THE DETERMINATION OF WATER QUALITY CHARACTERISTICS OF RUNOFF FOR CONSECUTIVE STORMS WITHIN NAIROBI'S CITY CENTRE WITH A VIEW TO PLANNING FOR ITS PROPER MANAGEMENT.

BY

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DECLARATION

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR ANY DEGREE IN ANY OTHER UNIVERSITY.

Abwao

ABWAO PETER (CANDIDATE)

THIS THESIS HAS BEEN SUBMITTED FOR EXAMINATION WITH MY APPROVAL AS THE UNIVERSITY SUPERVISOR.

DR. G.S. ONGWENYI

(SUPERVISOR) 3rd May, 1994.

DEDICATION

TO MY PARENTS, ISAYA AND ALFREDAH ABWAO, WHOSE SELFLESS SACRIFICE MADE IT POSSIBLE FOR ME TO ATTAIN UNIVERSITY EDUCATION.

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ABSTRACT

This study is on the determination of water quality characteristics of runoff for consecutive storms within Nairobi's city centre with a view to planning for its proper management. The geographical location of the city of Nairobi is one of the major causes of recurrent floods which have affected the city in the past one and a half decades. Increased surface runoff especially from the city centre is a result of reduced natural storage due to the artificial urban landscape. Management of this runoff which can take many forms, is an issue of great concern to urban planners and policy makers.

This study set out to investigate the volume of storm runoff generated from the city centre by a series of consecutive storms and to determine its chemical, physical and bacteriological qualities. The study also examined the variation of some of these quality parameters with each storm. A comparison of the water quality characteristics of runoff with guideline values for various uses (i.e domestic, agricultural and industrial) was then performed.

Both primary and secondary data were used in this study. The techniques of data analysis adopted in this study include Lloyd Davies formula, standard laboratory analytical procedures and techniques, graphical analysis and summary statistics. The random sampling procedure was used to pick the specific sampling pionts from where storm runoff samples were obtained. Ten samples were collected each from the selected sampling points within the first five minutes of each storm. composite samples were used inorder to minimize analysis costs.

From the analysis, it was found that the city centre, owing to its high runoff coefficient (0.9), generates large volumes of surface runoff during the rainy season. This vast quantities of storm runoff water from the city centre constitutes a potential resource which can be harnessed to supplement the existing water supply which is inadequate to meet the current demands.

Analytical results have revealed that the storm runoff water from the city centre is not as heavily contaminated as would have been expected. Furthermore, certain quality parameters such as cadmium, silver, molybdenum, nickel and selenium were not detected. Zinc, copper and mercury were only detected in the first three storm runoff samples indicating that the first few storms have a cleaning ("flush-off") effect on the city centre. The quality parameters which were found to exist in considerably high concentrations as to cause concern in the management of storm runoff water from the city centre are: iron, manganese, total suspended solids, total dissolved solids, oxygen demand, colour and turbidity. However, all these quality parameters can be regulated through conventional water treatment except oxygen demand (BOD and COD) which will require aeration. The bacteriological quality, though poor, can be improved through disinfection (e.g chlorination).

This study has recommended that the storm drainage system within the city centre should be redesigned in order to cope with the rapid changes taking place in this area which are continuously increasing the impervious area and that cleaning the drainage network especially during the dry spell should be enforced as a way of minimizing clogging of the drains. Various methods of detaining the runoff water have also been suggested.

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LIST OF ABBREVIATIONS

S No. - Storm Number

Ca - Calcium

Mg - Magnesium

Na - Sodium

K - Potassium

Fe - Iron

Mn - Manganese

Zn - Zinc

Cd - Cadmium

Pb - Lead

Cu - Copper

Ag - Siver

Mo - Molybdenum

Hg - Mercury

Cr - Chromium

Se - Selenium

Ni - Nickel

Cl - Chloride

F - Fluoride

No_2 - Nitrite

So_4 - Sulphate

Po_4 - Ortho Phosphate

TSS - Total Suspended Solids

Si - Silicon

FCD - Free Carbon Dioxide

PN - Permanganet Number

TH - Total Hardness

TA - Total Alkalinity

TDS - Total Dissolved Solids

COL - Colour

Tur - Turbidity

Con - Conductivity

MPN - Most Probable Number

LE - Less or Equal to

GE - Greater or Equal to

LT - Less Than

GT - Greater Than

IA - Impervious Area

RF - Rainfall

T.R.R.L - Transport Road Research Laboratory

* All units in Mg/l

* Except 1) Conductivity (μs/cm) and 2) Mercury (μg/l)

CHAPTER ONE: INTRODUCTION

1.1 STATEMENT OF THE RESEARCH PROBLEM

Among the developing countries, Kenya's population is known to be increasing rapidly. This is particularly true of the urban population. The rate of urbanization in kenya is very rapid and in the last two decades, the urban population has been growing within the range of 6 to 8% per annum (Obudho, 1986). This present growth trend of urban centres has resulted in an immeasurable number of urban environmental problems. For instance, such urban growth rates lead to strong changes in the natural space, with some damages to the components of the water cycle, and with grave consequences for the health and welfare of both the urban population and the rural population within the umland.

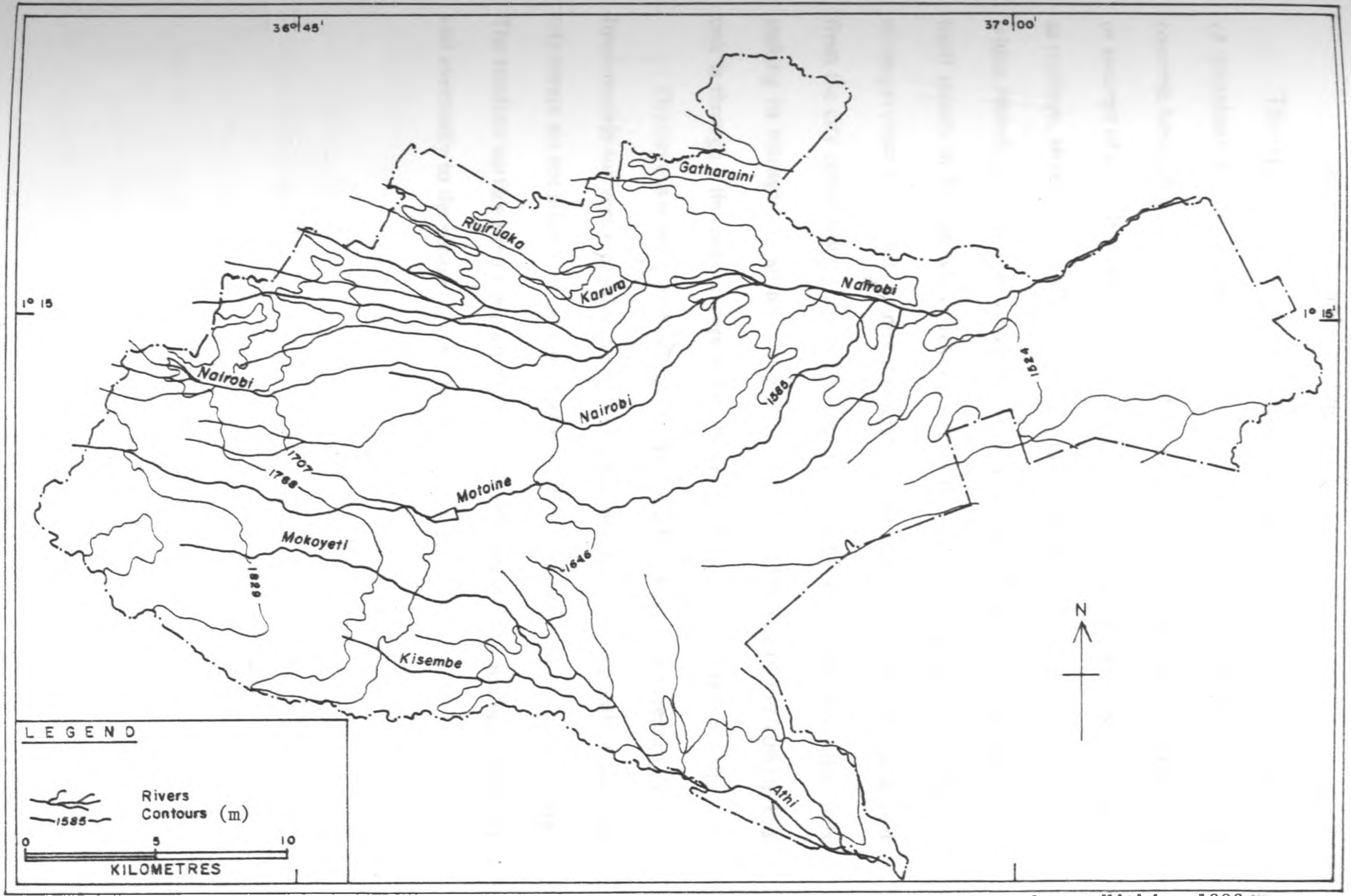
The major changes in the hydrological processes of urbanizing areas are due generally to three principal factors. These are:

i) Covering of parts of the urban catchment with impervious surfaces and compaction of the remaining non-paved surfaces which leads to low infiltration capacity and increased storm runoff thus aggravating the problem of flooding;

ii) Increased hydraulic conveyance of both natural and artificial drainage networks which are not adequately efficient to cope with the water flow resulting into bank bursts hence causing flooding which is destructive to human life and property; and

iii) The aspects of poor planning of land use for various urban functions for instance haphazard construction of buildings and roads without

Fig. 1 DRAINAGE PATTERN OF NAIROBI



Source. Kithia, 1992

adequate drainage facilities.

