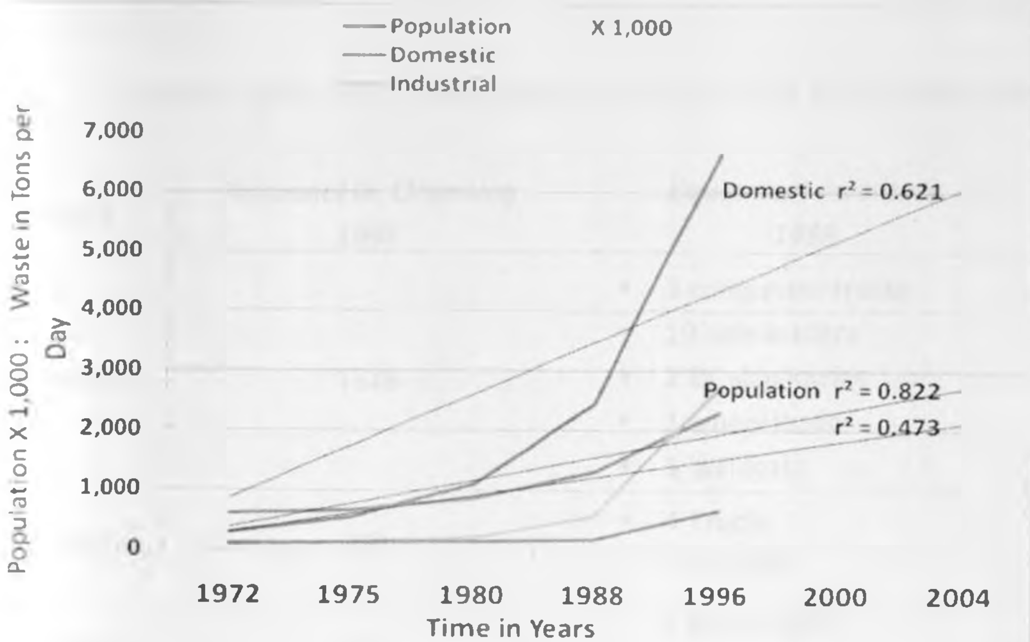


Figure 4.2. Nairobi's estimated total daily solid waste

The linear projections show the widening gap in rate of increase of domestic waste with population. Industrial waste is seen to be increasing at the same rate as population. It is worth noting that the rate of industrialisation will affect the actual waste generation and its composition. With respect to manufacturing industries, the bulk of solid wastes are generated from:

- Pesticide repackaging, formulation and distribution;
- Pharmaceuticals, where there are over 30 manufacturing companies;

- Plastics industry, where there are about 100 producing thermo setting, flimsy packaging;
- Soap, Perfumes, Cosmetics, Toiletry, Cement and Lime; and
- Ceramics, glass and petroleum.

4.6 Resources available

Solid waste management in Kenya should aim at providing adequate and affordable service, through the use of least cost, viable techniques. However, the objective of minimum cost must be subjected to a number of constraints, so that employment objectives, the real cost of imports and limitations on capital expenditure are also taken into account. An indication of the constraint levels is reflected in the equipment inventory of the study cities as presented in Table 4.2.

Table 4.2 Summary of personnel and equipment used in Solid Waste Management in Kenya

Town	*Personnel in Cleansing 1997*	*Equipment Inventory 1996*
Nairobi	1339	▪ 3 compactor trucks ▪ 19 side loaders ▪ 2 BC skip lorries ▪ 1 wheel loader ▪ 1 bulldozer
Mombasa	282	▪ 4 Trucks ▪ 3 Tractors
Kisumu	60	▪ 2 open trucks ▪ 2 comp trucks
Nakuru	74	▪ 5 minimatic trucks ▪ 2 lorries ▪ 1 compactor
Eldoret	55	▪ 6 minimatic trucks ▪ 2 lorries ▪ 1 forklift ▪ 1 compactor

Field studies

Also of importance in planning capital expenditure are possible shortages of skilled labour for operation and maintenance, and the availability and affordability of spare parts.

4.7 Solid waste handling

According to the JICA report (1998), only about 25 per cent of the estimated 1,500 tonnenes of solid waste generated daily in Nairobi was collected. Yet, until the mid 1970s the Nairobi City Council singly collected over 90 per cent of the waste. In the mid 1980s, the appalling NCC performance and demand for municipal solid waste management services attracted private sector providers. It was estimated that there were at least 60 private companies engaged in solid waste collection services in the city (JICA, 1998). Most of the solid waste generated in Kisumu remained uncollected with a collection efficiency estimated at 20%. The collection that took place was shared between the City Authority and a few un-authorised private collectors mainly concentrated in the high income areas, leaving the poor peri-urban neighbourhoods largely unattended. Waste transported to the dumpsite for disposal was not properly managed.

Many households, particularly in the peri-urban and extended areas did not have the privilege of any mode of collection, and have resorted to private burning of waste or digging their own pits to bury the waste on site. However, some common dumping grounds had developed in city service lanes and open grounds within the neighbourhoods, presenting unsightly scenes that generally offend the public and inhabitants alike. Plastic waste used in most packaging was the most conspicuous nuisance, often littering many parts of the city and the residential neighbourhoods, and sometimes blamed for livestock death and blockage of storm water drains. It was also notable that of the total amount of waste generated in Kisumu, approximately 60-65% was organic in character presenting enormous potential for recycling for farm use. Most clinical waste from the hospitals were incinerated, reducing the health related risks from exposure.

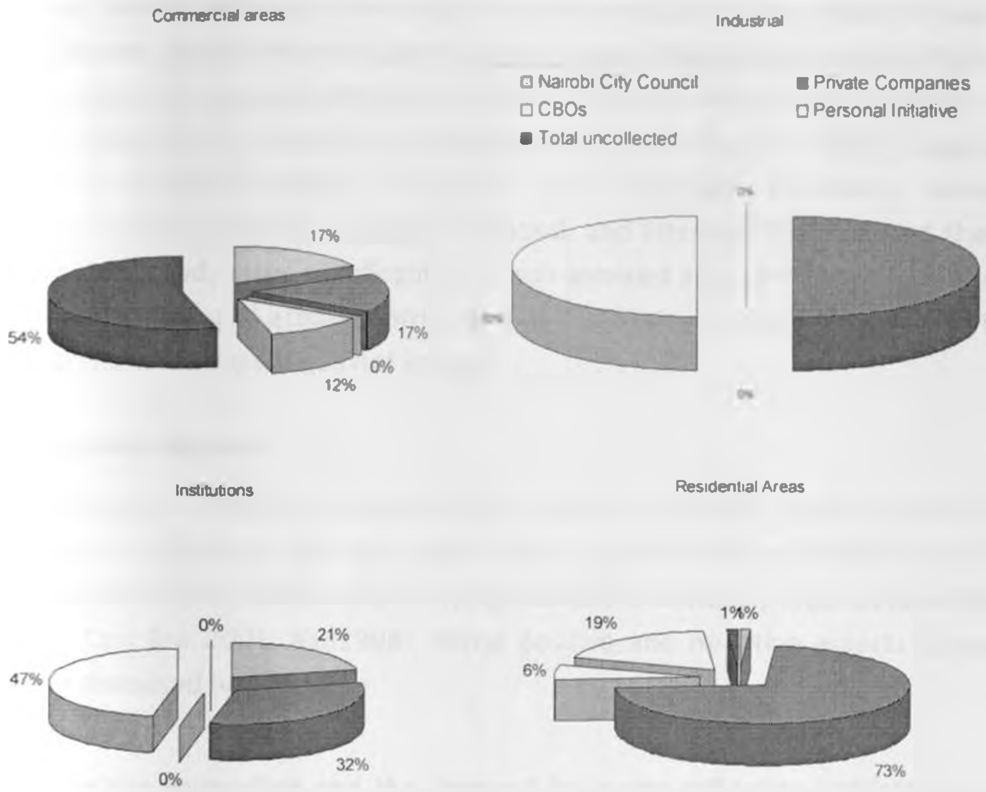
The towns have no transfer facilities. As a result of these disposal problems, almost all enterprises tend to use uncontrolled and unhygienic landfills as the predominant mode of disposal. To cut costs, many generators of solid wastes had taken to combustion at site, which caused air pollution problems. The bulk of these wastes contained plastics, which when burnt generate carcinogenic vinyl chloride monomers and dioxins. The generators and private waste collection firms, to reduce costs, dump the waste in illegal places since there was no effective monitoring system.

During the study carried out by *JICA (1998)* on the residents around the dumping site revealed serious complaints about smoke, smell, and broken glasses. Respiratory and stomach problems among children were common in the nearby clinics and were cited by the people interviewed. School children passing through the dumpsite often picked objects, which were dangerous to their health. Solid wastes in the cities were not segregated, with the exception of unstructured reuse of some waste materials at the household level. The private sector waste collectors, in addition, did not process waste in any way, which affected effective and efficient SWM. Consequently, the dumpsites were littered with all types of wastes from hospital wastes, manufacturing/industry wastes, paper and biodegradable materials.

4.8 Public-Private Partnerships

The Councils and private commercial companies are the principal providers of SWM services in Kenyan towns. A small number of other actors, including some industries and bulk generators, however, store and transport waste to the dumpsites by themselves. Surveys show that private companies and personal initiative were very important in the cities' waste collection sector and that many households were not served (Figure 4.3). In 1998, NCC accounted for 22 per cent of the solid waste collected in the city per day while a private firm contracted by NCC to offer SWM service in the central business district (CBD) accounted for 46 per cent and the other private companies the balance of 54 percent. Private companies served 45-73 per cent of the households, 32 per cent of the institutions, 50 per cent of the industries and 16.7 per cent of the commercial enterprises. About 81 per cent of the households served by private companies live in the high and middle-income areas (largely the western part) of the city.

The majority of the private companies were either small family ventures or a hybrid between a community based organization (CBO) and a private firm. However, there were about 10 fairly large firms. The councils which have the social responsibility of providing SWM services to all citizens concentrate their efforts on residential areas and institutions that can afford private service at the expense of areas inhabited by the poor. The appalling performance and the failure of private service to extend into low-income and unplanned settlement areas, community-based initiatives in waste collection, transport, and storage, trading and recycling started to emerge in 1992.



Source: Ikiara et al. (2004)

Figure 4.3: Relative importance of SW collection agencies in Nairobi

There are now a number of CBOs, including charitable organizations, ethnic associations, welfare societies, village committees, self-help groups, and residential (or neighbourhood) associations (RAs) involved in SW collection and disposal. Majority of the CBOs are engaged in waste composting although the main activity of about 44 per cent of them was neighbourhood cleaning (Ikiara et al., 2004). One-third of CBOs were involved in waste picking. Despite individual and localized performances, the community in general plays a significant role in waste management. NGOs and international organizations supported CBOs through training, marketing and provision of tools and equipment, among other ways. Approximately 55.6 per cent of the CBOs reported having been sponsored or facilitated by local and international NGOs and United Nations agencies like the UNFPA and UNCHS (HABITAT) (Ikiara et al., 2004).

The actual amount of waste removed from the municipal waste stream through this route was not known. Many informal agents (waste pickers, traders and dealers, itinerant buyers, informal dump service providers and informal recycling enterprises) were also involved in Nairobi's SWM sector, albeit as a secondary activity (Ikiara et al., 2004). These actors were involved in all SWM domains, including waste collection, separation, storage, re-use, recovery, recycling, trading, transport, disposal, and littering. They reduced the waste that was to be disposed, more significantly, in non-serviced areas inhabited by the urban poor. Like urban farmers, the actual contribution of these informal actors to SWM in the city and other parts of the country was not known.

4.9 Economic aspects

The inefficiency in SWM has impacted on economic activities, leading to macro-economic dimensions of resource use and conservation, and income generation in Kenya through establishment of small and medium enterprises and community organisations (Bartonnee et al, 1997; Carl Bro 2001; Kim1998). Some positive and negative aspects of economics in SWM are discussed herein.

- Solid waste generation and the demand for waste collection services in all the study areas generally show an increase with economic development.
- The efficient human resources management can contribute substantially to the economics of an ISWM. Figure 4.4 shows the global comparative collection efficiency of the study cities, all of which performed the least. This low collection efficiency can be looked at as a reflection of an opportunity which can be harnessed for economic gain in the solid waste management in the towns.
- Managing the low-cost collection services, whether through public participation or privatisation must be in check with trade-off between the objectives of low-cost collection service and environmental protection.
- The economic effectiveness of ISWM systems depends upon the life-cycle costs of facilities and equipment and the long-term economic impact of services provided. The situation in Kenya portrays total dilapidation in equipment, and where they exist, most are obsolete.
- Kenya should encourage private sector involvement in waste management to actually improve efficiency in the sector. Economic strategies should seek, firstly, to increase

effectiveness and labour productivity of MSWM and, secondly, to generate employment by expanding service coverage.

- Provide for recognition of industries that practice in-house waste reduction/reuse, through appropriate incentives

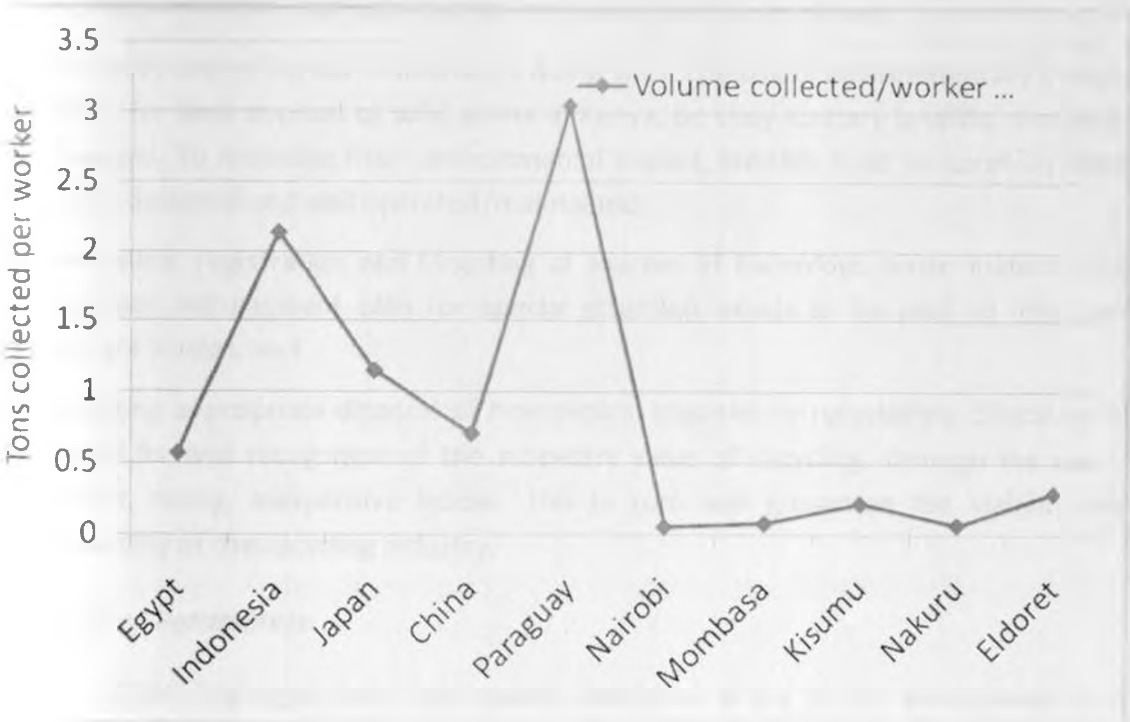


Figure 4.4: Global comparative collection efficiency of the study towns

4.10 Technical aspects

The planning of SWM in the solid waste sector is lacking and contributes to the poor implementation and maintenance of collection and transfer systems, waste recovery, final disposal and hazardous waste management in the study areas. Thus planning of SWM is key to an effective ISWM system. This can be done by the incorporation of:

- Technical facilities and equipment in the study towns were not designed and selected with careful regard to their operating characteristics, performance, and maintenance requirements and expected life-cycle costs. Close attention should be paid to preventive maintenance, repair and spare parts availability;

- None of the towns had transfer facilities and equipment that match the characteristics of local collection systems and the capacity of existing disposal facilities. Local collection systems should be designed with active participation of the communities concerned;
- There was Informal waste recovery and scavenging in all the towns. This can be more productive through support measures and appropriate technical design of the waste management systems. Public sector involvement in waste recovery and/or leasing of waste recovery rights to private sector enterprises can be considered;
- All the study towns use old mismanaged dump sites. The use of environmentally friendly methods for final disposal of solid waste in Kenya, be they sanitary landfills, should be encouraged. To minimise their environmental impact, landfills must be carefully sited, correctly designed and well operated/maintained;
- Identification, registration and targeting of sources of hazardous waste materials for appropriate management calls for special attention needs to be paid to infectious healthcare wastes; and
- Encouraging appropriate disposal of households' organics or recyclables. Education of the need for and recognition of the monetary value of recycling, through the use of abundant, ready, inexpensive labour. This in turn will guarantee the viability and sustainability of the recycling industry.