The replacement of pervious surfaces by impervious ones is a major process of urbanization. This is done by construction and paving of roads and by building concrete houses for various functions, thus in the place of forests, gardens, grasslands or swamps of pre-urban natural environment, we now have impervious surfaces such as rooftops, streets, side-walks and parking lots (Villiers, 1988). This is quite evident within Nairobi's city centre. This is where the process of urbanization has manifested itself mostly in the growth of relative size of the impervious areas and the decline of the pervious area. Consequently, tremendous amount of surface runoff is generated from the city centre (owing to reduced infiltration and high rainfall intensities) thus making its management an issue of great importance. One way of overcoming this task is through a thorough understanding of the quality of this surface runoff.

Drainage is a major problem in Nairobi and other major urban areas of Kenya. Impermeable surfaces created as a result of urban development especially within the city centre do not allow rain or other surface water to infiltrate and percolate easily. The resultant surface runoff is normally channelled to storm-water drainage channels and eventually to the receiving streams (fig. 1).

That which overtops the storm drains ends up flooding the streets before it drains away or evaporates. The consequent effect of this runoff to the receiving streams is two fold:

i) it overburdens the stream channels thus causing floods which are destructive to human life and property and;

ii) it pollutes the streams since it is channelled to storm-water drainage channels and eventually to these streams with all the dust, oil, grease and other wastes. Furthermore, this runoff often causes flooding within the city centre during heavy storms. It is therefore imperative that the quality of this surface runoff is well understood as a first major step in planning for its proper management.

The general principles regarding land use in urban areas of Kenya are enacted in the various policies namely: Building By-Laws, Local Government Act, Land planning Act, Land control Act and Public Health Act (Obudho, 1986). However, there have been uncoordinated and haphazard developments that do not comply with the planning regulations and guidelines especially in Nairobi city (Obudho *et al.*, 1990). This is quite evident within the city centre where various land use types have agglomerated without due concern for the consequences on the environment. This study is therefore an attempt to establish how the development of Nairobi's Central Business District has influenced the quality of surface runoff generated by a series of consecutive storms.

Urban runoff water contaminants can also originate from air pollutants (which are eventually washed down by rain), garbage and chemical additives in fuels

(Herfindahl and Kneese, 1965). However, these influences are understood only in principle and their magnitude is not well defined. With the existence of heavy traffic, garbage dumps, petrol stations, minor car repairs, heavy engineering constructions and other ordinary construction works within the city centre, it can be envisaged that the quality of surface runoff emanating from there is of great concern in terms of its management, hence the need for a study of this magnitude.

According to the American Council on Environmental Quality (1978), urban water runoff, a primary cause of water quality degradation in populous areas, contains sediments and toxic materials, particularly heavy metals which cause the most harm both to animals and plants; but bacteria, oxygen demanding materials, nutrients (organic and inorganic), oil and grease are also problematic. It is in this respect that this study has set out to find out the physical, chemical and bacteriological quality of surface runoff emanating from Nairobi's city centre to enable the institution of its proper management.

1.2 OBJECTIVES OF THE STUDY

The objective of this study was to determine the water quality characteristics of runoff for a series of consecutive storms within Nairobi's city centre with a view to planning for its proper management. Based on this broad objective, this study therefore examined the following specific objectives:

(i) estimation of the volume of runoff for each storm within the city centre during the short rains by use of Davies Lloyd formula.

(ii) determination of the chemical, physical, and bacteriological qualities of storm runoff from the city centre for each storm using standard laboratory analytical techniques.

(iii) establishment of how various quality parameters vary with each storm.

(iv) comparison of water quality characteristics of storm runoff with established water quality guidelines for various uses and to device strategies for water quality improvement and conservation.

This is a direct scientific study and therefore does not necesssarily require the use of hypothesis(es). However, the researcher is fully aware of the importance of hypothesis(es) in scientific investigation.

1.3 LITERATURE REVIEW

Written materials on urban runoff under different systems in various parts of Kenya, East Africa, Africa and the rest of the world are relevant to this study. A comprehensive bibliography has been adopted to assist future researchers in the same area of study. Not all references included are cited in the text. Some of the authors who have produced written material considered relevant to the present study are cited below:

Shaake (1970), argues that two most important of the numerous environmental problems resulting from the urbanization process are pollution and flooding. He gives an evaluation of urbanization factors intensifying flooding i.e increased impervious, compacted area, poor design and maintenance of drainage network. He does not consider how pollution affects the quality of flood water and the possibilities of managing this water based on its quality characteristics.

Urquidi (1968) notes that the urban growth, occurring at a considerably higher rate than overall population growth is rapidly gaining importance in the list of unsolved and perhaps insoluble, social and economic problems of the developing countries. However, this author overlooks environmental problems currently facing urban centres in developing countries; storm-water runoff management being one of them.

Chorley (1969) construes that towns and cities with their considerable areas of man-made impermeability alternating with cultivated gardens and open spaces as presenting special problems of disposal of rain water (storm-water) which historically has been linked with the disposal of domestic sewage and industrial effluent. However, Chorley limits his discussion to sewage and storm-water disposal in combined sewer systems which are too expensive to operate and maintain especially in developing countries such as Kenya. Furthermore he does not consider the quality of this storm runoff which is important in enabling various storm-water disposal alternatives to be considered.

Ward (1967) argues that in urban areas, over large infiltration capacity is considerably reduced; falling precipitation is caught by rooftops and roads, and is passed through drainage systems (where they exist) which have been designed to dispose it off into nearby streams as rapidly as possible with the result that immediately below large urban areas, there tends to be a marked and rapid build up of surface runoff which is accentuated where slopes are steep. Like most of the authors cited in this review, Ward considers flood water as a hazard by overemphasizing its physical damage.He does not look at the quality of this water and the possibility of harnessing it or safe disposal.

According to Mather (1923), water quality changes with urbanization. Not only does the sediment load of rivers increase as runoff from construction areas increases, but also pollution from city streets, industrial operations, domestic sewage treatment plants, as well as cesspools or septic tanks will all add to the pollution load. It is with this perspective that this study has set out to investigate water quality characteristics of storm runoff from the city centre with a view to planning for its proper management.

Biswas and Arar (1988) contend that urban storm runoff constitute the most important potential source of marginal quality water. This is more so in large cities of developing countries where recurrent shortages of potable or good quality water is a persistent problem. However, for the case of Nairobi city, this potential resource has not been given due attention and therefore study a study of this magnitude is inevitable.

Urban development is the most dramatic change of land use and the accompanying construction can greatly increase sediment yield (Wolman, 1964). For example, Walling and Gregory (1970) demonstrated that the annual sediment yield of some 200 tonnes/km^2 from a small agricultural catchment was increased by a factor of four after urbanization. Given heavy construction works currently going on within the city centre, it is of paramount importance that the quantity of sediments in surface runoff is established since it has a significant influence on the efficiency of the drainage system within the city and also contributes greatly to the sediment load of rivers draining the Nairobi area.

McPherson and Mangan (1974) noted that most studies of urban basins seem to be dealing mainly with contrasts in quantity rather than quality of runoff. This is very true of Nairobi city where even the few studies that have been done on the quality of runoff have tended to concentrate on the quality of water within river channels. The quality of surface runoff emanating from such land use types as the central business district (which contributes an immense amount of runoff) has not been given the concern it deserves.

Linsley, Kohler and Paulhus (1988) contends that urban storm drainage is flood control oriented. According to these authors, in urban drainage, the classical solution is channel improvement: either improved ditches or buried storm drains and in some instances small reservoirs are useful for reducing local floods. However, apart from physical damage of urban flooding, it is important to appreciate the quality of flood water since it has an influence on the entire hydrological system. Furthermore, the quality of flood water is important when considering its management e.g safe disposal or harnessing.

Sax (1974) notes that environmental contamination is an inevitable consequence of the activities of man and a natural phenomenon as well. He adds further that whether in an industrial society or in agricultural society, placing waste material, partially used consumer goods and other by-products into the environment by man has characterized his activities. This study therefore aims at revealing how this scenario has affected the quality of urban storm water runoff.

Lindh (1972), after considering the disruption of the hydrological cycle caused by towns and cities, foresaw the supply of water to densely populated areas as one of the major problems for the future; a problem few planners took into account.

Today, this problem exists in Nairobi city where most water problems are solved by the transfer of water; in the future, re-use of water, recirculation of water and harnessing of flood water must be employed to meet the increasing urban demand. This study therefore constitutes a steppingstone towards this strategy.

Alvarez and Sanchez (1980), in their study of the 80km² Duluvo creek Basin of Port Allegre, Brazil, considered the result of increases of impermeable area on storm-water discharge. They concluded that the first phase of urbanization (upto 20% imperviousness) are responsible for the biggest change in hydrological regime whereas the development of previously urbanised areas creates less dramatic changes, although they may be equally dangerous since the increase in volume of runoff will overload the drainage network which are generally old and under planned. Even though these authors recognise the large volume of runoff associated with urbanization process, they have down played the management issues (e.g. the conservation of storm-water) which can better be considered when the quality of the surface runoff is well understood.

The United Nations Development Programme report (1990) states that the sheer size of many urban centres in developing countries and their runaway growth rates makes the waste situation alarming. For instance, various urban land use types produce different kinds of wastes, some of which are not easy to dispose as is evidenced by heaps of wastes in the city centre. Some of these wastes can and do get washed by rain water causing toxic runoffs into the neighbourhoods and the surface water networks which eventually drain into large water bodies. Hence, there is need for a thorough assessment of the quality of runoff water from urban centres.

Sada and Oguntoyinbo (1981) consider air, Land and water pollution as having started with the first man on earth. Since then, pollution has been growing in extent and pungency. The greater the concentration of people in one area, the greater the amount of pollution, and the greater the amount of sophistication of a society, the more intricate and poignant its pollution. This is why the problem of pollution is getting more serious and complex in urban areas than in villages. For Nairobi, like other large cities, pollution emanating from any given land use type will be manifest in the resultant storm runoff. Given the concentration of urban activities in Nairobi's central business district and the large amount of runoff generated, an understanding of the quality of this runoff is imperative for its proper management.

Akintola (1981) asserts that in most parts of the world, this century has been a period of urbanization and population concentration has led to the creation of new ecosystems. The process of city establishment and growth leads to irretrievable changes in the physical landscape. As a result, the feedbacks come so suddenly that mans existing understanding of watershed processes has not been able provide answers to the numerous urban environmental problems. Within Nairobi's city centre, storm-water drainage is an important environmental problem. This study will therefore provide an insight into the management aspect of this storm-water drainage.

Bouvier (1988) gave a report of a three year study of twenty four urban watersheds in six metropolitan areas of West Africa (Niamey, Ougadougou, Bamako, Lome, Cotonou and Abidjan). His result imply that in any meaningful evaluation of storm runoff volumes and peaks in African urban centres, all types of surfaces should be carefully considered as sources of runoff contribution. However, apart from runoff volumes and peaks, there is need to evaluate the quality of storm runoff for the purposes of devising proper management options.

Krhoda (1986) examines the sediment sources, processes of erosion and the possible methods of dealing with sediment control in the city of Nairobi and especially the use of government legislation. He singles out sedimentation in urban areas as a factor aggravating the magnitude of flooding through silting of streams and drainage ways, clogging of storm inlets and blocking of drains as a result of mass movement. However, in a systematic investigation into storm-water management in urban areas, it is important to incorporate all other possible storm runoff contaminants since they have a profound effect on the entire hydrological regime.

Krhoda (1987) considers the problems of urban storm drainage in Nairobi and identifies three major causes of floods namely (i) the tropical thunderstorms that are so frequent in the area (ii) the geographical location of the city and (iii) poor drainage design and maintenance. However, a part from discussing the impact of these causes, this author does not recognise the importance of understanding the quality of the flood water as one way of giving an insight into its management.

1.4 OPERATIONAL DEFINITIONS

The following are some of operational definitions and concepts used in this study:

Urbanization:

Urbanization refers to the movement of people from rural areas to urban where they engage in primarily non-rural occupations or functions and also a change in their life style from rural to urban with its associated values, attitudes and behaviour.

An urban centre:

A settlement with more than 2000 inhabitants mainly engaged in non-agricultural activities thus concentrating on other commercial activities.

A city:

The term city is essentially a political designation referring to a place governed by some kind of administrative body or organization. Thus the term in itself has no size connotation, although normally a city is larger than a town or village.

Central Business District:

For the purposes of this study, this term is used interchangeably with the term 'city centre'. The term refers to that part of an urban area in which there is the greatest concentration of financial and professional services, major retail outlets, and is the focus of transport lines, where land use is most dense and land values are at their highest.

Surface runoff:

Surface runoff comprises the gravity movement of water over the surface of the earth.

Storm:

Any violent disturbance of the atmosphere resulting into rainfall.

Storm-water Drainage:

Storm-water drainage is concerned with the measures taken to control the flow of surface, by collecting and transporting it through suitably designed conduits, away from developed areas, where it would otherwise cause flooding, thereby impairing the safety, health and well being of the public and disrupting essential public and commercial services.

Water quality:

The term 'quality' as applied to water embraces the combined physical, chemical and biological characteristics of water.

Pollution:

The term pollution is used to denote intentional or unintentional contamination by foreign substances of either water, air or land media by such quantities of substances so as to render that resource unsuitable for a specific or any other established use.

Toxic material:

Toxic materials are those with the ability to cause damage to living tissues, impairment of central nervous system, severe illness, or in some cases, death, when ingested, inhaled, or absorbed by the skin.

Infiltration:

This is the process whereby water soaks into, or is absorbed by the soil

Percolation:

Percolation is the downward flow of water through the zones of aeration towards the water table.

Impermeability:

This refers to the property of soil or rock that does not permit the passage of fluids, especially of water.

Evaporation:

The process by which water is changed from a liquid to a gas.

Hydrological cycle:

This refers to the continuous circulation of water from the earth's surface to the atmosphere and back to the earth's surface, brought about by evaporation from the water and the land and by evapotranspiration from vegetation, giving rise to water vapour in the atmosphere which condenses, forms clouds, and returns to the earth's surface as precipitation, swelling the oceans, seas, lakes and rivers, or becoming ground water.

A guideline value:

This is a prescribed limit of quality which describes the desirable value of a substance in water taking into account its aesthetic and health related values.

Water quality standards:

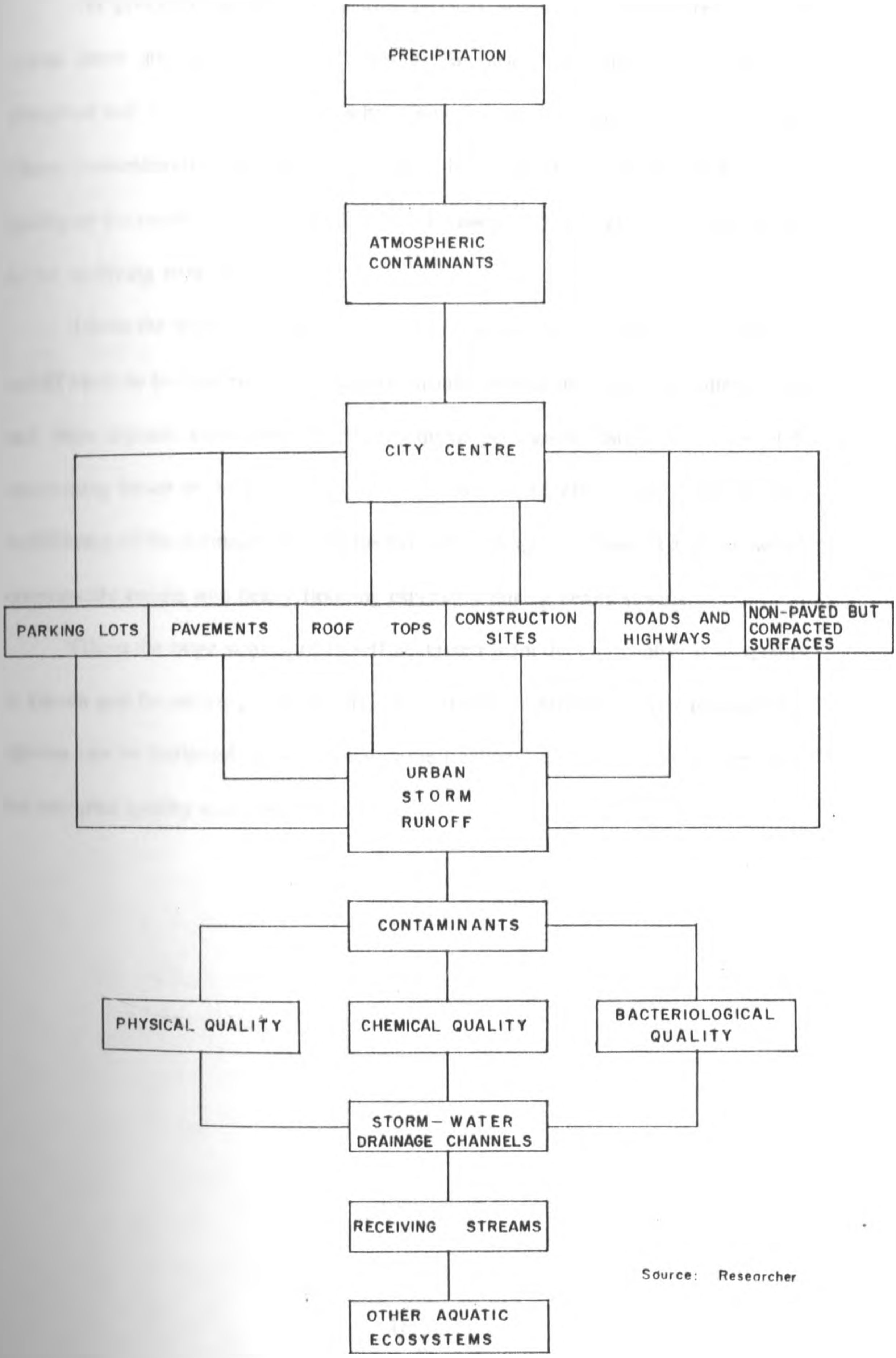
This is a legally prescribed limit for pollution or quality which is established under statutory authority (the law).