4.11 Pollution Parameters

Cointreau, (2004) highlights that open dumps also pose a risk to the environment in a different manner. Microorganisms present in the refuse use the refuse as a food source. Under the anaerobic (no oxygen) conditions typical in most dumps, these microorganisms convert the organic material in the refuse to methane and carbon dioxide. As the gas rises through the dump and escapes into the atmosphere, it sometimes picks up other organic compounds. The presence of large amounts of methane in this uncontrolled environment may result in explosions and fires. Additionally, this untreated gas may contain other compounds that pose a substantial health risk to nearby communities. The results of the heavy metals contents for the samples tested varied as shown in Figure 4.5.

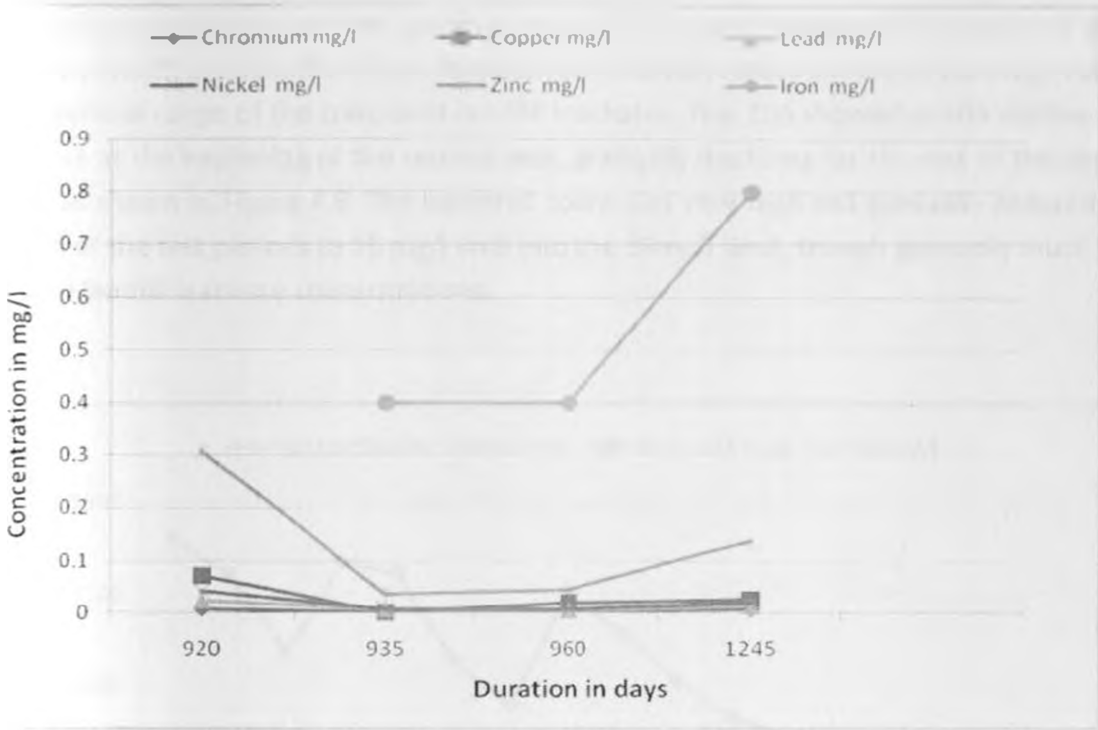


Figure 4.5: Heavy metal content of the leachate samples

The results indicated that the leachate had heavy metal contents. The pollutants concentrations are compared to typical values for landfill sites (Figure 3.4), and they all fall in the lower ranges, i.e;

- Chromium with a value of 0.05 mg/l against an typical average of 0.02 – 18 mg/l;
- Copper with a value of 1 – 1.3 mg/l against an typical average of 0.1- 90 mg/l;
- Lead with a value of 0.01 mg/l against an typical average of 0.001 – 1.44 mg/l;
- Zinc with a value of 0.5 – 5 mg/l against an typical average of 0.6 – 220 mg/l; and
- Iron with a value of 0.3 -38 mg/l against an typical average of 200 – 500. mg/l.

All the heavy metals tested for, had their concentrations reducing within the test period, except for zinc whose concentrations increased towards the end of the test period. Though none of the metals had the high values as compared to the landfill, their threat to ground water contamination is real in areas where shallow wells are used.

The specific conductivity and the bacterial count of the leachate dropped to about one sixth and one seventh of the initial values respectively. The TDS values started at very high values in the general range of the compared landfill leachates. The TDS showed gentle decline and small rise at the beginning of the second year, gradually declining for the rest of the period of test as shown in Figure 4.6. The bacterial count was very high and gradually reduced, by the end of the test periods to 16 mg/l well into the 30mg/l limit, though generally much less than the landfill leachate concentrations.

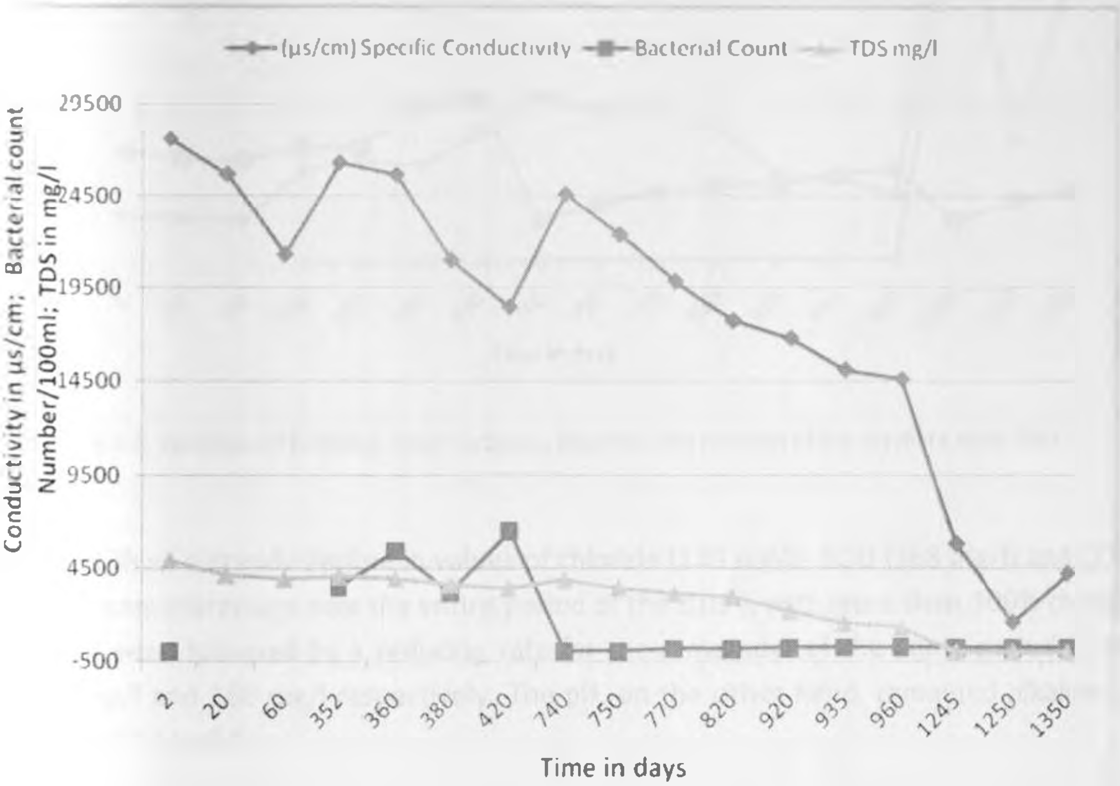


Figure 4.6: Variation of specific conductivity, bacterial count and total disolved solids of the leachate with Time

In Figure 4.7 the total hardness started at 154 mg/l to 874 mg/l by the end of the test period. Alkalinity started at 348 mg/l with a slight drop in the first month and rose for the remaining period of the first year before dropping in the second year ending at 213 mg/l. The nitrates and total hardness on the other hand started low over the first two years and suddenly rising in the third year of study.

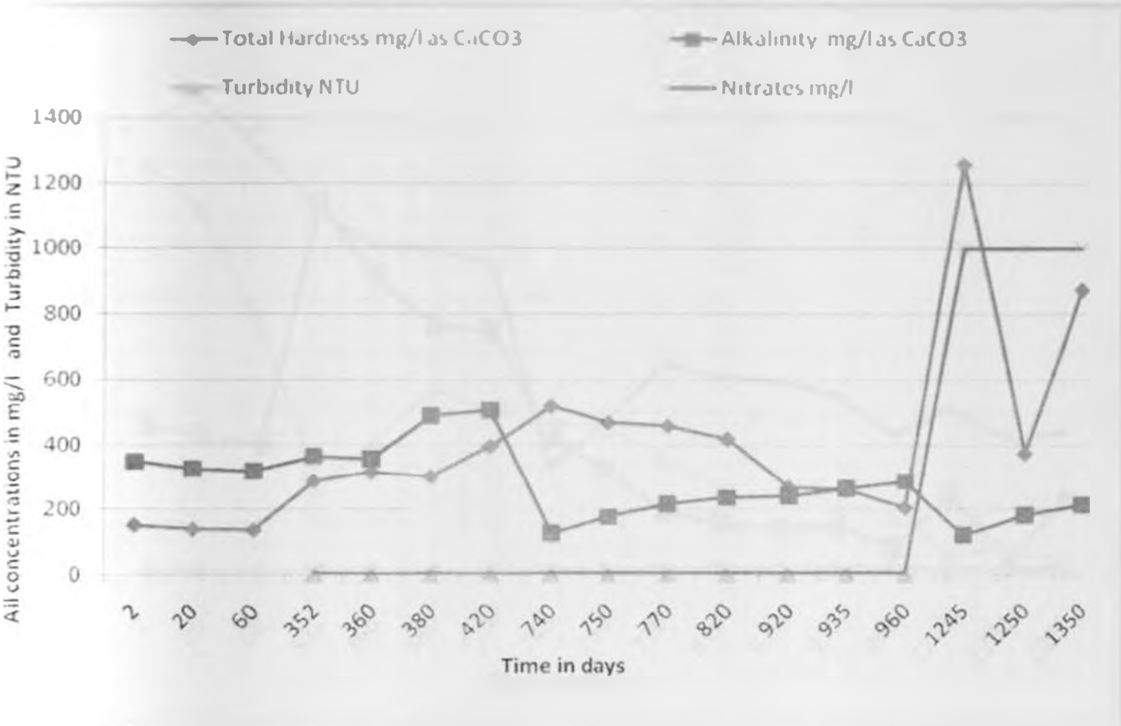


Figure 4.7: Variation of turbidity, total hardness, alkalinity and nitrates of the leachate with Time

Figures 4.8 show a steady decline in values of chloride (138 mg/l), BOD (368 mg/l) and COD (473 mg/l) concentrations over the entire period of the study, with more than 100% change in the first year, followed by a reducing rate for the remainder of the study period to 68 mg/l, 16 mg/l and 130 mg/l respectively. The pH, on the other hand, remained alkaline in the range of 7.1 to 8.6.

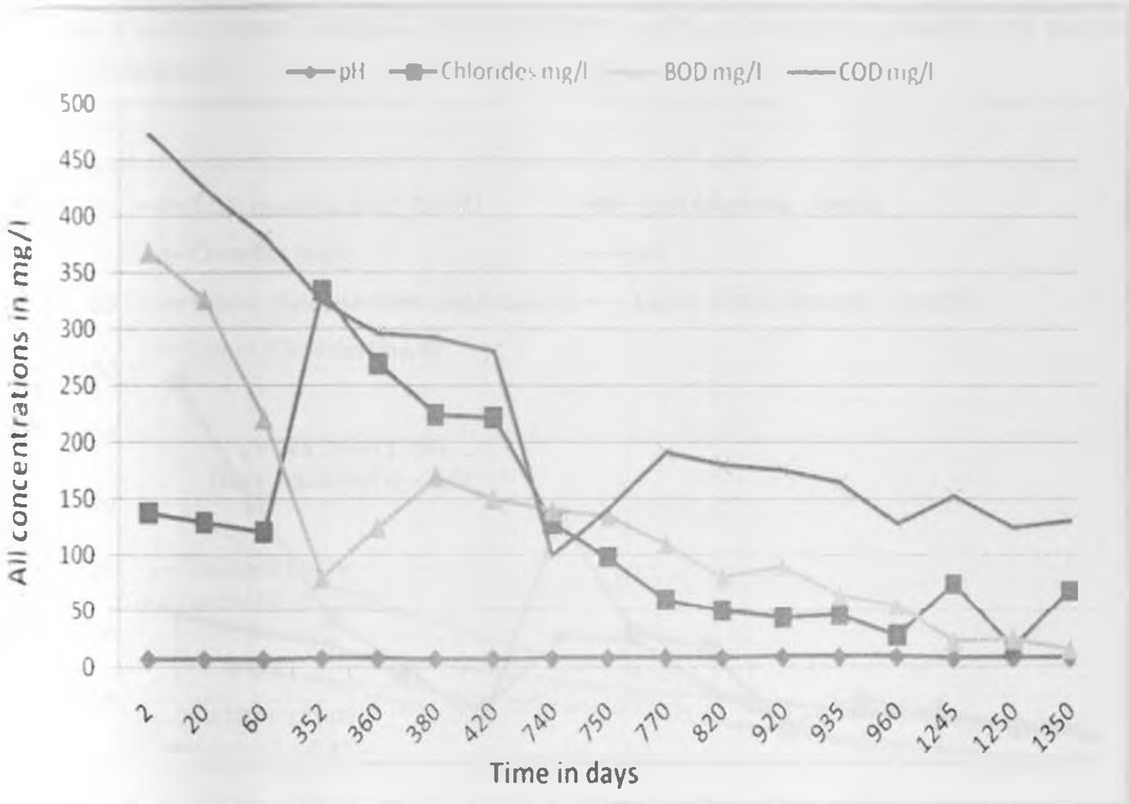


Figure 4.8: Variation of pH, Chloride, BOD and COD of the leachate with Time

4.12 Pollution Variation with Depth

The soil samples from the test holes exhibited a decline in total alkalinity, total hardness and chloride concentrations, with increase in depth (Figure 4.9). Hardness and total alkalinity were modelled exponentially, giving fits with coefficient of determination of 0.70 and 0.64 respectively. Chlorides exhibited a linear variation with a coefficient of determination of a 0.85.

The coliform counts, BOD and COD concentration reduced throughout the period of the study. As reflected in Figure 4.10, the coliform counts, BOD and COD trends were fitted exponentially with coefficient of determination of 0.44, 0.73 and 0.72 respectively. Notable variation was with the DO which was much higher in the samples from test hole C and a polynomial fit made on the data, resulting in a coefficient of determination of 0.65. In all samples, the initial coliform count, BOD and COD concentrations of the solid waste was much higher than the first set of concentrations transmitted into the soil strata.. The parameters also showed reduced concentrations with an increase in depth and distance from the dump site.