1.5 CONCEPTUAL FRAMEWORK

The conceptual model (fig. 2) gives a derived framework of the research problem. The model structurally attempts to present a theoretical impression of the effect of some attributes of the city centre on the quality of storm runoff.

Precipitation contains dissolved substances largely determined by the air quality and wind patterns of the region. In areas where there is heavy air pollution such as over the city of Nairobi, the atmosphere is a complex chemical system controlled by dozens of chemical and photochemical transformations. Therefore precipitation falling over the city centre accumulates some contaminants which are bound to be reflected in surface runoff.

Fig 2 : A CONCEPTUAL MODEL ILLUSTRATING SOME ASPECTS OF RUNOFF WATER QUALITY FROM THE CITY CENTRE



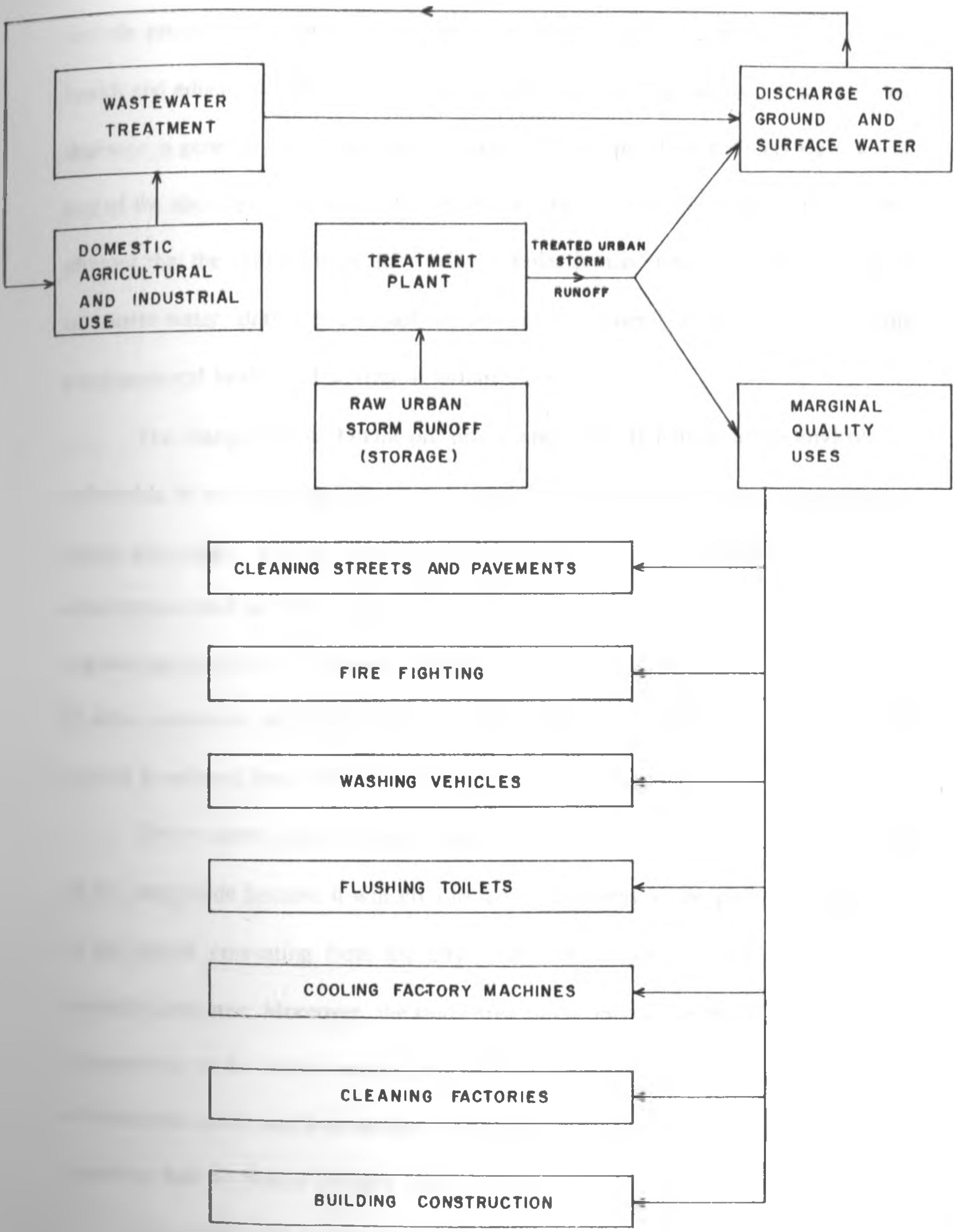
Source: Researcher

As precipitation falls on various surfaces within the city centre, it moves across them and in the process transports a variety of contaminants including dissolved and suspended materials which have been picked along the path of flow. These contaminants consequently influence the physical, chemical and biological quality of the resultant surface runoff which is channelled through storm-water drains to the receiving streams.

Given the immense area which is impervious within the city centre, the storm runoff tends to be conveyed very quickly through the drains to the receiving streams and other aquatic ecosystems with consequent ecological disruptions. The main intervening factor to the quick flow of runoff within the city centre is the inherent inefficiency of the drainage channels (as a result of clogging by wastes and silt) which occasionally results into heavy flooding especially during heavy storms.

Given the large volume of runoff generated from the city centre; if its quality is known and the efficiency of the drainage network improved, proper management options can be instituted. Among them is the treatment and harnessing of the water for marginal quality uses (fig. 3).

Fig 3 : A MODEL ILLUSTRATING INTERCONNECTION BETWEEN URBAN STORM RUNOFF, TREATMENT AND USE/SAFE DISPOSAL



Source: Researcher

1.6 JUSTIFICATION OF THE STUDY

In developing countries, Kenya included, the priorities for urban development include provision for food, water, shelter, clothing, domestic sanitation, transport, health and education. Urban hydrology is considered a marginal discipline and urban drainage is generally not taken into consideration except when it affects significantly any of the above priority needs. However, as urbanization intensifies, it is becoming obvious that the attainment of these primary objectives is closely linked to the quality of storm-water drainage as part of the more general problems of flooding, environmental health and welfare in urban areas.

The changes induced in the pre-urban landscape often make urban environment vulnerable to pollution and drainage hazards which are the two major concerns of urban hydrology. For a long time, the solution to the problems arising from urbanization such as water supply and drainage protection were considered as purely engineering problems. The result of the attitude is that scientific evaluation of impacts of urbanization on the hydrological systems especially the quality of surface runoff is least developed hence the need for a study of this magnitude.

Urban storm runoff being a major environmental factor necessitates a study of this magnitude because it will go a long way in assessing the pollution magnitude of the runoff emanating from the city centre with a view to suggesting possible remedial measures. Moreover, the study area can be envisaged as the most urbanized environment in the whole country and will therefore provide a fairly good indicator of what other small and intermediate urban centres are bound to experience with time assuming that no radical changes will occur in urban planning policies.

The world wide process of urbanization and industrialization and deficiencies in the knowledge of urban hydrological processes and its implications for adequate water resources planning and management have led to international action and co-operation since 1970 (McNamara, 1985). Within the framework of the International Hydrological Decade (IHD) of 1965 to 1974 and its successor the International Hydrological Programme (IHP) of 1975 to 1985, UNESCO took the initiative to promote several activities such as symposia and workshops and to prepare state-of-the art reports and manuals on urban hydrological processes. However, for developing countries such as kenya, this initiative has only partially succeeded in arousing the interest of decision makers , technicians and researchers in the hydrology of their urban environments hence the need for a study of this nature.

1.7 SCOPE AND LIMITATIONS OF THE STUDY

1.7.1 SCOPE

This study is principally a geographical inquiry into the water quality characteristics of storm runoff for consecutive storms within Nairobi's city centre with a view to planning for its proper management. It is based on primary data collected during a field study of the area for the period 1991. The primary data collected focuses mainly on the physical, chemical and bacteriological quality of storm runoff for a series of storms during the short rains. The study serves to identify major storm runoff quality parameters and how they vary with a series of consecutive storms.

1.7.2 LIMITATIONS

This study is based in Nairobi city and specifically the city centre. Its major concern is on the physical, chemical and bacteriological characteristics of storm runoff generated within the city centre by a series of storms during the 1991 short rains. Though a study of this nature based on the whole city is possible, it was not plausible given the time limit and resources available for the research.