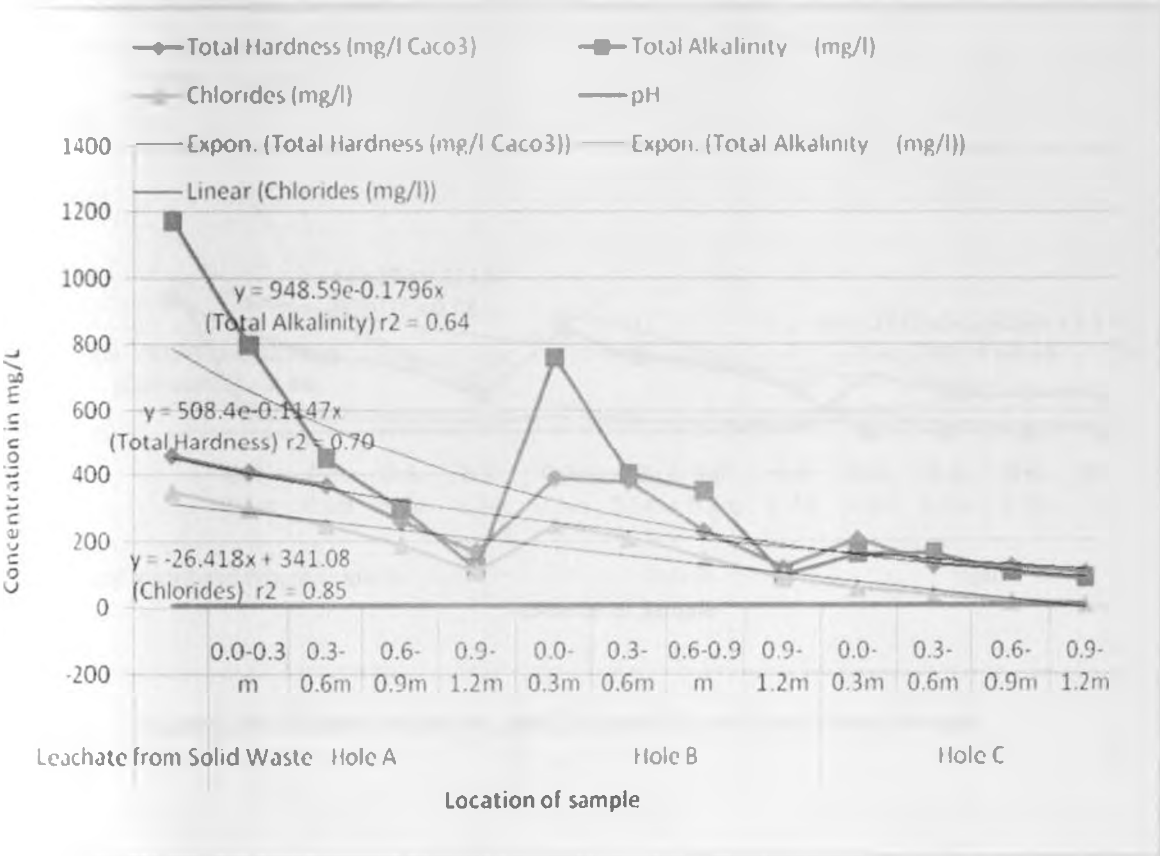


Figure 4.9: Variation of total hardness, total alkalinity, chloride and pH with depthin the test pits

In Figure 4.10, the iron and nitrate concentrations dropped with depth in test holes A and B, but shot more than ten times in the iron concentration in test hole C. The same trend was noted as the sample point radius increased. In all samples, the initial concentrations of the three parameters in the solid waste were much higher than the first set of concentrations transmitted into the soil strata. The total hardness was accompanied by a corresponding rise in turbidity in samples from test hole C. Though exponential fits were tried on the nitrates and turbidity (Figure 4.11), they were not good enough with values of the coefficient of determination of 0.63 and 0.21 respectively.

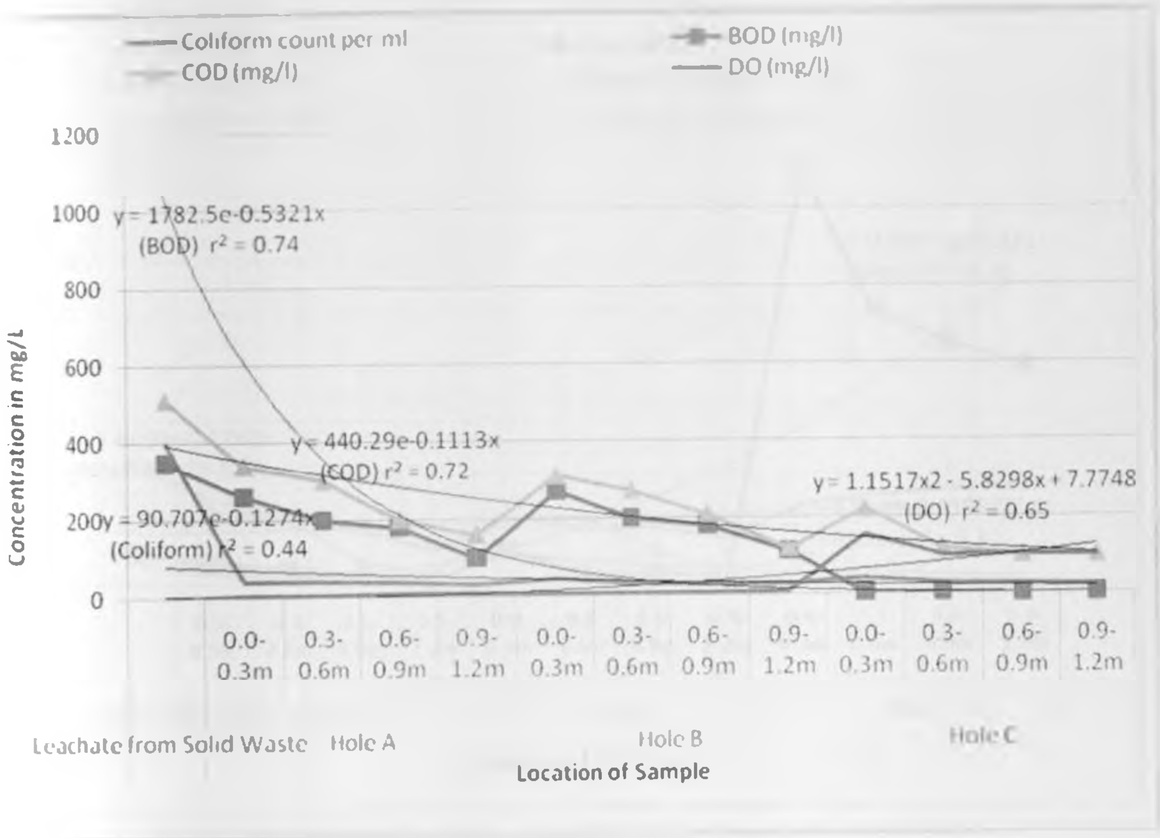


Figure 4.10: Variation of coliform, BOD, COD and DO with depth in the test pits

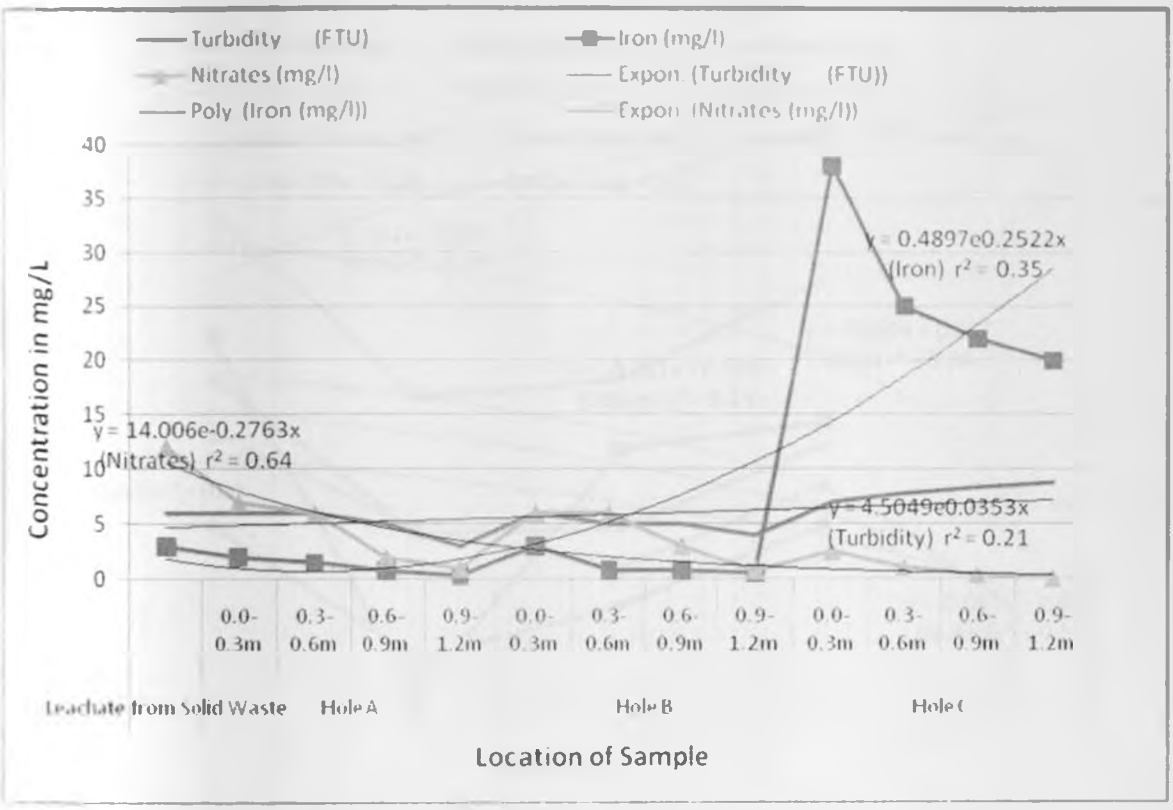


Figure 4.11: Variation of turbidity, iron and nitrates with depth in the test pits

4.13 *Results for the Pollution Linear Trend Analysis*

In order to understand and manage the pollution threats, the pollutants' behaviours were investigated for their trends. The plots in Figures 4.12 to 4.15 show linear fits of the results.

In figure 4.12, the iron concentrations had a rising trend through the test period and gave a coefficient of determination of 0.75. The other heavy metal parameters, namely zinc, copper, nickel and lead reduced in concentration over the test period, with coefficient of determinants of 0.26, 0.25, 0.28 and 0.31respectively. Thus the linear fit was only good for zinc.

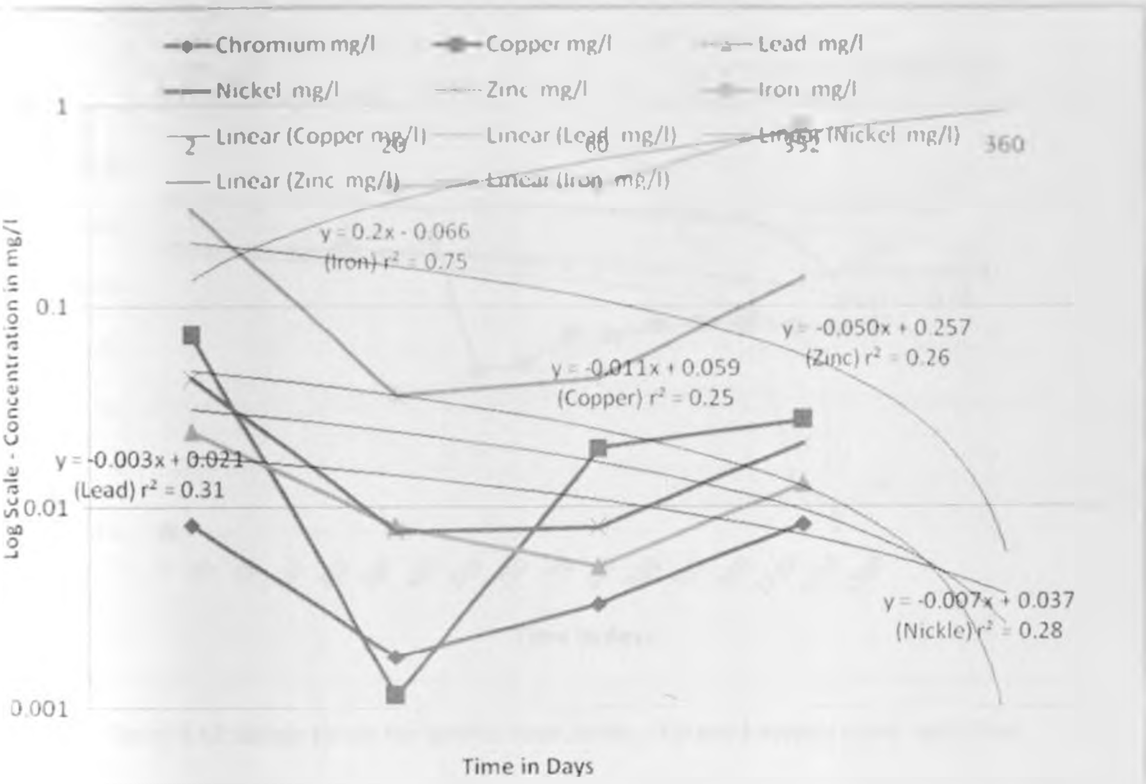


Figure 4.12: Linear trends for heavy metal content of leachate sample

The linear fits made to the TDS, bacterial count and the specific conductivity as illustrated in Figures 4.13 had coefficients of determination of 0.88, 0.25 and 0.80 respectively. Unlike the other two parameters, linear fit did not suite bacterial count.

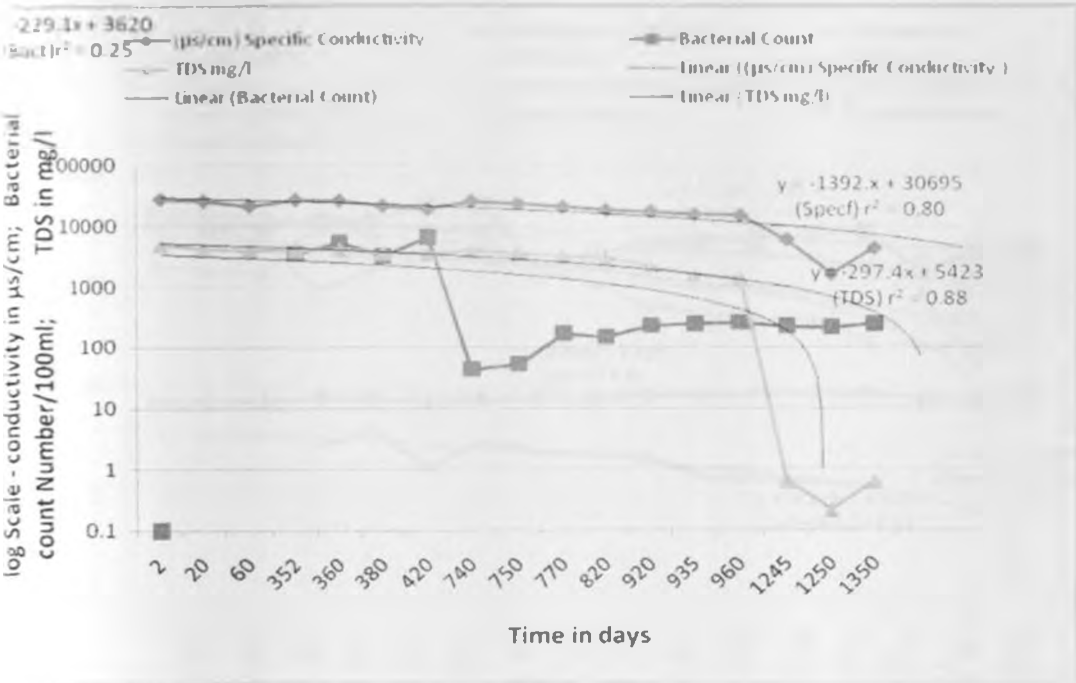


Figure 4.13: Linear trends for specific conductivity, TDS and bacterial count with Time

Figure 4.14, illustrates the trends for BOD, alkalinity, chlorides, turbidity and COD on linear fits. Their respective cofficients of determinations were 0.74, 0.34, 0.46, 0.65 and 0.77, showing that BOD and COD were best suited.

In Figure 4.15, total hardness,nitrates, and alkalinity are illustrated on linear fits. Their respective cofficients of determinations were 0.34, 0.44 and 0.34, which were not very good fits.

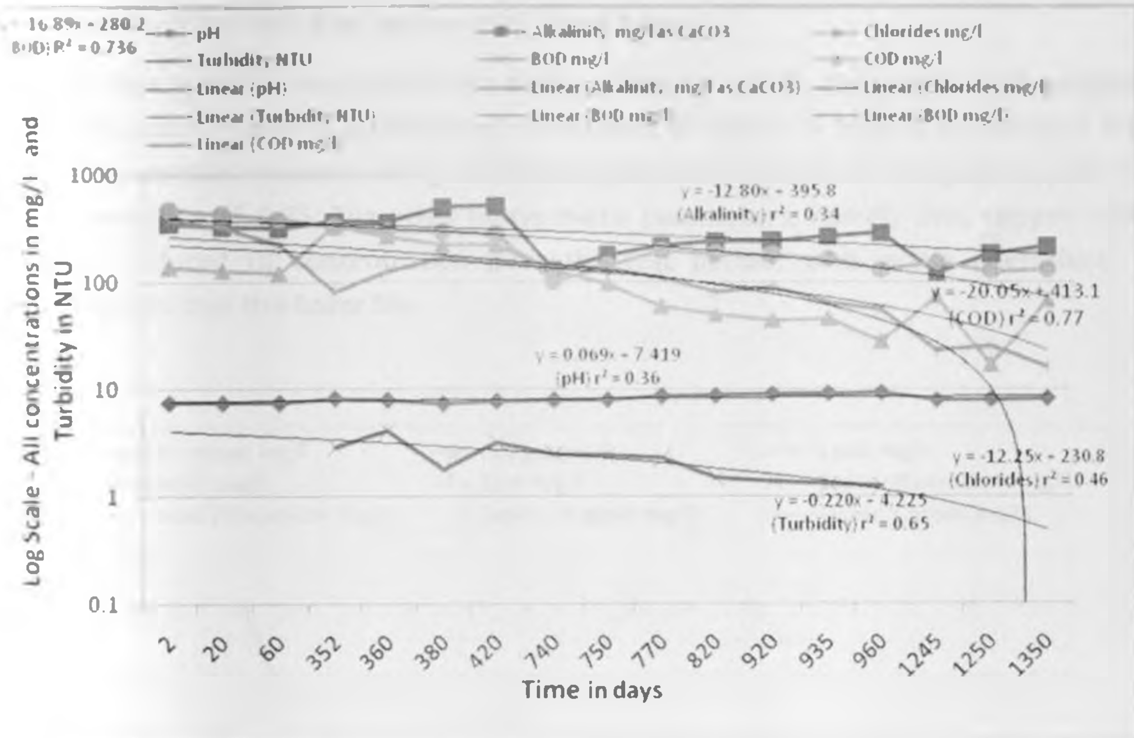


Figure 4.14: Linear trends for pH, turbidity,alkalinity, chloride and COD with Time

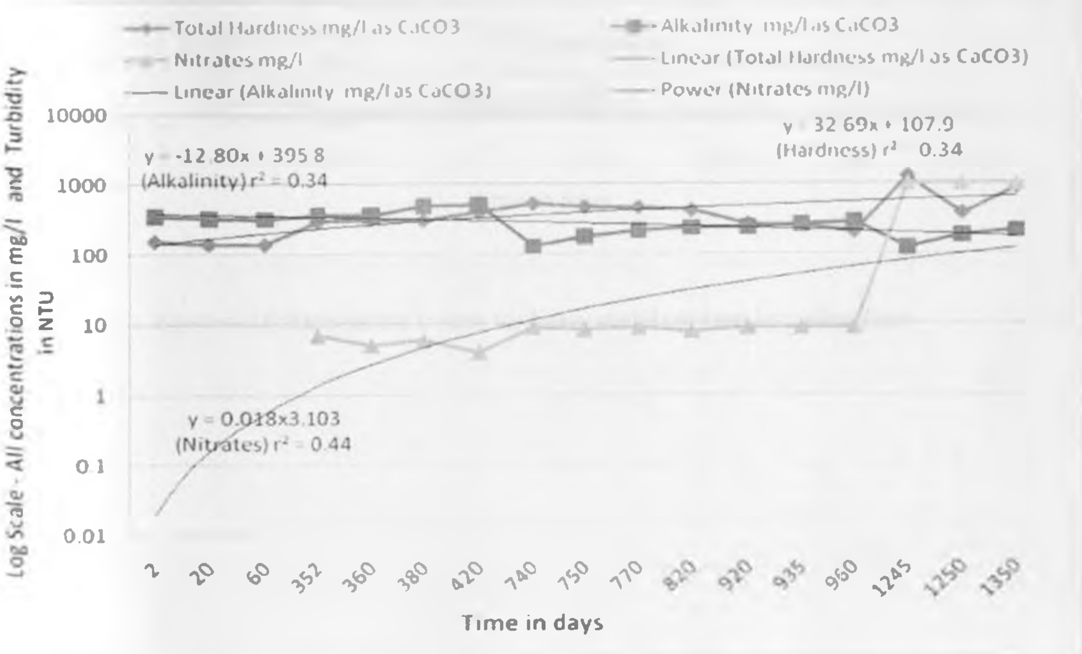


Figure 4.15: Linear trends for total hardness, nitrates and alkalinity with Time

4.14 Results of the Pollution Exponential Trend Analysis

Since the best possible trend cannot be deduced by one test fit, the results were subjected to an exponential trend fit as presented in the plots in Figures 4.16 to 4.19. In Figure 4.16, the iron concentrations had a rising trend throughout the test period and gave a coefficient of determination of 0.75. The other heavy metal parameters, namely zinc, copper, nickel and lead reduced in concentration over the test period, with worse coefficients of determination than the linear fits.

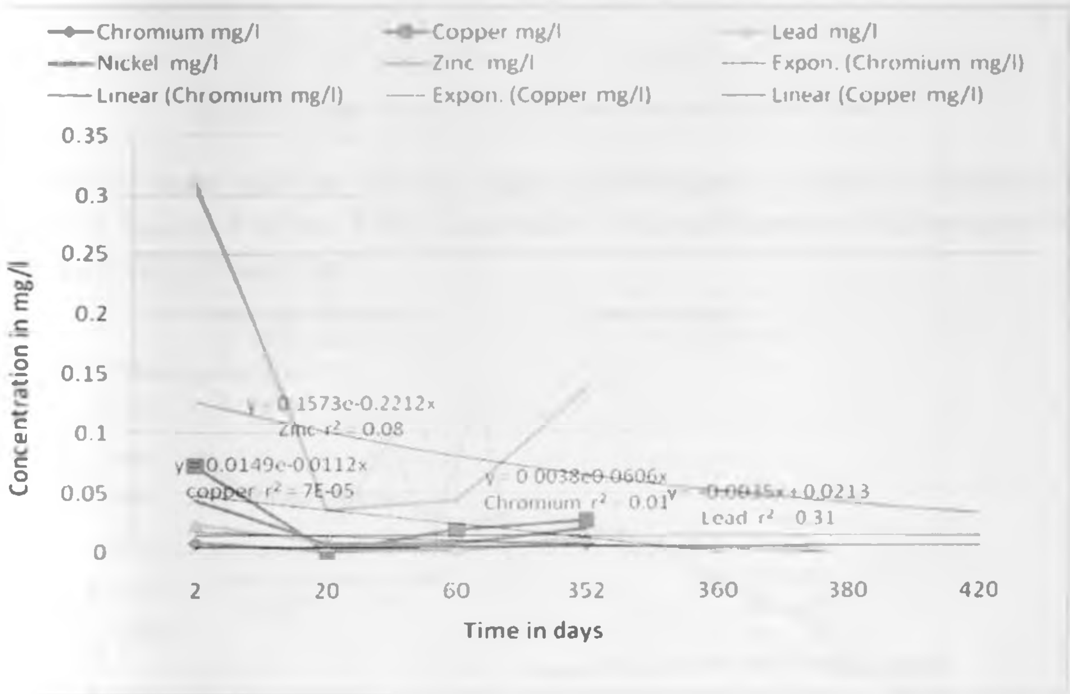


Figure 4.16: Exponential trends for heavy metal content in the leachate

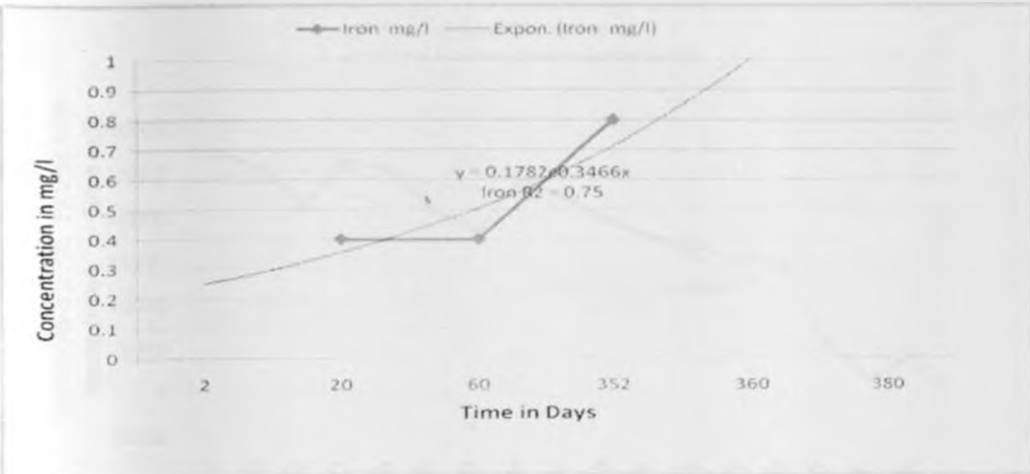


Figure 4.17: Exponential trends for iron in the leachate with time

Polynomial fits were made to the TDS, bacterial count and the specific conductivity as illustrated in Figures 4.18 and 4.19, respectively. The coefficients of determination were found to be 0.95, 0.27 and 0.89.

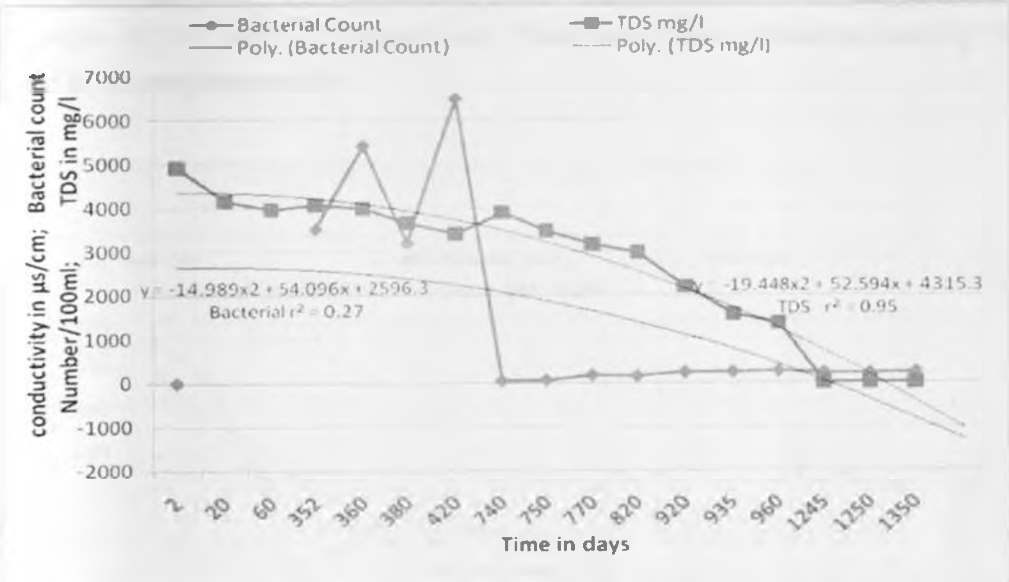


Figure 4.18: Exponential trends for bacterial count and total dissolved solids with time

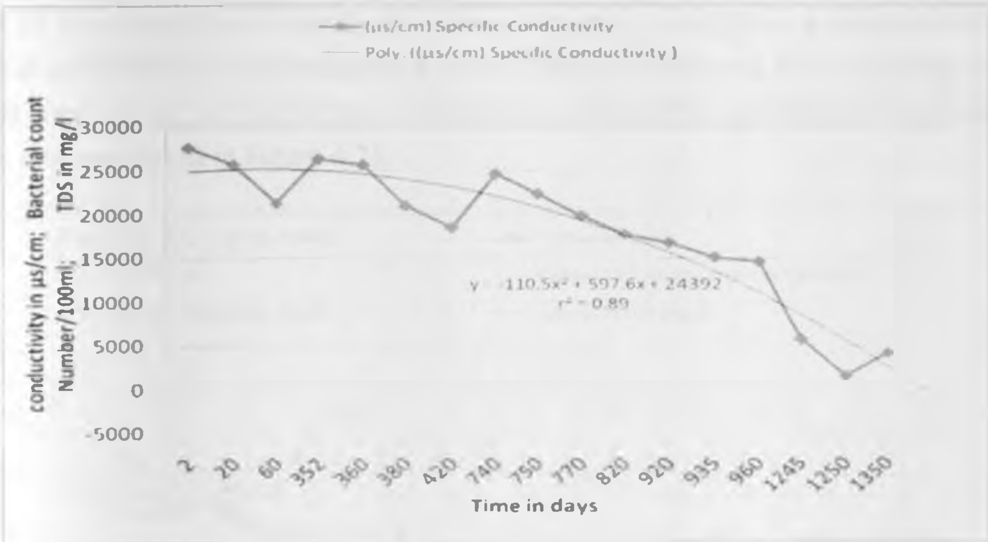


Figure 4.19: Exponential trends for specific conductivity of the leachate with time

The BOD and turbidity concentrations fitted exponentially with a coefficient of determination of 0.81 and 0.71 respectively. These were two parameters among the ones best suited by the exponential fit.

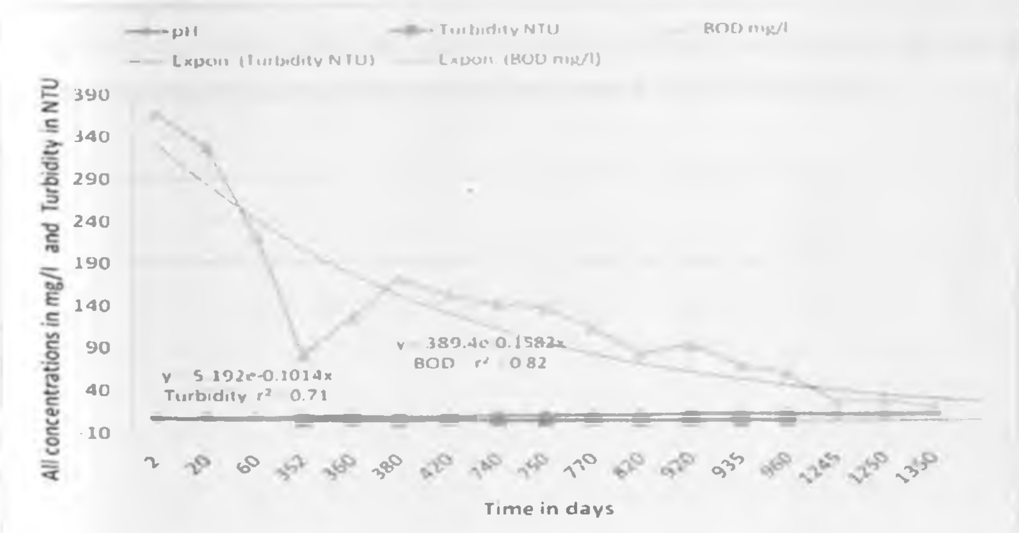


Figure 4.20: Exponential trends for turbidity and BOD of the leachate with time

Figure 4.22 illustrates the trends for alkalinity, chlorides and COD on exponential fits. Their respective cofficients of determinations were 0.3413, 0.586 and 0.73, showing that only COD was best suited for the fit as in conformity to the BOD coefficient of determination with the exponential fit in Figure 4.21.