It is also not feasible in a study of this type to discuss all the constituents and properties of water. A great many constituents are associated only with those waters which pass through very unusual geological formations or receive wastes from various industrial processes. In addition, a number of properties have little or no effect on water quality. Therefore only those constituents and properties which significantly affect the application of water to beneficial uses and are likely to constitute storm runoff generated from the city centre are considered.

1.8 SUMMARY OF CHAPTERS

The study is divided into five chapters. Chapters one and two are introductory chapters in which the study problem and the background of the study area are presented. The research methodology is discussed in chapter three. Chapter four is concerned with data analysis, presentation and discussion. Chapter five gives a summary of findings, conclusions and recommendations.

CHAPTER TWO: BACKGROUND TO THE STUDY AREA

2.1 LOCATION AND SIZE

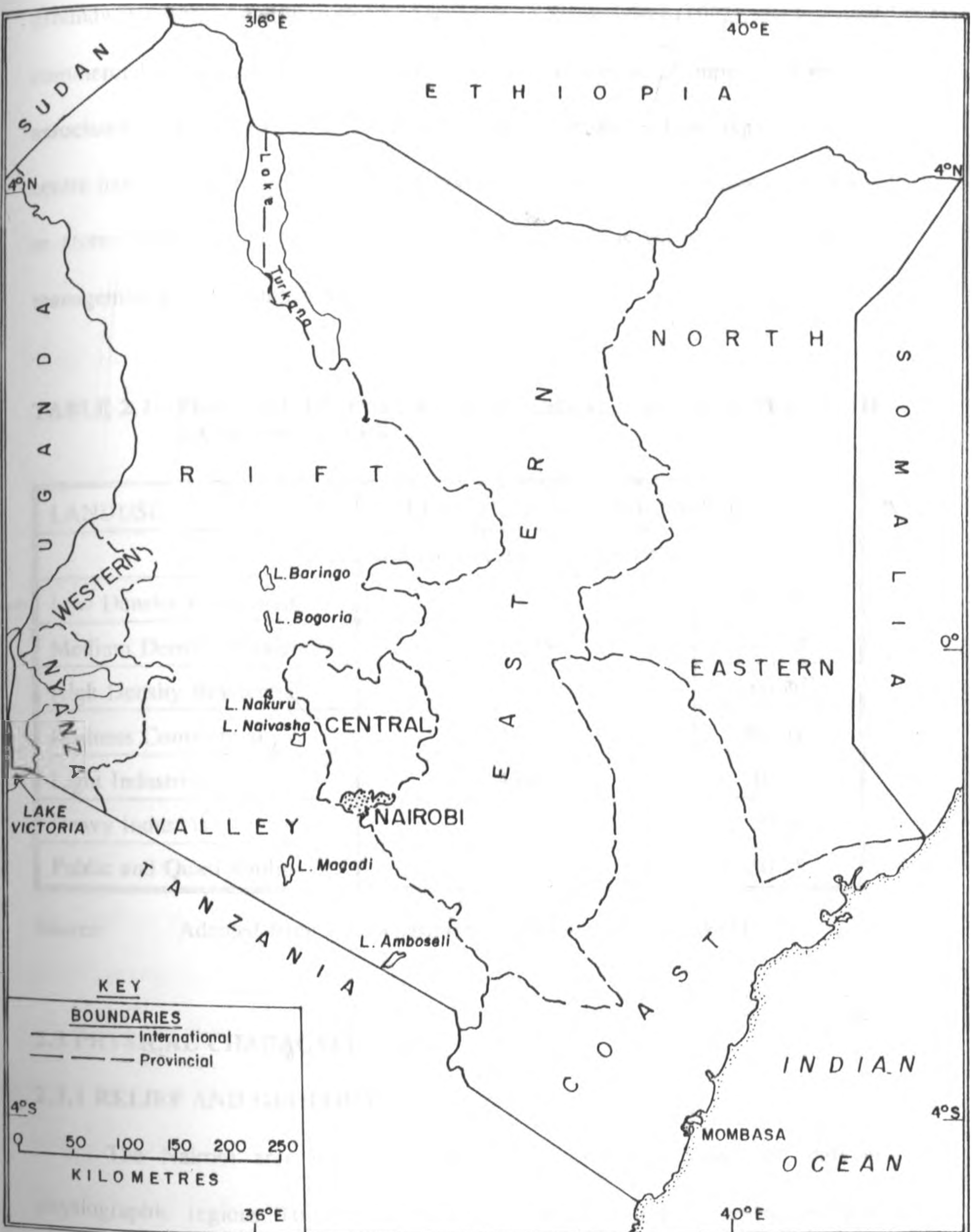
The present study was conducted in Nairobi city. Nairobi city is located in the southern end of the agricultural heartland of Kenya, 1° 19' South of the equator and 36° 59' East of the prime meridian (fig. 4). The administrative boundary covers an area of 690 square kilometres. It is by far the smallest administrative province in Kenya but yet the most important in terms of the activities and functions it performs.

2.2 URBAN DEVELOPMENT AND THE HYDROLOGICAL CYCLE

An urban development usually starts with the removal of vegetation from an area. Vegetation facilitates a continuous downward movement of water through infiltration process. In addition, vegetation protects the soil from sealing under the impoundments of raindrops. Vegetation cover also retains some water on the leaves and branches in the form of interception storage, reduces the impact of rain drops from causing erosion, provides the litter that has a "blotter effect" of rain water and supplies humus to the soil when plants' leaves decay.

The city of Nairobi used to have abundant swamps, ill-drained river valleys and flood prone regions (Krhoda, 1991). Grading and filling eliminated these swamps and have reduced the natural catchment storage (especially in the city centre where over 90% of the surface is concrete), increased surface runoff and decreased

Fig.4 LOCATION OF STUDY AREA



groundwater storage and base flows. According to Stankowiski (1972), the business commercial area of any major city has the largest percentage of impervious surface associated with it (Table 2.1). Therefore of all the urban land use types , the city centre has the largest percentage of impervious area and thus is a major contributor to storm runoff. If the quality of this storm runoff is established, its proper management can be planned for.

TABLE 2.1: PERCENT OF IMPERVIOUS SURFACE ASSOCIATED WITH LAND USE TYPES

LANDUSE	PERCENT OF SOIL IMPERVIOUSNESS	
	Soil conservation service 1971	Stankowski
Low Density Residential	20-30	12-40
Medium Density Residential	25-35	30-60
High Density Residential	30-40	60-80
Business Commercial	40-90	80-100
Light Industrial	45-65	40-70
Heavy Industrial	50-70	70-90
Public and Quasi Public	-	50-75

Source: Adapted from US Department (1972) and Stankowski (1972)

2.3 PHYSICAL CHARACTERISTICS

2.3.1 RELIEF AND GEOLOGY

The Nairobi area can be divided into two distinct and well defined physiographic regions. To the west and the is a hilly and broken country generally known as the Kikuyu plateau. The land falls from an altitude of 1905 metres above sea level at the plateau to 1676 metres above sea level at the city centre. Under natural conditions, this would imply that the storm runoff generated from the eastern flanks of the kikuyu plateau would flow towards the area occupied by the city centre. However, this does not occur due to the artificial nature of the landscape within the city brought about by various urbanization processes. The plateau surface is covered with a lava discharge known as the Nairobi trachyte.

To the east and south of the city are the flat and featureless Athi-Kapiti plains whose altitude above sea level is approximately 1500 metres. Therefore most of the storm runoff emanating from the city centre flows towards the Athi-Kapiti plains and eventually to the tributary streams of the Athi river. This is however significantly influenced by the presence of artificial storm drains within the city centre. The parent rocks of these plains are successive layers of the Nairobi and Kapiti phonolites both of which are volcanic in origin. They have been weathered down to produce the heavy black cotton soil of the plains.

2.3.2 NATURAL AND ARTIFICIAL DRAINAGE

The numerous tributary streams of the Athi River have curved deep and steep sided valleys on the kikuyu plateau in the West-North-West and East-South-East directions (fig. 1). The valleys pass out into the plains towards the Athi River.

The storm drainage system in Nairobi is constituted of a combined sewer-storm system in the city centre and separated systems in the other districts. With the frequent flooding problem, the combined sewer-storm system is not efficient because the waste water treatment plants do not have adequate capacity to handle such large quantities of water. Furthermore, the efficiency of the drainage system serving the city centre is considerably reduced by sedimentation and clogging (Krhoda, 1987).

This has led to the direct discharge of some of the storm runoff water into the tributary streams of the Athi River with consequent ecological disruptions.

Therefore, if the quality of storm runoff generated from the city centre is known and the efficiency of the drainage system improved, proper management options can be instituted.

2.3.3 CLIMATE

Climate is the average weather conditions of a place over a long period of time normally an average of 35 years. The weather of Nairobi is influenced by South-West trade winds and the North-East trade winds. The North-East trade winds, laden with little moisture from the Indian subcontinent prevails between December and March. This subsiding air-mass is usually dry. However, orographic effects tend to create an occlusion as a result of a cold air-mass from Aberdare mountains (Krhoda, 1991). The storms caused by this air-mass approaches the city either from the South or North East. The South East trade winds on the other hand obtain their maximum intensity between April and May. This system is repeated, although weakly, in the months of september to November.