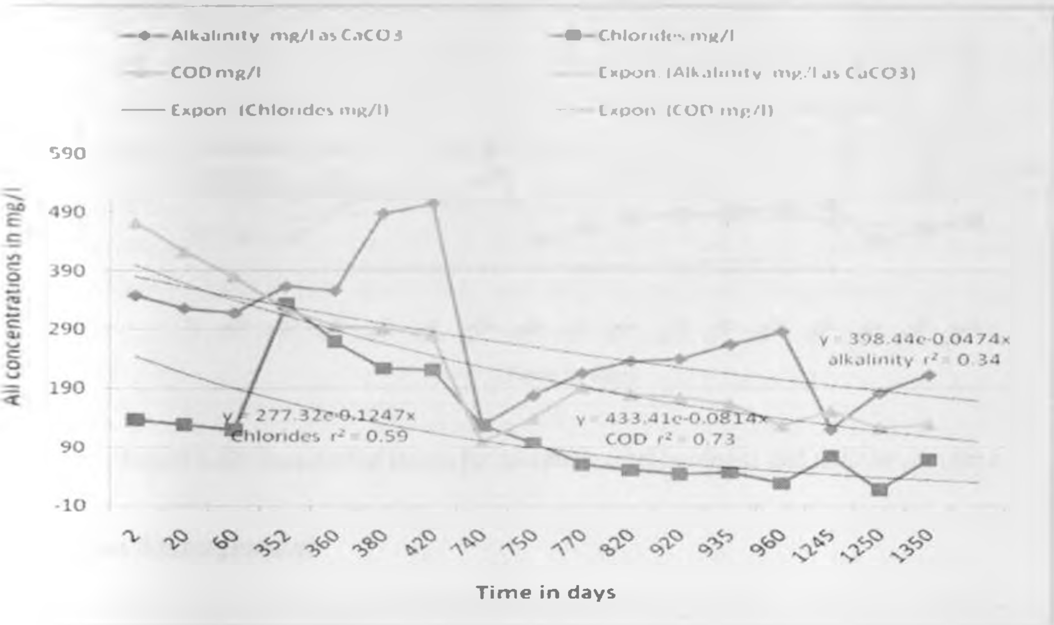


Figure 4.21: Exponential trends for alkalinity, chlorides and COD in the leachate with time

Figure 4.22, illustrates the trends for alkalinity, total hardness and nitrates on exponential fits. Their respective cofficients of determinations were 0.34, 0.42 and 0.58.

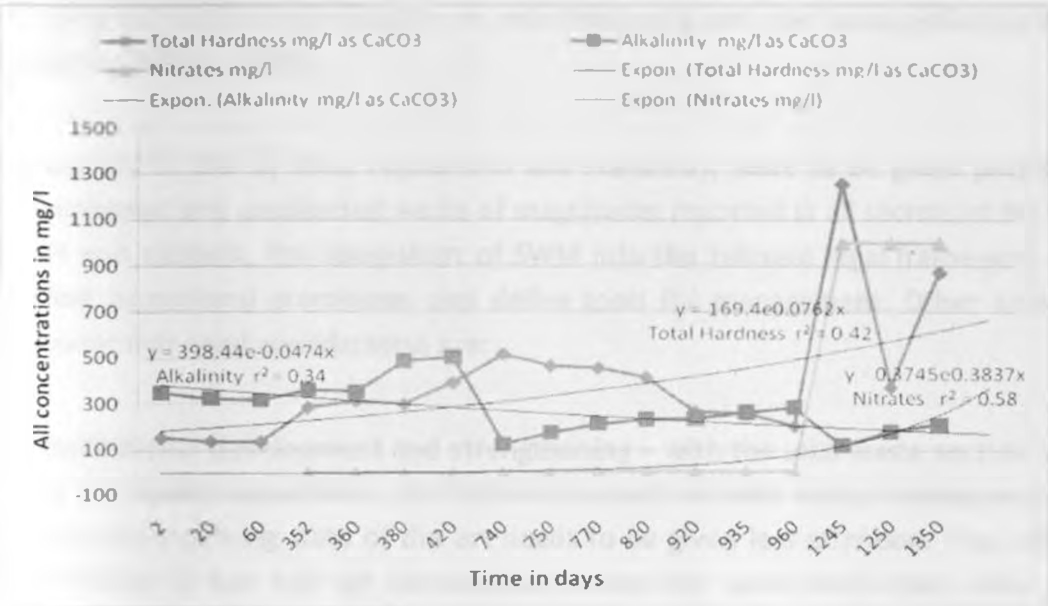


Figure 4.22: Exponential trends for alkalinity, total hardness and nitrates with time

4.15 Waste Management

Municipal Solid Waste Management (MSWM) in the study towns faces problems typical of other developing countries (Shah, 2000). These problems can be described as:

- inadequate service coverage and operational inefficiencies of services;
- limited utilization of recycling activities;
- poorly managed landfill disposal; and
- inadequate management of hazardous and healthcare waste.

The councils in the study towns have not been considering solid waste management as an integral part of public health and environmental control (UNEP, 2009). This is of particular importance in the highly populated informal settlements in these urban areas, as highlighted in collections profiled in Chapter 2.6. Through the 1980's to early 2000 the management structures have also not focused on policy support, institutional development, private sector involvement, user participation, technical development and hazardous waste management. This is confirmed by the current initiatives being pushed to stream line the SWM programs in the country (NCC, 2001). The impetus in pollution control is rather timid and seems to be mostly crisis driven (Chapter 2.6); a good example is the reluctance by which policy and supporting legislation on industrial liquid and solid waste pollution is being implemented (NEMA, 2001).

If enforcement of the by laws, regulations and standards, were to be given priority, the state of unkempt and uncollected waste of magnitudes reported in all sectors of the towns would be non existent. The integration of SWM into the relevant legal framework would also define operational procedures and define tools for management. Other aspects of management that need consideration are:

- **Institutional development and strengthening** – with the solid waste section housed in the health department, the technical aspects of solid waste management, with the accompanying state of the art needs to be given less attention. The collection efficiency is low and not comparable to even the worst performing cities in the world (Figure 2.7 and 2.8). In the three bigger towns, Nairobi, Mombasa and Kisumu, there should be a decentralisation of authority and administrative measures to build the powers and capacities of local governments commensurate with their SWM responsibilities. This should also include dissemination of know-how through literature, case studies, project documents and articles.
- **Research capacity within the country** – solid waste management is dynamic and calls for continued research and links to the state of the art technology. The link and appreciation of the role of research in the industry continues to complicate the SWM of the towns. There is need for utilisation of existing research and consulting capacities in institutions of higher learning to provide and adopt prompt home grown solutions to SW management problems (Nas et al., 2004).
- **Private sector involvement** has in the past filled the gap left by non performing councils. There is evidence of their recognition and this is being supported through practical guidelines and tools for satisfactory working relationships with councils (ISWA, 2002; NCC, 2001).
- **User participation** has been adopted in low income communities and proves to be a useful avenue for job creation and small business initiatives for youth groups (Scheinberg, 2001). They have also provided recycling and reuse application albeit in a small scale. If supported through documentation, practical guidance and tools can reduce the low collection statistics, highlighted in Chapter 2.13, for the unplanned settlements of the towns.

- **Technical development** including guidelines, efficient management methods and ICT tools have not been adopted in the study towns. Such tools may include Geographic Information Systems (GIS), Management information Systems (MIS) and Global Positioning Systems (GPS). Adopting these Decision Support Systems (DSS) is important as:

    - 80% of information used by solid waste mangers has a spatial component and can be well captured and represented with GIS;

    - GIS would also Integrate information from various levels of jurisdiction (city, zone, range and health ward level);

    - GIS also makes assimilation of voluminous information for analysis simpler and faster;

    - Dynamic and flexibility can then be built in the maps and other spatial data for the councils jurisdictions;

    - The MIS makes resources (personnel, financial and equipment) management equally dynamic and efficient; and

    - Waste collection and disposal routing with GPS tracking for the fleet can also guarantee a higher level of resource utilisation, than reported in Chapter 2.

- **Hazardous waste** management in all the towns was not given explicit attention and pose grave danger to both the handlers and the disposal sites (ground water). EMCA (1999) outlines responsibilities and requirements which have not been fully embraced by the concerned administrators and the public. Guidelines for small and scattered hazardous waste sources as well as large industrial and commercial waste generators should be followed and compliance encouraged.

All the councils studied have room for SWM sectoral growth in the following areas:

- Consumer sensitisation, through education on waste separation, reuse and recycling;
- Encourage waste reduction by consumers. Encourage waste separation at source;
- Encourage waste paper-recycling, supported with the necessary equipment (paper balers, shredders, alligator shears etc.);
- Plastics recycling targeting input to meet the current NEMA stipulations on plastic production;

- Encouraging import of equipment to manufacture products from waste – includes roofing tiles, fencing posts etc; and
- Encouraging steel industries to increase recycling in their production. Investment in Bio-digesters to compost the organic waste.

All of these suggestions have a major job creation opportunity with the current informal waste recyclers and collectors forming SMEs.

4.16 Pollution of Ground Water

The absence of transfer facilities in the study towns compounded the management challenges. Most waste generators tend to use uncontrolled and unhygienic landfills as the predominant mode of disposal. To cut costs, many generators of solid wastes had taken to combustion at site, which caused air pollution problems. The bulk of these wastes contained plastics, which when burnt generate carcinogenic vinyl chloride monomers and dioxins. The generators and private waste collection firms, to reduce costs, dump the waste in illegal places since there was no effective monitoring system.

In the study towns there was no concrete pollution control for discharges and measures taken to prevent non-point source pollution on land and by inference to groundwater protection; practically any activity on the surface can have an effect on the quality of underground water. Being out of sight, it is not always apparent that damage has been, or is being, done to the groundwater resource and yet clean-up of groundwater pollution is expensive and may take hundreds of years.

The need to prevent groundwater pollution is therefore important because of the long term impact as well as the dependency on groundwater resources for many current and future drinking water supplies. The concept of groundwater pollution risk is based on the interaction between the potential pollution load and the vulnerability derived from the natural characteristics of the strata. All the study towns are located in catchments with solid waste dumps on critical groundwater recharge surfaces. Long term ground water pollution studies are thus necessary to:

- Identify the threats areas;
- Document the groundwater use in these hot spots;
- Monitor quality from hot spots; and
- Inform mitigation measures.

4.17 Leachate Quality

The quality of leachate depends on the prevailing atmospheric temperatures, elapsed time since the waste was deposited at the site, the composition of the waste and the availability of moisture and oxygen. On the other hand, the quantity of leachate depends on the precipitation falling on a waste, groundwater intrusions, moisture content of the waste and the site exposure. When any of these increases, the amount of leachate produced also increases. The reducing concentrations of the parameters can be attributed to natural attenuation. This is the process by which the concentration of leachate parameters is reduced to lower levels by natural processes (Lee, 2003). Attenuation of leachate occurs in two stages; in the first stage, soil in the initially unsaturated zone reacts with the leachate constituents and alters the leachate. This was the case in the samples taken from the test pits. The second stage of attenuation was mimicked in the long term laboratory study of the leachate quality. This would be the scenario in the ground water aquifer.

Natural attenuation can take place by the exchange of ions of one type by ions of another type without disturbing the mineral structure of the soil (known as the isomorphous substitution) (Lee, 2002). This mainly involves clay minerals. It may also take place when the microorganisms break down the organic debris. The resulting small sized organic debris infiltrates the pore spaces in the soil reducing permeability. This also increases the surface area onto which leachate constituents can be absorbed. The microorganisms can also lead to the production of complex organic compounds which react with leachate constituents. The leachate constituents may also get adsorbed on the surfaces of individual clay particles. This greatly reduces the total dissolved solids in the leachates. In the percolation process, the suspended and settle able constituents may get physically trapped by the random structure of the soil system.

From the leachate quality results the specific conductivity, BOD, COD, TDS and Iron modelled linearly, gave good results with r^2 values of 0.80, 0.74, 0.77, 0.88 and 0.75 respectively. The specific conductivity and TDS gave a better with the poly fit of r^2 values of 0.89 and 0.95 respectively. On the other hand the Turbidity and BOD exhibit better fit of r^2 values of 0.71 and 0.82 on the exponential model than linear fits. The other parameters tested in this study were not able to fit well in the three categories of fits, indicating the degree of variability in their biological and physical processes with time.

The heavy metal concentrations expressed the widest variation over the study period, though the linear trend (with r^2 for copper, 0.25; zinc, 0.26; Iron, 0.75) fitted better in the heavy metal concentration than the exponential fits

4.18 Leachate Migration Modelling

The samples analysed in the study revealed that the concentration of COD, BOD, total hardness, TDS, Chlorides, nitrates, iron and conductivity decreased with depth while those of DO, pH and alkalinity increased with depth. Presence of these pollution indicators is clear evidence that leachates can be a source of ground water pollution. Presence of these elements in ground water does not necessarily mean that it is polluted; pollution criteria will depend on the type of use of the water. The study further revealed that the level of pollution indicators in the leachate generated from solid waste is higher than that for the leachate after it infiltrates into the soil. This means that leachate washed directly to surface waters has higher potential to pollute than that percolating into the water bearing strata below the dumping site.

The results of the parameters investigated were tested in linear and exponential model with the exponential fits giving the best possible models. The best fits were with the Total hardness, alkalinity, BOD, DO and TDS with R2 values of 0.7, 0.64, 0.73, 0.65 and 0.72 respectively.

5. CONCLUSION AND RECOMMENDATIONS

5.1 *Conclusions*

The following conclusions can be made from the findings of this study.

5.1.1 The state of solid waste management

The key issues of efficient management of solid waste (Prevention awareness; Infrastructure Development; Collection/Recycling; and Regulation and enforcement) were noted to have been ignored or not prioritized and need to be considered in the ISWM plans for the urban centres.

5.1.2 The shortcomings of current solid waste management practices

The aspects identified for improved management included;

- Employing an appropriate waste management system in the urban centres;
- Adopting a multi disciplinary approach in solid waste management;
- Engaging the public in preventative and minimisation of waste wherever possible, and to use the facilities made available for safe collection and disposal of waste.
- The need to participate in source separation and recycling services provided, and remove household hazardous waste for safe disposal;
- The business and Industrial sectors need to implement best practice in relation to waste prevention, minimisation, recycling and disposal, and also to implement greener policies in-house. They will ensure that all waste leaving their premises has appropriate documentation and is handled by legal operators;
- The Packaging Industry (including re-pack), is responsible for improving packaging waste reduction, reusability and recyclability, as well as funding recycling and recovery of packaging;
- The role of private sector participation in solid waste management has a positive effect in the collection handling and disposal of waste in Kenya. The private waste sector will continue to expand collection and recycling services, provide innovative technologies and assist in the promotion of awareness on waste management. They are required to follow the waste hierarchy and waste plan objectives with improvements in data reporting and compliance; and

- Voluntary NGO & Community Groups should be encouraged to undertake waste projects at local level. Increased responsibility will be taken for waste management through community schemes with support from Local Authorities.

5.1.3 *Leachate composition*

- Municipal solid waste contains a variety of potentially significant chemical constituents that could be adverse to ground water quality.
- The pollution of environment by accumulation in uncollected waste and use of poor disposal techniques is real. The underlying consequence of this sorry state is the deterioration of the environment in the form of air, water and land pollution.
- Current leachate from uncollected waste may ultimately ingress into the underlying aquifers with negative impacts on the use of existing boreholes. This situation is critical in cases of shallow wells and unconfined aquifers.
- The pollution levels remain quite high and in most cases above the water quality standard as reflected in the presentation on Figure 5.1.

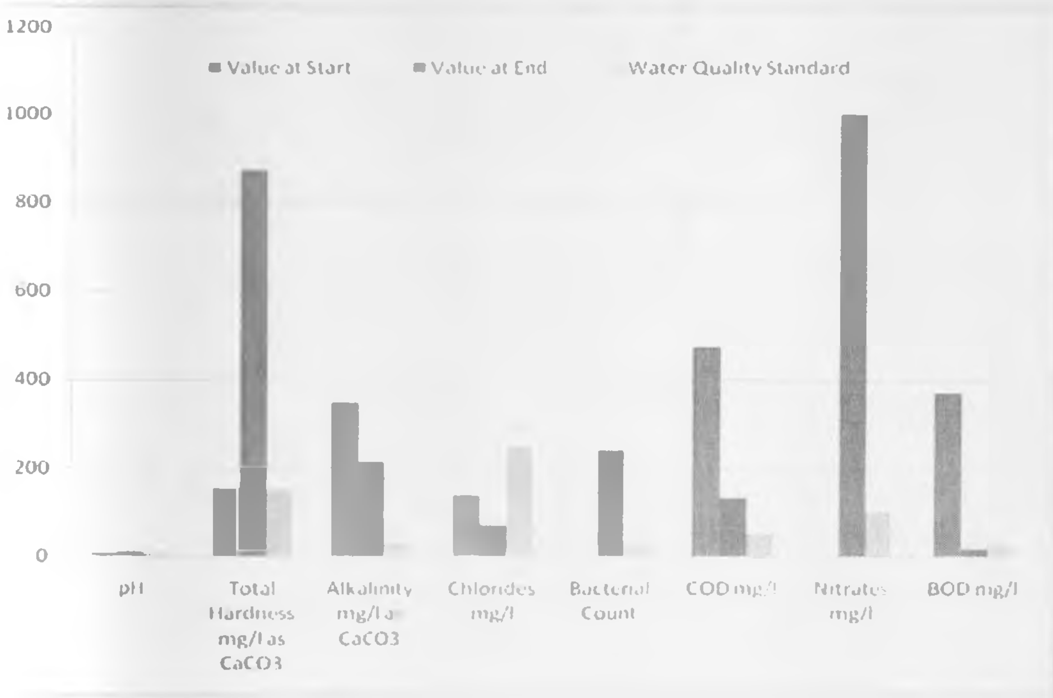


Figure 5.1: Comparative concentrations of pollutants in the leachate sampled over time

5.1.4 *Pollution migration*

- The leachate samples confirmed the migration of pollutants into the ground.

- There were reductions in the pollution concentrations with time and space, but the concentrations at the end of the study still pose health risks.
- Fitting of appropriate model tools can enable the prediction and understanding of the pollutant movement.

5.2 *Recommendations*

- There is need for the country to embrace an integrated solid waste management system to accommodate the array of stakeholder interests.
- Town Councils should work on ways of reducing the level of accumulation of uncollected waste.
- Modelling of ground water pollution should be done on a continues basis as the old waste sites have long term impact on the ground water use.
- Models used must be simple to use and interpret but dynamic enough to accommodate the variation in parameter behaviour.

REFERENCES

ADB (African Development Bank), (2002). Study on Solid Waste Management Options for Africa. Final Project Report.

American Public Health Association (APHA), (1985). Standard Methods for the Examination of Waste and Waste Water.

Arntzen J.W and Fidzani N.H. (2000). Human and Solid Waste Management in Urban Africa: A Case Study of Accra, Gaborone and Harare. Earthscan Publications, London.

Bartonnee, Carle R. (1997). Strategies for Improving Urban Waste Management: Lessons from a Decade of World Bank Lending. HazWaste World/Superfund XVII Conference, Washingtonne, D.C. (Accessed Nov 2006).
http://www.undp.org/pppue/pppueold/library/files/bartonne01.doc

Bear J., Tsang C.F. and Marsily G. (editors), (1993). Flow and Contaminant Transport in Fractured Rock. Academic Press Inc., San Diego, 560pp.

Bear, J. (1972). Dynamics of fluids in porous media, 1st edition. America. Elsvier Publishing Company.

Bernstein, J. (2004). Toolkit for Social Assessment and Public Participation in Municipal Solid Waste Management. Urban Environment Thematic Group, The World Bank, Washingtonne, D.C. (Accessed Nov 2006).
http://www.worldbank.org/urban/uswm/socialassesstoolkit.pdf

Bjornsson, G., Axelsson, G. and Flövenz, Ó.G. (1994). Feasibility study for the Thelamork low-temperature system in N-Iceland. Proceedings 19th Workshop on Geothermal Reservoir Engineering, Stanford University, U.S.A., Pg 5-13.

Bledsoe, B. P. and Watson, C. C., (2001). Effects of Urbanization on Channel Instability. Journal of the American Water Resources Association 37(2):255-270.

Boley, G. L. (1991). Refuse-Derived Fuel (RDF)—Quality Requirements for Firing in Utility, Industrial, or Dedicated Boilers. International Joint Power Generation Conference, San Diego, CA..

Carl Bro (2001). "Study of the Environmental Situation in Three Urban Centres". Consultants report, Ministry of Local Government, Kenya, July 2001.

Chandran N. (1993). Solid Waste Management in Emerging Industrialised Countries. http://www.eco-web.com/register/01060.html. (Accessed Nov 2006)

Coad, A. (1998). Solid Waste Management: Directory of English-Language Publications and Organisation for Low- and Middle Income Countries. SKAT, St. Gallen, Switzerland.

Cointreau, Sandra.(2004). "Sanitary Landfill Design and Siting Criteria." World Bank/Urban Infrastructure Note. The World Bank, Washingtonne, DC, USA. May 1996 and updated November 2004.

Cointreau, S.J. (1982). Environmental Disposal of Urban Solid Waste in Developing Countries. Urban Development Technical Paper No. 5, The World Bank, Washingtonne, DC, USA.

Cointreau-Levine, S. (1994), Private Sector Participation in Municipal Solid Waste Services in Developing Countries; Vol. 1: The Formal Sector. Urban Management Program Discussion Paper No. 13. UNDP/UNCHS/World Bank, Urban Management Program.

Cointreau-Levine, S., and A. Coad (2000). Private Sector Participation in Municipal Solid Waste Management: Guidance Pack (5 volumes). SKAT, St. Gallen, Switzerland. (Accessed Nov 2006) http://www.worldbank.org/urban/solid_wm/erm/CWGfolder/GuidancePackTOC.pdf

CPIS. (1993). Enterprises for the recycling and composting of municipal solid waste, conceptual work, vol. 1. Jakarta, Indonesia: Centre for Policy and Implementation Studies (CPIS) and Harvard Institute for International Development (HIID).

Dow, C. L. and DeWalle D. R. (2000). Trends in Evaporation and Bowen Ration on Urbanizing Watersheds in Eastern United States, Water Resources Research 36(7):1835-1843.

El-Kadi, A.I., Oloufa, A.A., Eltahan, A.A., Malik, H.U. (1994), Use of a geographic information system in site-specific groundwater modelling. Groundwater, v. 26, pp. 281-288. July 1994.

EMCA (1999), Environmental Management and Coordination Act Republic of Kenya, No. 8 of 1999. Government Printer. Nairobi, Kenya.

EMC (2007). Solid Waste Management: Issues and Challenges in Asia ©APO 2007, ISBN: 92-833-7058-9. Report of the APO Survey on Solid-Waste Management 2004–05 Edited by the Environmental Management Centre, Mumbai, India.

Environmental Resources Management (ERM)(2000) Review of Current Municipal Solid Waste Dump Sites in the Greater Colombo Area, Western Province, Sri Lanka, Colombo Environmental Improvement Project and Presidential Task Force on Solid Waste Management.

Environmental Resources Management (ERM) (2000). Strategic Planning Guide for Municipal Solid Waste Management. CD-ROM prepared for the World Bank, SCD and DFID, Waste-Aware, London. (Accessed Nov 2006).
http://www.worldbank.org/urban/solid_wm/erm/start_up.pdf

EPHC (2002). "Plastic Shopping Bags in Australia", National Plastic Bags Working Group Report to the National Packing Covenant Council, Environment Protection and Heritage Council, Australia.

Farid s.p.a (1985). Planning Commission on Nakuru Municipality Solid waste. Report by the Republic of Kenya and the Republic of Italy.

Fatta D., Papadopoulos A. and Loizidou M. (1999). A study on the landfill leachate and its impact on the groundwater quality. Environmental Geochemistry and Health, June 1999, vol. 21, no. 2, pp. 175-190(16). Kluwer Academic Publishers, the Netherlands.

Government of Kenya (January 2001), 1999 population and housing census- counting our people for development, Ministry of finance and Planning (Central Bureau of Statistics) Volume 1.

Government of Kenya, Local Government Act (CAP 265). Government Printer.

Government of Kenya, Public Health Act (CAP 242). Government Printer.

Grisak, G.E. and Pickens, J.F. (1980). Solute transport through fractured media. 1. The effect of matrix diffusion. Water Resource. Res., 16, 719-730.

Haukohl, J., Marxen, U., and T. Rand (2000), Municipal Solid Waste Incineration: Decision Maker's Guide. The World Bank, Washingtonne DC, USA.

Herrmann, R.F., Shann, J.F.(1997). Microbial Community Changes During the Composting of Municipal Solid Waste. Microb Ecol (1997) 33:78–85

Hoornweg, D., Thomas, L., Otten, L. (1999), Composting and Its Applicability in Developing Countries, Urban Waste Management, Working Paper Series #8. The World Bank, Washingtonne DC, USA. (Accessed Nov 2006)

http://wwwwds.worldbank.org/servlet/WDS_IBank_Servlet?pcont=details&eid =000009265_3970128111924

Humphrey L. (2002). Solid Waste Management in Nairobi, STAT-USA Market Research Reports 12/02/2002. U.S. & foreign commercial service and U.S. Department of State.

Inter-American Development Bank (IDB) (2003). "Economic Instruments for Solid Waste Management: Global Review and Applications for Latin America and the Caribbean", Environment Network regional policy dialogue study series, Inter-American Development Bank, Washingtonne DC, USA.

Ikiara M. M. (2002). "Access of Developing Country Urban Poor to Solid Waste Management (SWM) Services: Role and Potential of Public-Private Partnerships (PPPs)" Background Paper Prepared for The Micro Infrastructure Project: Infrastructure Service Entitlements and Urban Poverty in Kenya.

Ikiara, M.M., Karanja, A.M. and Davies T.C. (2004). "Collection, Transportation and Disposal of Urban Solid Waste in Nairobi", Baud, I., J. Post and C. Furedy (eds.), Solid Waste Management and Recycling: Actors, Partnerships and Policies in Hyderabad, India and Nairobi, Kenya, Chapter 4, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Integrated Waste Services Association (IWSA). (1993). The IWSA Municipal Waste Combustion Directory. 1993 Update of U.S. Plants.

International Solid Waste Association (ISWA) and UNEP (2002). Waste Management: Industry as a partner for sustainable development, ISWA and UNEP, United Kingdom.

JICA (1998). "The Study on Solid Waste Management in Nairobi City, Republic of Kenya", Japan International Cooperation Agency (JICA).

Johannessen, L., M. Dijkman, C. Bartonnee, D. Hanrahan, M. Boyer, C. Chandra.(2000) "Health Care Waste Management Guidance Note". Health, Nutrition, and Population, World Bank, Washingtonne, DC, May 2000.

John R. Holmes, (1983) - Practical Waste Management, Aylesbury, UK. Published by John Wiley and Sons.

Jones-Lee, A. and Lee, G.F. (2000), "Appropriate Use of MSW Leachate Recycling in Municipal Solid Waste Landfilling". Proceedings of Air and Waste Management Association 93rd National Annual Meeting, CD rom paper 00-455, Pittsburgh, PA, June 2000. http://www.gfredlee.com/nwqmcl.html. (Accessed Nov 2006)

Kim P. (1998). Community-Based Waste Management for Environmental Management and Income Generation in Low-Income Areas: A Case Study of Nairobi, Kenya in association with Mazingira Institute, Nairobi, Kenya.

Kleis, Heron and Dalager, Søren (2004) 100 Years of Waste Incineration in Denmark, A historical review of incineration in Denmark.

Klundert, A. van de & I. Lardinois (1995). Community and private (formal and informal) sector involvement in municipal solid waste management in developing countries. Background paper for the UMP Workshop in Ittingen 10-12 April, 1995.

Knox, A. (2005) Overview of incineration, An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW), University of Western Ontario, Canada.

Kwach, O.H. and Antoine, P. (2000), "Mukuru Recycling Centre", UNCHS (Habitat) Report, July 2000.

Lagerkvist, A. (1997). Landfill Dictionary. ISWA International.

Lee, G. F. and Jones-Lee, A., (2007). "Groundwater Quality Protection Issues," Report of G. Fred Lee & Associates, El Macero, CA, February 2007; Presented in part at CA/NV AWWA Fall Conference, Sacramento, CA, October (2007). (Accessed June 2008). http://www.gfredlee.com/Groundwater/GWProtectionIssues.pdf

Lee, G.F. (2003), "Comments on the California Integrated Waste Management Board Landfill Facility Compliance Study," Comments Submitted to CIWMB by G. Fred Lee & Associates, El Macero, CA, November (2003a). (Accessed Nov 2006) http://www.gfredlee.com/CIWMBcomments11-20-03.pdf.

Lee, G.F.(2002), "Solid Waste Management: USA Lined Landfilling Reliability," An invited submission for publication in Natural Resources Forum, a United Nations Journal, New York, NY, December (2002). (Accessed Nov 2006) http://www.gfredlee.com/UNpaper-landfills.pdf.

Lee G.F. and Lee, J. (1991) Landfill Solid and Hazardous Waste and Ground Water Quality Protection. (Accessed Nov 2006) http://www.scisoftware.com/publications/publications/publications.html.

Meyer, W. & R. Schertenleib (1992). Community participation in solid waste management. 18th WEDC Conference in Kathmandu, Nepal, pp. 132-135.

Ministry of Water Resources Management and Development (1996) Kenya Drinking Water Quality Standards.

Moyo, S.S. (1998). "Privatisation of Municipal Services in East Africa". UNCHS.

Mombasa Municipal Council, (1979 -1994). Cleansing Superintendent's Annual Reports.

Mufeed S. (2007). Solid Waste Management and its Impact on the Ground Water Systems in Parts of Delhi. Jamia Millia Islamia University.

Mulei, A. and Crispin Bokea (eds.). (1999). Micro and Small Enterprises in Kenya: Agenda for Improving the Policy Environment. The International Center for Economic Growth (ICEG), Nairobi.

Nas, P.J.M., Jaffe, R. (2004). Informal waste management - Shifting the focus from problem to potential. Environment, Development and Sustainability 6: 337–353.

Nairobi City Council, NCC (2001). "Policy on Private Sector Involvement in Solid Waste Management", Department of Environment, Nairobi City Council, Kenya.

National Center for Resource Recovery (NCRR) Inc. (1974) - Sanitary Landfill. Published by Lexingtonne Books.

Nelson, E.J. and Booth, D.B. (2002). Sediment Sources in an Urbanizing, Mixed Land-Use Watershed. Journal of Hydrology 264:51-68.

Nielsen, D.M (1993) Practical handbook of ground water monitoring. Lewis Publishers.

NEMA, (2001). Report on Ban of the use of Plastic Bags in Kenya.

Ongoro E.W (2003), Summary of Presentation by Ms. Elizabeth Wanyera Ongoro, Naivasha Report, UNCHS Habitat.

Oweis S.I. and Khera, R.P. (1990). Geotechnology of Waste Management, Butterworth and Co. Publishers.