Major storms occur between November and May ; the period within which the study was carried out in order to establish how the quality of the storm runoff varies from one storm to another for a series of consecutive storms. The long rains begins in mid-March and continues to the end of May while the short rains occur between October and December although some storms have been recorded in the dry months of January and February.

The mean temperatures of the city of Nairobi are closely associated with the distribution of cloud cover. The maximum temperatures occur during the afternoons of clear skies when insolation is maximum. The minimum temperatures on the other hand are greatly influenced by strong radiational cooling associated with clear night skies. Therefore large diurnal range of temperature can be expected. Consequently, rainfall received especially within the city centre after a long dry and hot period normally has portions of it lost through evaporation since the surface absorbs large quantities of heat.

2.4 POPULATION AND PUBLIC SERVICES

The population of the city doubled between 1976 and 1986 to a total of approximately 1 million people (Obudho, 1986). This increase in population has been due to natural increase as well as immigration of rural population to urban areas in order to seek employment. With such an increase of population , a lot of stress has been laid on the provision of public services among them being water supply and sanitation and also on the maintenance of these infrastructures. The city centre is mainly affected because of the concentration of population and commercial activities. Proper management of storm runoff either through its safe disposal or harnessing is one way of improving urban infrastructure to counter the present stress imposed by rapid population increase.

2.5 SUMMARY

The geographical location of the city of Nairobi is one of the major causes of recurrent floods which have affected the city in the past one and a half decades. Increased surface runoff especially from the city is a result of reduced natural storage due to the artificial urban landscape. With proper understanding of the quality of this runoff, proper management options can be devised.

Relief and geology have little effect on storm runoff from the city centre due to the presence of artificial storm drains. However, with a proper understanding of the quality of storm runoff from the city centre based on major storms coupled with an efficient drainage system , proper storm runoff management options can be adopted. This will go along way in improving urban infrastructures which are already strained by rapid population increase.

CHAPTER THREE: RESEARCH METHODOLOGY

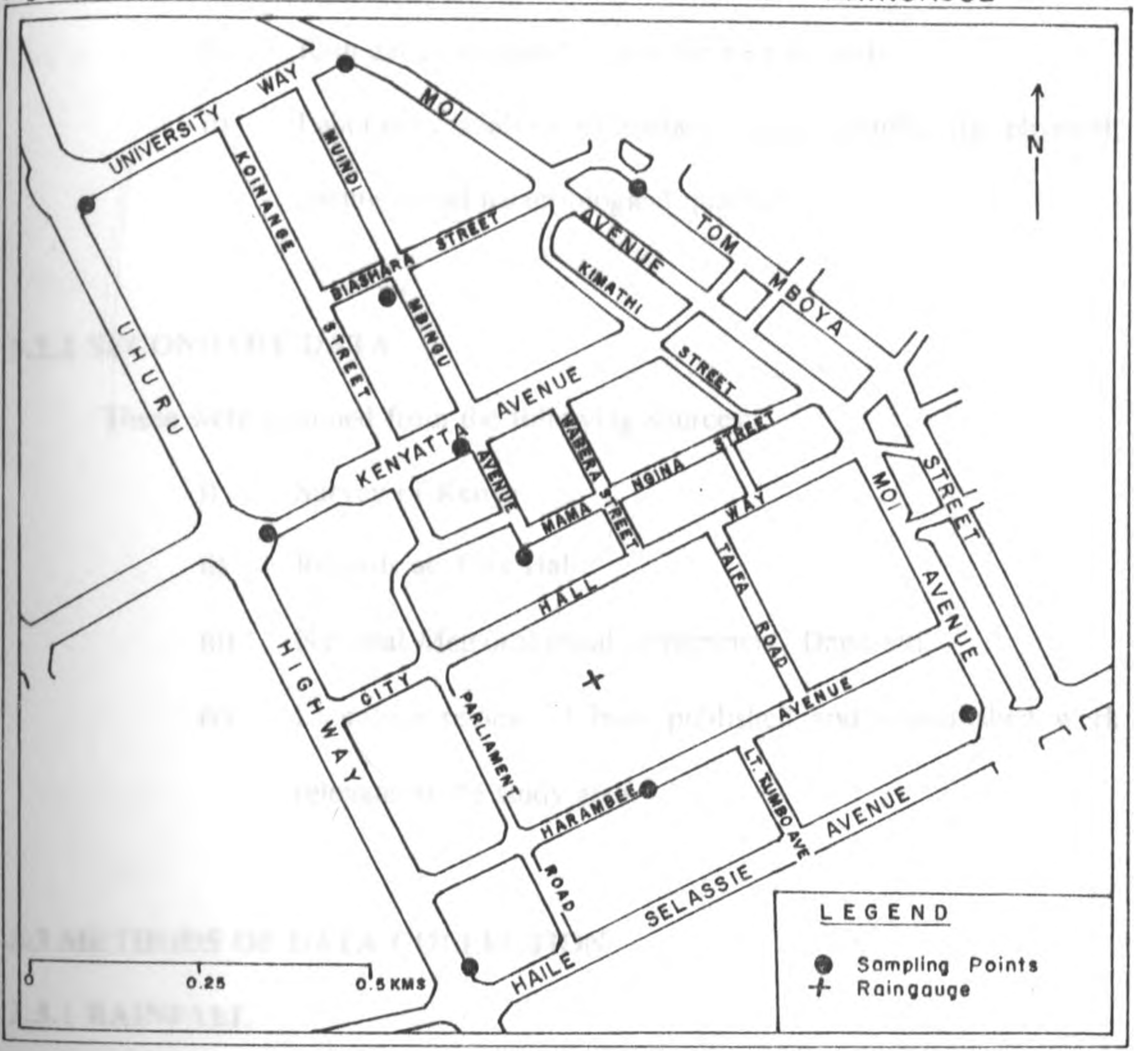
Several techniques presented below are applied for the purposes of this study in the collection, analysis and presentation of relevant quantitative and qualitative data.

3.1 SAMPLING DESIGN

All storms generating runoff over the study area during the study period formed the population of interest. Since a series of consecutive storms was required, all storms received during this period had their associated runoff water sampled for subsequent laboratory analysis. Therefore these storms also formed the sampling frame.

The random sampling procedure was used to pick the specific sampling points from where storm runoff samples were obtained. For the purposes of physical and chemical analysis, ten storm runoff samples were collected each from the selected sampling points (fig. 5) within the first five minutes of each storm in order to minimize the influence of runoff generated outside the study area.The samples were then composited in equal proportions in order to obtain one sample for physicochemical analysis. For the case of bacteriological samples, the same procedure was used only that ten sterilised syringes were used for each sampling session to obtain the ten samples for compositing. Composite samples were preferred in order to minimize analysis costs.

Fig.5 SAMPLING POINTS AND LOCATION OF RAINGAUGE



Source: Survey of Kenya, 1978

3.2 SOURCES OF DATA

3.2.1 PRIMARY DATA

These were obtained from the following sources:

i) Rain gauge installed within the area of study.

ii) Laboratory analysis of surface runoff samples for physical, chemical and bacteriological qualities.

3.2.2 SECONDARY DATA

These were obtained from the following sources:

i) Survey of Kenya.

ii) Records at City Hall.

iii) National Meteorological Department, Dagoretti.

iv) Literature review of both published and unpublished work relevant to the study area.

3.3 METHODS OF DATA COLLECTION

3.3.1 RAINFALL

Rainfall amounts over the study area during the study period were estimated on the basis of the vertical depth of water that would have accumulated on a level surface if the rainfall remained where it fell. This was done by the use of a standard gauge with a collector (receiver) of 20.3cm diameter centrally located in the study area (fig. 5). For each rain, its duration was recorded for the purposes of estimating its intensity.

3.3.2 STORM RUNOFF

The storm runoff associated with each storm is determined by the use of Lloyd Davies formula. The formula recognises the direct relationship of rainfall and runoff and translates rainfall into runoff by the formula:

$$Q = C \cdot Ap \cdot i \qquad \text{(i)}$$

Where:

Q = runoff in cubic metres per second (m^3/Second)

C = a constant (cumec per hectare for a rainfall of 1mm per hour)

= $10{,}000 \cdot 1/100 \cdot 1/60 \cdot 1/60 = 1/360 = 0.00278$)

Ap = Impermeable area in hectares

i = rainfall intensity in mm/hr

The impermeable area (Ap) is obtained by:

$$Aps = A \cdot P \qquad \text{(ii)}$$

Where

Ap = Impermeable area

A = Total area contributing

P = Runoff coefficient

In the case of Nairobi city , the runoff coefficient is 0.8 o (Table 3.1) and the total contributing area is 140 hectare.