Perla, M. (1997). Community Composting in Developing Countries. Biocycle, June, pp. 48-51.

Pfammatter, R., Schertenleib, R. (1996), Non-Governmental Refuse Collection in Low-Income Urban Areas. Lessons Learned from Selected Schemes in Asia, Africa and Latin America. SANDEC Report No. 1/96, EAWAG/SANDEC.

Qasim, S.R., and Chiang, W. (1994). Sanitary Landfill Leachate Generation, Control and Treatment. Technomic Publishing Company, Inc., Lancaster, PA. 1994.

Ramboll (2006). Waste to Energy in Denmark, Publication by the Danish Ministry of Energy, Denmark.

Ratemo M. and Hussein A. (2003).Selection, design and implementation of economic instruments in the Kenya Solid Waste Management Sector. Draft report by Government of Kenya and UNEP.

Rifai, H.S., Hendricks, L.A. Kilborn, K. and Bedient, P.B. (1993). A geographic information system (GIS) user interface for delineating wellhead protection areas. Ground Water. V. 31, No. 3, pp. 480-488.

Robinson, B.A. and Tester, J.W. (1984). Dispersed fluid flow in fractured reservoirs: An analysis of tracer-determined residence time distributions. J. Geophys. Res., 89, 10374-10384.

Rothenberger, S. et al. (2006). Decentralised Composting for Cities of Low and Middle-Income Countries - A User's Manual. Eawag/Sandec and Waste Concern.

Rotich K. Henry, Zhao Yongsheng, and Dong J. (2005). Municipal solid waste management challenges in developing countries – Kenyan Case Study. Waste Management. Volume 26, Issue 1, 2006, Pages 92-100.

Rouse, J. And Ali, M. (2008): Marketing Compost - A Guide for Compost Producers in Low and Middle-Income Countries. Eawag/Sandec.

Rukunga G.K., (2007), Environmental Health for East Africa, AMREF Rural Health Series No.16

Rushbrook PE, Pugh, MP. (2000), Solid Waste Landfills in Middle and Lower Income Countries: A Technical Guide to Planning, Design, and Operation. World Bank, Washingtonne, DC.

Rutherford, L.A., Mathews, S.L., Doe, K.G., Julien, G.R.J (2000) Aquatic Toxicity and Environmental Impact of Leachate Discharges from a Municipal Landfill. Water Quality Research Journal, Canada, 35, 1: 39-57.

Sangjun, I., Brannan, K.M. and Mostaghimi, S. (2003). Simulating Hydrologic and Water Quality Impacts in an Urbanizing Watershed. Journal of the American Water Resources Association (JAWRA) 39(6):1465-1479.Dec 2003.

Scheinberg, A. (2001a). Integrated Sustainable Waste Management – the Concepts. Tools for Decision-makers. Experiences from the Urban Waste Expertise Programme (1995-2001).

Scheinberg, A. (2001b). Micro and Small Enterprises in Integrated Sustainable Waste Management. Tools for Decision-makers. Experiences from the Urban Waste Expertise Program (1995-2001).

Scheinberg, A. (2001c). The Organic Waste Flow in Integrated Sustainable Waste Management. Tools for Decision-makers. Experiences from the Urban Waste Expertise Program (1995-2001).

Schübeler P., Wehrle K. and Christen J, (1996). Conceptual Framework for Municipal Solid Waste in low-income Countries. A UNDP/UNCHS report. Working Paper No 9.

Shah, K. L. (2000). Basics of Solid and Hazardous Waste Management Technology. Prentice Hall, Upper Saddle River, N.J.

Shamrukh, Mohamed, Corapcioglu, M, Hassona, Fayek A, (2001). Modelling the effect of chemical fertilizers on ground water quality in the Nile Valley aquifer, Egypt. Ground Water, Jan/Feb 2001.

Shamsi, S. and Ahmed R., (1996). Community Participation in Urban Waste Solid Management. Case Study Report for the Urban Waste Environmental Program.

SIDI (1993) Metropolitan Colombo Solid Waste Management Study, Secretariat for Infrastructure Development and Investment, Colombo, Sri Lanka.

Skitt, J. (1992). 1000 Terms in Solid Waste Management. ISWA International.

Srinivas H. (2008). Solid Waste Management: A Policy and Programme Matrix http://www.gdrc.org/uem/waste/swm-matrix.html. (Accessed June 2009).

Tchobanoglous, G., Theisen, H. and Vigil, S. (1993) Integrated Solid Waste Management Engineering Principles and Management Issues.McGraw Hill Publishers, New York.

United Nation Center for Human Settlements (UNCHS) (2009). Privatization of Municipal Services In East Africa: Governance Approach to Human Settlements Management. Report on Solid Waste, March 2009.

UNEP (2009a), Developing Integrated Solid Waste Management Plan - Training Manuals Volume 1: Waste Characterization and Quantification with Projections for Future.

UNEP (2009b), Developing Integrated Solid Waste Management Plan - Training Manuals Volume 2: Assessment of Current Waste Management System and Gaps therein.

UNEP (2009c), Developing Integrated Solid Waste Management Plan - Training Manuals Volume 3: Targets and Issues of Concern for ISWM.

UNEP (2009d), Developing Integrated Solid Waste Management Plan - Training Manuals Volume 4: ISWM Plan.

UNEP, IETC (2004), Waste Management Planning, an Environmentally Sound Approach for Sustainable Urban Waste Management – An Introductory Guide for Decision-makers. International Environmental Technology Center (IETC), United Nations Environment Program, Division of Technology, Industry and Economics.

UNEP, IETC (1996), International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management. International Environmental Technology Centre Japan. SMI (Distribution Services) Limited, Stevenage, Hertfordshire, SG1 4TP, England [B].

UNEP (2004). The Use of Economic Instruments in Environmental Policy: Opportunities and Challenges, Geneva.

UNEP (1976) - International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management. Technical Publication Series by UNEP International Environmental Technology Centre (IETC), issue No. 6

UNEP (2005). Selection, Design and Implementation of Economic Instruments in the Solid Waste Management Sector in Kenya: The Case of Plastic Bags

USEPA, (2006). Solid Waste Combustion/Incineration. (Accessed Nov 2006) http://www.epa.gov/epaoswer/non-hw/muncpl/landfill/sw_combst.htm

USEPA, (2006). Decision Makers Guide to Solid Waste Management, Vol II.

Van de Klundert, A., Anschütz, J. (2001). Integrated Sustainable Waste Management - the Concept. Tools for Decision-makers. Experiences from the Urban Waste Expertise Programme (1995-2001).

Wilson, D., Whiteman, A., Tormin, A. (2001), Strategic Planning Guide For Municipal Solid Waste Management; CD-ROM, DFID and The World Bank.

World Bank (2008), Improving Municipal Solid Waste Management in India - A Sourcebook for Policy Makers and Practitioners.

Zurbrügg, C. (2003), Solid Waste Management in Developing Countries: Solid waste management includes all activities that seek to minimise the health, environmental and aesthetic impacts of solid wastes, Eawag/Sandec.

GLOSSARY

Aerobic composting - a method of com-posting organic wastes using bacteria that need oxygen. This requires that the waste be exposed to air, either via turning or by forcing air through pipes that pass through the material.

Anaerobic digestion - a method of composting that does not require oxygen. This composting method produces methane. Also known as anaerobic composting.

Ash - the noncombustible solid by-products of incineration or other burning process.

Autoclaving - sterilization via a pressurized, high-temperature steam process.

Biodegradable material - any organic material that can be broken down by microorganisms into simpler, more stable com-pounds. Most organic wastes (e.g., food, paper) are biodegradable.

Bottom ash - relatively coarse, noncombustible, generally toxic residue of incin-eration that accumulates on the grate of a furnace.

Combustibles - burnable materials in the waste stream, including paper, plastics, wood, and food and garden wastes.

Compactor vehicle - a collection vehicle using high-power mechanical or hydraulic equipment to reduce the volume of solid waste.

Composite liner -a liner system for a land-fill consisting of an engineered soil layer and a synthetic sheet of material.

Compost - the material resulting from com posting. Compost, also called humus, is a soil conditioner and in some instances is used as a fertilizer.

Composting - biological decomposition of solid organic materials by bacteria, fungi, and other organisms into a soil-like product.

Construction and demolition debris - waste generated by construction and demolition of buildings, such as bricks, concrete, drywall, lumber, miscellaneous metal parts and sheets, packaging materials, etc.

Controlled dump - a planned landfill that incorporates to some extent some of the features of a sanitary landfill: siting with respect to hydrogeological suitability, grading, compaction in some cases, leachate control, partial gas management, regular (not usually daily) cover, access control, basic record-keeping, and controlled waste picking.

Energy recovery - the process of extracting useful energy from waste, typically from the heat produced by incineration or via methane gas from landfills.

Fly ash - the highly toxic particulate matter captured from the flue gas of an incinerator by the air pollution control system.

Garbage - in everyday usage, refuse in general. Some MSWM manuals use garbage to mean "food wastes," although this usage is not common.

Hazardous waste - waste that is reactive, toxic, corrosive, or otherwise dangerous to living things and/or the environment. Many industrial by-products are hazardous.

Heavy metals - metals of high atomic weight and density, such as mercury, lead, and cadmium, which are toxic to living organisms.

Household hazardous waste - products used in residences, such as paints and some cleaning compounds, that are toxic to living organisms and/or the environment.

Humus - the end product of composting, also called compost.

Integrated solid waste management - coordinated use of a set of waste management methods, each of which can play a role in an overall MSVVM plan.

Leachate - liquid (which may be partly produced by deromposition of organic matter) that has seeped through a landfill or a compost pile and has accumulated bacteria and other possibly harmful dissolved or suspended materials. If uncontrolled, leachate can contaminate both groundwater and surface water.

Materials recovery facility (MRF) - a facility for separating commingled recyclables by manual or mechanical means. Some MRFs are designed to separate recyclables from mixed MSW. MRFs then bale and market the recovered materials.

Methane - an odourless, colourless, flammable, explosive gas, CH,, produced by anaerobically decomposing MSW at landfills.

Microenterprise - a synonym for small-scale enterprise: a business, often family-based or a cooperative, that usually employs fewer than ten people and may operate "informally."

Mixed waste - unsorted materials that have been discarded into the waste stream.

Municipal solid waste - all solid waste generated in an area except industrial and agricultural wastes. Sometimes includes construction and demolition debris and other special wastes that may enter the municipal waste stream. Generally excludes hazardous wastes except to the extent that they enter the municipal waste stream. Sometimes defined to mean all solid wastes that a city authority accepts responsibility for managing in some way.

Municipal solid waste management - planning and implementation of systems to handle MSW.

Open dump - an unplanned "landfill" that incorporates few if any of the characteristics of a controlled landfill. There is typically no leachate control, no access control, no cover, no management, and many waste pickers.

Pollution - the contamination of soil, water, or the atmosphere by the discharge of waste or other offensive materials.

Putrescible - subject to decomposition or decay. Usually used in reference to food wastes and other organic wastes that decay quickly.

Pyrolysis - chemical decomposition of a substance by heat in the absence of oxygen, resulting in various hydrocarbon gases and carbon-like residue.

Recyclables - items that can be reprocessed into feedstock for new products. Common examples are paper, glass, aluminium, corrugated cardboard, and plastic containers.

Recycling - the process of transforming materials into raw materials for manufacturing new products, which may or may not be similar to the original product.

Refuse - a term often used interchangeably with solid waste.

Refuse-derived fuel (RDF) - fuel produced from MSW that has undergone processing. Processing can include separation of recyclables and noncombustible materials, shredding, size reduction, and pelletizing.

Resource recovery - the extraction and utilization of materials and energy from wastes.

Reuse - the use of a product more than once in its original form, for the same or a new purpose.

Sanitary landfill - an engineered method of disposing of solid waste on land, in a manner that meets most of the standard specifications, including sound siting, extensive site preparation, proper leachate and gas management and monitoring, compaction, daily and final cover, complete access control, and record-keeping.

Source reduction - the design, manufacture, acquisition, and reuse of materials so as to minimize the quantity and/or toxicity of waste produced.

Source separation - setting aside of compostable and recyclable materials from the waste stream before they are collected with other MSW, to facilitate reuse, recycling, and composting.

Special wastes - wastes that are ideally considered to be outside of the MSW stream, but which sometimes enter it and must often be dealt with by municipal authorities. These include household hazardous waste, medical waste, construction and demolition debris, war and earthquake debris, tires, oils, wet batteries, sewage sludge, human excreta, slaughterhouse waste, and industrial waste.

Transfer - the act of moving waste from a collection vehicle to a larger transport vehicle.

Transfer point - a designated point, often at the edge of a neighbourhood, where small collection vehicles transfer waste to larger vehicles for transport to disposal sites.

Transfer station - a major facility at which MSW from collection vehicles is consolidated into loads that are transported by larger trucks or other means to more distant final disposal facilities, typically landfills.

Waste characterization study - an analysis of samples from a waste stream to determine its composition.

Waste collector - a person employed by a local authority or a private firm to collect waste from residences, businesses, and community bins.

Waste dealer or Scavenger - a middleman who buys recyclable materials from waste generators and itinerant buyers and sells them, after sorting and some processing, to wholesale brokers or recycling industries.

Waste picker - a person who picks out recyclables from mixed waste wherever it may be temporarily accessible or disposed of.

Waste reduction - all means of reducing the amount of waste that is produced initially and that must be collected by solid waste authorities. This ranges from legislation and product design to local programs designed to keep recyclables and compostables out of the final waste stream.

Waste-to-energy (WTE) plant - a facility that uses solid waste materials (processed or raw) to produce energy. WTE plants include incinerators that produce steam for district heating or industrial use, or that generate electricity; they also include facilities that convert landfill gas to electricity.

Windrow - an elongated pile of aerobically composting materials that are turned periodically to expose the materials to oxygen and to control the temperature to promote biodegradation.

Yard waste - leaves, grass clippings, pruning, and other natural organic matter discarded from yards and gardens.

APPENDICES

Appendix A – Tables of Basic Solid Waste Data

Table A1: The solid waste composition variation for Mombasa over time.

Year	Population	Gen/day (Tonne/day)	Waste collected (Tonne/day)	% age collected	Kg/day/person
1979	400,000	160	160	100	0.4
1984	425,634	170	169	99.4	0.4
1988	500,000	229	143	62.4	0.46
1992	540,612	300	196	65.33	0.55
1994	600,000	449	192	42.8	0.75
1996	800,000	464	192	41.4	0.58

Projections by Norconsult — Source: cleansing superintendent annual reports

Table A2: The relative composition of solid wastes generated in Kenya.

Type of Waste	Test site	Nairobi	Mombasa	Kisumu	Nakuru	Eldoret
Food	35.7	51	75.8	54	75	74.7
Paper	8.8	18	5.6	4.5	6.5	6.1
Plastic	17.3	15	4	6.1	4.4	
Textiles	5.7	3	-	-	-	-
Glass and Metal	4.0	7	7.3	10.5	8.8	6.5
Other	28.6	6	7.3	24.9	5.1	12.7
Total	100	100	100	100	100	100

Source: Average of Field studies done between 1996 to 2002

Table A3: Nairobi's estimated total daily amounts of solid waste.

Year	1972		1975		1980		1988		1996	
Population	617,000		669,222		868,028		1,300,000		2,300,000	
	t/d	Kg/cap	t/d	Kg/cap	t/d	Kg/cap	t/d	Kg/cap	t/d	Kg/cap
Domestic	300	0.65	560	0.8	1100	1.0	2440	1.3	-	-
Industrial	70	-	120	-	200	-	550	-	-	-
Earth	100	-	110	-	130	-	160	-	-	-
Total	**470**	-	**790**	-	**1430**	-	**3110**	-	**1000**	-

Note: t/d = Tonnees per day, Kg/cap = Kilograms per capita

Source: Nairobi City Council, May 1996

Table A.4: Comparative collection efficiency of workers in urban centres.