TABLE 3.1 : RUNOFF COEFFICIENT FOR NAIROBI

Description of area	Runoff Coefficient
City centre	0.7-0.9
District centre	0.5-0.6
Industrial-Heavy	0.6-0.9
Industrial-Light	0.5-0.8
Residential-High Density	0.6-0.7
Residential-Medium Density	0.5-0.6
Residential-Low Density	0.4-0.5
Parks and Gardens	0.1-0.4
Unimproved areas	0.05-0.2

Source: T.R.R.L (1975)

Therefore the impermeable area (Ap) for the City Centre is:

$$Ap = 140 \times 0.8$$

$$= 112 \text{ ha}$$

3.3.3 STORM RUNOFF QUALITY

The actual determination of the specific quality characteristic (physical, chemical and bacteriological) were based on standard analytical procedures and techniques developed through years and whose detailed description is outlined in this chapter.

3.3.4 DATA COLLECTION LIMITATIONS

i) Only storms during the shorts rains were considered due to time and financial constraints. The heavy and intense storms which characterizes the long rains are expected to give different results.

ii) Accurate rainfall data (amounts and intensities) could not be obtained due to lack of automatic recording gauges. Further more, safe installation sites for manual gages are virtually non-existent within the study area hence the use of one gage.

iii) Most of the laboratory equipment used for physical and chemical analysis of storm runoff samples were accurate only up to one decimal place. Consequently, some constituents could have passed undetected in certain samples.

iv) The study does not consider organic constituents of health significance (Appendix 2)

3.4 DATA ANALYSIS AND PRESENTATION

The following are the main techniques and methods used in the analysis and presentation of the data collected for the purposes of this study:

3.4.1 LABORATORY METHODS

Rainwater and Thatcher (1960), termed water analysis "micro-chemistry with micro-volumes, because all the determinations require the quantitative determinations of either milligrams of microgram quantities or fractions thereof". Techniques by which water analysis is made and which are briefly reviewed below include, gravimetric analysis, spectro-photometric analysis, volumetric analysis and flamephotometric analysis plus gas chromatographic analysis. Techniques which relate to heavy metals analysis are also discussed in some detail in this section.

a) Gravimetric analysis

Gravimetric analysis techniques in water analysis are generally tedious and time wasting because of the usual necessity for precipitation, filtration, washing, ignition and weighing. These were not used in the current study.

b) Volumetric analysis

Volumetric analysis or otherwise filtration method is usually more rapid than the gravimetric analysis if the titrant reagent is specific for the constituent. The sensitivity and/or precision may also exceed that of a gravimetric analysis for some determinations. It was widely used in the present study for the analysis of water quality parameters as pH, total hardness and alkalinity.

c) Spectrophotometric analysis

Colorimetric determinations based on visual estimation of colour have long been used in water analyses by the use of colorimeters. By comparing colours of the solutions whose concentrations are not known with the already prepared standard solutions whose concentration is known, the unknown concentration can be determined.

d) Flame-Photometric analysis

By use of a flame-photometer or the modified flame spectrophotometer, the determination of particular elements in the water, especially the alkali metals (these metals have characteristic flame colouration) can be achieved. The intensity of the colouration of a given metal is determined. The intensity of colouration is proportional to the concentration of the particular element in solution.

Other instrumental analysis such as Turbidimetry, Polarimetry, Atomic spectrophotometry (ASS) and Chromatographic analysis are often used.

Suspended solids (SS), Total Dissolved solids (TDS), Colour, Turbidity, Electric conductivity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), Chloride and Fluoride were all analyzed according to the standard methods. Suspended solids were determined by filtration of a well mixed sample on a standard glass-fibre filter disk (0.45mm filter; detection limit ss=< 5mg/l). BOD was determined over 5 days for biochemical oxidation of organic substances. The detection limit for BOD is about 5mg/l. The same was done for the chemical oxygen demand (COD).

Chloride content and Fluoride were measured by filtration with mercuric nitrate solution (American Public Health Association, 1973), detection limit= 10mg/l for the chloride and 0.1mg/l for fluoride content. Sulphate and Orthophosphate were analyzed according to APHA (1975), detection limit= 0.01mg/l.

e) Heavy Metal Analysis

Heavy metal detection in the storm runoff water samples is one of the objectives of the present study. Their detection levels were an indication of their concentrations in the samples.

Water samples for metal analyses were filtered through a standard type 0.45mm pore diameter membrane filter. The samples were then preserved by acidifying with concentrated nitric acid to pH=2 (APHA, 1975).

Metals were analyzed by use of atomic absorption spectrophotometer (ASS) technique 1971). The technique has a wide application in the metal analysis because of its speed, low cost per analysis, simplicity and frequent ability to analyze complex mixtures without prior separation. The atomic absorption spectrophotometry technique uses the principles of atomic absorption and electron emission , thus making it more precise, accurate and cheap. Its uses and procedures have been documented by Burrell (1975). Its often useful for heavy metal determination in water analysis. The heavy metals analyzed were Copper (Cu), Zinc (Zn), Lead (Pb), Manganese (Mn), Mercury (Hg), Cadmium (Cd), Silver (Ag) and Chromium (Cr). Consequently, the results of the analysis represent filtrate (Dissolved) metals. Quantification of the metals was based upon calibration curves of standard solutions of metals. These calibration curves were determined every time before analysis of water samples (approximate detection limits for Cu= < 0.1mg/l; Zn= 0.01mg/l; Pb= ,0.05mg/l; Hg= < 0.01mg/l). Generally, the instrument detection limit was set at 0.1 mg/l.

It should be noted that the analysis was done directly and pre-concentration techniques, including co-precipitation, ion exchange and solvent extraction were not utilized for the analysis of metals in the samples.

In spite of the inherent instrument and technique problems associated with ASS, spectrophotometers are well suited for water analysis because often the determinants of small quantities of substances can often be detected readily and accurately and the difference in technique of individual analyses are also minimized.

f) Bacteriological Analysis

For the purposes of human consumption and public water supplies, a set of micro-biological indicator organisms have been identified and is now commonly applied to determine the hygienic suitability of water for drinking (Faecal Coliforms 3/100ml).

3.4.2 GRAPHICAL ANALYSIS

In this study, graphical analysis has been used to establish how the water quality characteristics of surface runoff compares with selected quality guidelines for:

(i) domestic consumption;

(ii) irrigation;

(iii) chemical and allied industries;

(iv) food processing industries; and

(v) protection of aquatic life.

The comparison of water quality characteristics of surface runoff with selected quality guidelines is done by plotting the deviations of each physicochemical parameter from the selected quality guide values against the corresponding storms (see

appendix 3)

The specific use guidelines adopted for this study are presented in appendix 1(a) to 1(f). These are based on:

(i) Department of National Health and Welfare, Canada, 1969.

(ii) Environmental Studies Board, Canada, 1973.

(iii) U.S. Environmental Protection Agency, 1976.

(iv) Australian Water Resources Council, 1974.

3.4.3 SUMMARY STATISTICS

A part from tables and graphs which are used to enable the discerning of trends and patterns in the data, more exact measures of data are also used. This involves the use of summary statistics to describe certain characteristics of the data set. The main summary statistics used to describe data in this study are (i) the mean and (ii) the standard deviation. The minimum and maximum values for certain parameters recorded during the study period are also considered.

3.4.3.1 THE MEAN

This is a measure of central tendency representing the arithmetic average of a set of observations. This is given by:

$$\bar{X} = \frac{\sum X}{n}$$

where:

$\bar{X}$ = Sample Mean
$\sum X$ = $\sum$ of values of all observations
n = Number of elements in the sample

3.4.3.2 STANDARD DEVIATION

This refers to the positive square root of the variance; a measure of dispersion in the same units as the original data, rather than in the squared units of the variance. It is given by:

$$S = \sqrt{\frac{\sum (X-\overline{X})^2}{n-1}}$$

$$= \sqrt{\frac{\sum X^2}{n-1} - \frac{n\,\overline{x}^2}{n-1}}$$

Where:

S = Sample Standard Deviation

X = Value of each of the n observations

$\overline{X}$ = Mean of the sample

n-1 = Number of observations in the sample minus 1.

3.4.4 INTERPRETATION OF ANALYTICAL RESULTS

The quality of storm runoff water is compared with the recommended guidelines for domestic and industrial uses since these are the heaviest consumers of water in the city. Guidelines for irrigation are also considered because watering of lawns and flower gardens is known to consume a lot of good quality water which otherwise can be conserved for use during dry spells.

Since the storm runoff water is discharged into the receiving streams with consequent effects on the aquatic life, guidelines for protection of aquatic life are also considered. Furthermore these streams are used as a source of water supply for those who reside along them.

Therefore it is against the background of the quality guidelines for these uses that the storm water runoff quality has been assessed.

CHAPTER FOUR: STRATEGIES FOR STORM WATER RUNOFF MANAGEMENT

4.1 INTRODUCTION

This chapter examines the quantity of runoff generated for each storm and its quality characteristics as it varies for the thirty consecutive storms during the study period. Strategies for the management of this storm water runoff based on its inherent characteristics are also considered. Results of the following study objectives have been considered in this chapter:

i) Estimation of runoff quantity for each storm during the study period.

ii) Determination of the water quality characteristics of each storm.

iii) Establishment of the variation of water quality characteristics of each storm.

iv) Comparison of water quality characteristics of runoff with established water quality guidelines and devising strategies for water quality improvement and conservation.