	Country	No of Collection personnel	Volume Collected Tonne/day	Volume collected/worker Tonne/day
1	Egypt	400	227	0.5675
2	Indonesia	1424	3036	2.1320
3	Japan	6000	6883	1.1472
4	China	2083	1472	0.7067
5	Paraguay	140	426	3.0429
6	Nairobi	1339	71.8	0.0536
7	Mombasa	282	21.6	0.0766
8	Kisumu	60	12.9	0.2150
9	Nakuru	74	4.8	0.0649
10	Eldoret	55	15.8	0.2873

Appendix B –Table B1: Summary of Rainfall Data Used in the Simulations.

YEAR	2000		2001		2002		2003		2004		Averages		
Month	*Rainfall*	*Days of Rain*	*Rainfall*	*Days of Rain*	*Rainfall*	*Days of Rain*	*Rainfall*	*Days of Rain*	*Rainfall*	*Days of Rain*		*Rainfall*	*Days of Rain*
Jan	2.7	1	439.8	15	43	4	52	3	133.9	6	Jan	134.28	5.8
Feb	0	0	31.7	6	55.4	4	15.7	3	31.7	8	Feb	26.9	4.2
Mar	39.5	6	294.5	12	89.9	7	28.6	5	85.8	6	Mar	107.66	7.2
Apr	107.7	10	144.4	15	205.2	14	232.9	10	311.8	11	Apr	200.4	12
May	85.2	7	108.9	9	142.9	13	271.8	21	199.2	9	May	161.6	11.8
June	24.1	3	106.9	2	0.6	0	37	4	9.4	1	June	35.6	2
July	4.6	2	25.4	3	22.5	2	2.2	1	9.4	0	July	12.82	1.6
Aug	9.2	2	17.6	2	6.4	2	12.3	5	10.1	1	Aug	11.12	2.4
Sept	38.6	3	27.6	1	26.2	3	44.2	2	23.4	4	Sept	32	2.6
Oct	25.7	3	35.5	5	75.2	9	70.4	9	75.7	11	Oct	56.5	7.4
Nov	174.7	18	158.7	9	161.5	14	167.4	12	169.9	14	Nov	166.44	13.4
Dec	90.8	9	13.3	4	262.8	19	17.2	3	62	7	Dec	89.22	8.4

(Source: Metrological Department, Ministry of Environment)

Appendix C - Table C1: Input and Output Volumes of Water Applied to the Solid Waste

Date	Time	Sample height in cm	Water input in ml	Water output in ml
4/12/2002	8:00 AM	48	3700	
5/12/2002	8:00 AM	47.5	177	627
	8:30 AM	47.4		710
	2:00 PM	47		212
	2:30 PM	47		300
6/12/2002	8:00 AM	46.8	177	
	2:00 PM	46.5		29
	2:30 PM	46.5		88
7/12/2002	8:00 AM	46.3	177	
	2:00 PM	46.2		28
	2:30 PM	46.1		106
8/12/2002	8:00 AM	45.8	177	
	2:00 PM	45.6		33
	2:30 PM	45.6		112
9/12/2002	8:00 AM	45.5	177	
	2:00 PM	45.5		35
	2:30 PM	45.5		117
10/12/2002	8:00 AM	45.4	177	
	2:00 PM	45.4		36
	2:30 PM	45.4		119
11/12/2002	8:00 AM	45.3	177	
	2:00 PM	45.3		34
	2:30 PM	45.3		121
Σ			**4939**	**1673**
%mc				**66**
27/03/03	9:00 AM	44	280	
28/03/03	9:00 AM	43.9	280	0
	9:30 AM	43.9		45
	3:00 PM	43.7		0
	3:30 PM	43.7		57

Date	Time	Sample height in cm	Water input in ml	Water output in ml
29/03/03	9:00 AM	43.6	280	
	3:00 PM	43.6		50
	3:30 PM	43.6		140
30/03/03	9:00 AM	43.6	280	
	3:00 PM	43.6		95
	3:30 PM	43.6		120
31/03/03	9:00 AM	43.5	280	
	3:00 PM	43.5		175
	3:30 PM	43.5		200
1/4/2003	9:00 AM	43.4	280	
	3:00 PM	43.4		70
	3:30 PM	43.4		105
2/4/2003	9:00 AM	43.2	280	
	3:00 PM	43.2		55
	3:30 PM	43.2		150
3/4/2003	9:00 AM	43.2	280	
	3:00 PM	43.1		65
	3:30 PM	43.1		200
4/4/2003	9:00 AM	43.1	280	
	3:00 PM	43.1		10
	3:30 PM	43.1		90
5/4/2003	9:00 AM	43	280	
	3:00 PM	43		56
	3:30 PM	43		140
Σ			**2800**	**1683**
%mc				**40**
16/03/04	9.00 am	43	380	-
17/03/04	9.00 am	43	380	340
18/03/04	9.00 am	43	380	332
19/03/04	9.00 am	42.9	380	350
20/03/04	9.00 am	42.8	380	368
21/03/04	9.00 am	42.8	380	320

Date	Time	Sample height in cm	Water input in ml	Water output in ml
22/03/04	**9.00 am**	**42.7**	**380**	**370**
23/03/04	9.00 am	42.7	380	340
24/03/04	9.00 am	42.7	380	323
25/03/04	9.00 am	42.6	380	350
26/03/04	9.00 am	42.6	380	360
27/03/04	9.00 am	42.5	380	344
29/03/04	**9.00 am**	**42.5**	**380**	**370**
30/03/04	9.00 am	42.5	380	311
31/03/04	9.00 am	42.5	380	336
1/4/2004	9.00 am	42.4	380	368
2/4/2004	9.00 am	42.4	380	356
3/4/2004	9.00 am	42.4	380	329
4/4/2004	9.00 am	42.3	380	345
5/4/2004	**9.00 am**	**42.3**	**-**	**362**
TOTAL			**7220**	**6564**
%mc				**9**
8/4/2004	9.00 am	42.2	131	-
9/4/2004	9.00 am	42.1	131	126
10/4/2004	9.00 am	42.1	131	110
11/4/2004	9.00 am	42	131	128
12/4/2004	9.00 am	42	131	115
13/04/04	9.00 am	42	131	130
14/04/04	9.00 am	41.9	131	100
15/04/04	**9.00 am**	**41.7**	**131**	**98**
16/04/04	9.00 am	41.7	131	120
17/04/04	9.00 am	41.6	131	125
18/04/04	9.00 am	41.6	131	96
20/04/04	9.00 am	41.6	131	101
21/04/04	9.00 am	41.5	131	108
22/04/04	**9.00 am**	**41.4**	**131**	**118**
23/04/04	9.00 am	41.4	131	114
24/04/04	9.00 am	41.4	131	106

Date	Time	Sample height in cm	Water input in ml	Water output in ml
25/04/04	9.00 am	41.3	131	102
26/04/04	9.00 am	41.2	131	121
27/04/04	9.00 am	41.2	131	124
28/04/04	9.00 am	41.2	131	107
29/04/04	**9.00 am**	**41.1**	**131**	**103**
30/04/04	9.00 am	41.1	131	109
1/5/2004	9.00 am	41.1	131	111
2/5/2004	9.00 am	41	131	117
3/5/2004	9.00 am	41	131	120
4/5/2004	9.00 am	40.9	131	125
6/5/2004	**9.00 am**	**40.9**	-	**102**
TOTAL			**3406**	**2936**
%mc				**14**
20-01-06	8.00 AM	38.8	150	-
21-01-06	8.00 AM	38.8	150	-
22-01-06	8.00 AM	38.7	150	-
23-01-06	8.00 AM	38	150	-
24-01-06	8.00 AM	38	150	35
25-01-06	8.00 AM	38	150	203
26-01-06	8.00 AM	38	150	49
27-01-06	8.00 AM	38	150	225
28-01-06	8.00 AM	38	150	160
29-01-06	8.00 AM	38	150	135
30-01-06	8.00 AM	38	150	150
31-01-06	8.00 AM	38	150	160
1/2/2006	8.00 AM	38	150	165
TOTAL			**1950**	**1282**
%mc				**34**
20-02-06	8	38	84	75
21-02-06	8	37.9	84	76
22-02-06	8	37.9	84	80
23-02-06	8	37.9	84	95

Date	Time	Sample height in cm	Water input in ml	Water output in ml
24-02-06	8	37.9	84	52
25-02-06	8	37.9	84	80
26-02-06	8	37.9	84	71
27-02-06	8	37.8	84	74
28-02-06	8	37.9	84	85
1/3/2006	8	37.9	84	70
2/3/2006	8	37.9	84	64
3/3/2006	8	37.9	84	65
4/3/2006	8	37.9	84	66
5/3/2006	8	37.9	84	80
6/3/2006	8	37.9	84	75
7/3/2006	8	37.9	84	74
8/3/2006	8	37.9	84	76
TOTAL			**1428**	**1258**
%mc				**12**
29-03-06	8.00 AM	37.9	150	88
30-03-06	8.00 AM	37.9	150	85
31-03-06	8.00 AM	37.9	150	78
1/4/2006	8.00 AM	37.9	150	76
2/4/2006	8.00 AM	37.9	150	76
3/4/2006	8.00 AM	37.9	150	140
4/4/2006	8.00 AM	37.9	150	130
5/4/2006	8.00 AM	37.9	150	150
6/4/2006	8.00 AM	37.9	150	125
7/4/2006	8.00 AM	37.9	150	105
8/4/2006	8.00 AM	37.9	150	99
9/4/2006	8.00 AM	37.9	150	150
10/4/2006	8.00 AM	37.9	150	150
			1950	**1452**
%mc				**26**

Appendix D – Tables of parameter standard values

Table D1: USEPA, Ground and Drinking Water Contaminants and MCLs

Contaminant	MCLs in mg/l unless stated
Turbidity	n/a
Coliform	Zero
Viruses	Zero
Antimony	0.006
Arsenic	0.01
Asbestos	7
Barium	2
Cadmium	0.004
Chromium	0.1
Copper	1.3
Cyanide	0.015
Mercury	0.002
Nitrate	10
Selenium	0.002
Benzene	0.005
Aluminium	0.05 to 0.2
Chloride	250
Colour	15 colour units
Fluoride	2
Iron	0.3
Manganese	0.05
Odour	3 threshold odour number
pH	6.8 to 8.5
Silver	0.1
Sulphates	250
TDS	500
Zinc	5

(Source: www.epa.gov/safewater/mcl.html)

Appendix D – Tables of parameter standard values

Table D1: USEPA, Ground and Drinking Water Contaminants and MCLs

Contaminant	MCLs in mg/l unless stated
Turbidity	n/a
Coliform	Zero
Viruses	Zero
Antimony	0.006
Arsenic	0.01
Asbestos	7
Barium	2
Cadmium	0.004
Chromium	0.1
Copper	1.3
Cyanide	0.015
Mercury	0.002
Nitrate	10
Selenium	0.002
Benzene	0.005
Aluminium	0.05 to 0.2
Chloride	250
Colour	15 colour units
Fluoride	2
Iron	0.3
Manganese	0.05
Odour	3 threshold odour number
pH	6.8 to 8.5
Silver	0.1
Sulphates	250
TDS	500
Zinc	5

(Source: www.epa.gov/safewater/mcl.html)

Table D 2: Kenya Drinking Water Quality Standards (1999)

Substance Or Characteristic	Drinking Water	Bottled Drinking Water
Colour in true colour units, max	15	15
Taste and odour, max	Not offensive	Not offensive
Suspended matter, max	Nil	Nil
Turbidity in FTU, max	5	1
TDS in mg/l, max	1500	1500
Hardness as $CaCO_3$, max	500	500
Aluminium as Al mg/l, max	0.1	0.1
Chlorides as Cl^- mg/l max	250	250
Copper as cu, mg/l ,max	0.1	0.1
Iron as Fe, mg/l, max	0.3	0.3
Manganese as mn, mg/l, max	0.1	0.1
Sodium as Na, mg/l, max	200	200
Sulphate, mg/l, max	400	400
Zinc as Zn mg/l, max	5	5
pH	6.5 to 8.5	6.5 to 8.6
Magnesium as mg/l max	100	101
Chloride as Cl, mg/l, max	0.2 to 0.5	0.2 to 0.6
Calcium as Ca, mg/l, max	250	Nil
Ammonia(A) mg/l, max	0.5	0.5
Arsenic as As, mg/l, max	0.05	0.05
Cadmium as Cd, mg/l max	0.005	0.005
Lead as Pb, mg/l, max	0.05	0.05
Mercury(total as Hg), mg/l, max	0.001	0.001
Selenium as Se, mg/l max	0.01	0.01
Chromium as Cr,mg/l max	0.05	0.05
Cyanide as Cn mg/l, max	0.01	0.01
Phenolic substances, mg/l, max	0.002	0.002
Barium, Ba, mg/l, max	1	1
Nitrate as No3, mg/l	10	10
Fluoride as F, mg/l, max	1.5	1.5
Coliforrns in 250 ml	Shall be absent	Shall be absent

Appendix E – Table E.1: Parameter Concentrations with Depth

Parameter	Leachate from Solid Waste	Concentration with increase in depth												water std as 100%
		Hole A				Hole B				Hole C				
		0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2	
Total Hardness (% of std)	307	273	247	173	113	260	253	153	80	137	85	84	71	
Total Hardness (mg/l Caco3)	460	410	370	260	170	390	380	230	120	206	128	126	106	150
Total Alkalinity (% of std)	3920	2667	1500	1000	400	2533	1333	1167	333	540	547	353	293	
Total Alkalinity (mg/l)	1176	800	450	300	120	760	400	350	100	162	164	106	88	30
Chlorides (% of std)	140	120	100	76	44	100	84	60	36	24	16	7	5	
Chlorides (mg/l)	350	300	250	190	110	250	210	150	90	60	40	18	12	250
pH (% of std)	98	104	105	111	114	107	103	110	111	110	112	112	108	
pH	6.87	7.3	7.37	7.8	7.95	7.5	7.2	7.7	7.8	7.68	7.82	7.81	7.5	7

Parameter Concentrations with Depth (cont.)

Concentration with increase in depth

Parameter	Leachate from Solid Waste	Hole A				Hole B				Hole C				water std as 100%
		0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	
Conductivity	22,700	22000	15700	14200	10500	19800	16700	12300	9900	9600	6300	5900	5600	
Turbidity (% of std)		40	40	33	20	40	33	33	27	47	52	56	59	
Turbidity (FTU)		6	6	5	3	6	5	5	4	7	7.8	8.4	8.8	15
Iron (% of std)	1000	667	500	267	100	1000	267	267	167	12667	8333	7333	6667	
Iron (mg/l)	3	2	1.5	0.8	0.3	3	0.8	0.8	0.5	38	25	22	20	0.3
TDS(% of std)	1220	642	456	252	236	840	654	446	408	240	120	70	60	
TDS(mg/l)	6100	3210	2280	1260	1180	4200	3270	2230	2040	1200	600	350	300	500
DO (mg/l)	0	6.5	7.3	8.3	8.6	6.4	7.2	7.3	8.2	154	100	102	98	

Parameter Concentrations with Depth (cont.)

Parameter	Leachate from Solid Waste	Concentration with increase in depth												water std as 100%
		Hole A				Hole B				Hole C				
		0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	0.0-0.3m	0.3-0.6m	0.6-0.9m	0.9-1.2m	
COD (% of std)	1024	680	600	400	320	620	540	420	240	440	240	200	200	
COD (mg/l)	512	340	300	200	160	310	270	210	120	220	120	100	100	50
BOD (% of std)	1167	867	667	600	333	900	667	600	373	13	10	3	1	
BOD (mg/l)	350	260	200	180	100	270	200	180	112	4	3	1	0.4	30
Nitrates (% of std)	12	7	6	2	1	6	6	3	1	3	1	0	0	
Nitrates (mg/l)	12	7	6	2	1	6	6	3	0.8	2.5	1.1	0.4	0.1	100
Coliform count/100 ml	400	40	39	35	30	42	31	28	26	38	25	22	20	nil