4.2 ESTIMATION OF STORM RUNOFF QUANTITY

Thirty consecutive storms were considered for this study. The runoff volume for each storm is estimated by the use of Lloyd Davies formula [eq.(i)] and the result is presented in table 4.1. During the study period, the maximum amount of rainfall received was 80mm while the minimum amount received was 6mm. During the same period, the

TABLE 4.1: THE STORM RUNOFF ASSOCIATED WITH EACH STORM AS DETERMINED BY THE LLOYD DAVIES FORMULA

Storm No.	R.F. Amount(mm)	R.F. Duration(hrs.)	R.F. Intensity(mm/hr)	Constant	I.A. Area (ha)	Runoff Volume(m3/sec)
1	10	1.3	6.7	0.21	112	15.76
2	8	2	4	1.25	112	560
3	7	2	3.5	1.09	112	427.28
4	8	1	8	2.49	112	2231.04
5	11	4	2.75	0.86	112	264.88
6	6	0.45	8	2.49	112	2231.04
7	13	1.5	8.67	2.7	112	2621.81
8	7	1	7	2.18	112	1709.12
9	14	3	4.67	1.45	112	758.4
10	12	4	3	0.93	112	312.48
11	17	5	3.04	0.95	112	323.46
12	20	5	4	1.25	112	560
13	16	8	2	0.62	112	138.88
14	9	5.3	1.8	0.56	112	112.9
15	25	5	5	1.56	112	876.6
16	32	7	4.5	1.4	112	705.6
17	8	1.3	5.33	1.66	112	990.95
18	80	7	11.43	3.56	112	4557.37
19	60	3	20	6.22	112	13932.8
20	35	4.45	7.37	2.29	112	1890.26
21	22	5.15	4.19	1.3	112	610.06
22	46	6.45	6.65	2.07	112	1541.74
23	41	6	6.83	2.13	112	1629.36
24	29	2.45	10.55	3.28	112	3875.65
25	62	8	7.75	2.4	112	2083.2
26	51	5.45	9.4	2.93	112	3084.71
27	18	3.5	5.14	1.6	112	921.09
28	13	5	2.6	0.81	112	235.87
29	35	7	5	1.56	112	873.6
30	18	6	3	0.9	112	302.4

maximum and minimum rainfall intensities realized were 20mm/hr and 0.67mm/hr respectively.

The average volume of storm runoff generated from the city centre during this period therefore is 1679.18m^3/sec. with a standard deviation of 2450.32m^3/sec. It is evident from these results that the city centre contributes large and variable quantities of runoff water during the rainy seasons. This is further supported by the city centres' high runoff coefficient.

This vast quantities of storm runoff water from the city centre constitutes a potential resource which can be harnessed to supplement the existing water supply which is inadequate to meet the current demand. Furthermore this will go a long way in curbing the recurrent floods which are known to cause destruction to property and inconvenience to city residents.

4.3 WATER QUALITY CHARACTERISTICS OF STORM RUNOFF FROM THE CITY CENTRE

4.3.1 Constituents and properties of storm runoff

Some of the physicochemical parameters of storm runoff considered in this study embraces the individual and combined effects of the substances present. The possibility of utilizing this storm runoff water to serve various uses is determined, to a large extent, by the constituents found in it, as well as its properties. For the purposes of this study, these constituents and properties are categorized as:

i) Cations;

ii) Anions;

iii) Nonionic constituents; and

iv) Properties.

4.3.1.1 CATIONS

The cations (positively charged ions) which were determined in routine analyses of storm water runoff include: calcium, magnesium, sodium and potassium. Because of their importance, each is considered subsequently in more detail. Other cations considered in this study include: Aluminium, Iron, Manganese, Chromium, Nickel, Copper, Lead, Zinc, Selenium, Cadmium, Silver, Molybdenum, and Mercury.

a) Calcium and Magnesium

These two cations are similar in many respects and are among the most abundant cations in the earths crust and are both dissolved freely from many rocks and soils. This could explain their presence in storm water runoff. In general, concentrations of calcium in freshwater are somewhat greater than those of magnesium, because of the greater abundance of calcium in the earth's crust. This is in conformity with the results of this study (Table 4.2).

Calcium and magnesium are both essential elements in man's diet. In addition, both of these substances are generally desirable in limited quantities for most beneficial uses of water [appendix 1(a)-(f)]. Calcium also aids in maintaining the structure of plant cells, and is desirable for irrigation because it improves the soil structure. High concentrations of calcium in water are relatively harmless to all organisms and may reduce toxicity of certain chemicals compounds to fish. Guidelines for calcium concentrations in drinking water have been established not for health reasons but rather to alleviate the adverse tendency of calcium to contribute hardness.

Magnesium on the other hand is also non-toxic and pose a concern neither to public health nor to aquatic life. The presence of magnesium is beneficial for the heart and nervous systems; however, taste considerations are also important.

The results of this study indicates that the maximum concentrations of calcium detected in storm water runoff was 86 mg/l while that of magnesium was 44 mg/l. On the other hand, the minimum concentrations for the two elements was 4.8 mg/l and 0.2 mg/l respectively. It is therefore safe to conclude that calcium and magnesium in storm water runoff from the city centre are not major polluters of the receiving streams based on the considered quality guideline [appendix 1(a)-(f)]. Furthermore, most storms generated runoff with calcium and magnesium concentrations within tolerable limits for certain uses.

b) Sodium and Potassium

Sodium is an important cation and significant in the balance of total cations. It is usually found in association with potassium, and both have similar chemical properties. However, sodium is more abundant in water than potassium and this is clearly brought out in the values obtained for the two elements during the study (Table 4.2).

The presence of sodium and potassium in storm water runoff could be attributed to the contact of water with sodium and potassium bearing rocks/soils and municipal sewage leakages.

Sodium is used in the normal functioning of processes of the human body but may adversely affect those with cardiac, renal and circulatory problems. People on restricted sodium diets are advised not to drink water whose sodium concentrations exceed 20 mg/l. Waters whose sodium concentrations do not exceed 270 mg/l are generally considered acceptable for drinking.

Moderate quantities of potassium do not adversely affect the use of a water. Although potassium is an essential nutrient for plant and animal life, very high concentrations (>200 mg/l) of potassium may be harmful to human nervous and digestive systems. No recommended limit has been prescribed for potassium.

If both sodium and potassium are present together in quantities from 50 to 100 mg/l, certain industries may be affected, since foaming, scaling, or corrosion may result upon heating.

The foregoing prescribed limits for sodium and potassium for various uses compares favourably with the field data (Table 4.2). It can therefore be justly concluded that sodium and potassium concentrations in storm water runoff from the city centre does not render this water unfit for certain beneficial uses. conversely, this runoff in regard to sodium and potassium does not adversely affect the receiving streams. This is further supported by the fact that the maximum concentrations of sodium and potassium in the storm water runoff realized during the study was 50 mg/l and 40 mg/l respectively while the minimum values registered for these cations were 4.8 mg/l and 1 mg/l respectively.

c) Iron and Manganese

Although iron and manganese are usually present in only minor concentrations compared to the other cations already considered, these two constituents are of major significance with respect to water quality criteria for domestic and industrial supplies.

This study shows that unlike in natural waters, manganese is found in greater concentrations than iron in storm water runoff from the city centre. Possible sources of manganese in the city centre could be soils and sediments especially from construction sites. On the other hand, iron could emanate from corrosion of iron and steel materials within the city centre.

Few adverse effects are attributable to the presence of iron. In water, iron can discolour clothes, plumbing fixtures, and causes scaling which encrusts pipes. Excessive concentrations may promote bacterial activity in pipes and service mains. To minimize such adverse effects, an acceptable level of 0.3 mg/l has been proposed (Department of National Health and Welfare, 1969).

Iron is highly objectionable for drinking water because of its bittersweet astringent taste. Drinking water concentrations of less than 0.05 mg/l are more palatable (Department of National Health and Welfare, 1969).

Although iron is a minor plant nutrient, toxicity has been recorded at concentrations in excess of 20 mg/l (Torry, 1976). High iron concentrations may cause fixation of essential elements required by plants and thus detrimental. To avoid such effects, irrigation waters on neutral or alkaline soils should not exceed 20 mg/l and on acid soils 5.0 mg/l (Environmental Studies Board, 1973). A critical level of 0.3 mg/l total iron has been proposed for the protection of the aquatic environment.

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d) Other cations

Other cations which are significant with respect to water and are considered in this study include: aluminium, chromium, nickel copper, lead, zinc, selenium cadmium, silver, molybdenum and mercury. From table 4.2, it is evident that cadmium, silver, molybdenum, nickel, and selenium were not detected in any of the thirty storm water runoff samples analyzed.

Aluminium has not been shown to be harmful to public health and, therefore, no drinking water guidelines have been formulated. Waters used for irrigation should generally be limited to 5.0 mg/l, although the maximum is set at 20 mg/l for use on fine-textured neutral or alkaline soils(Environmental Studies Board, 1975).

It can be seen from the field results (Table 4.2) that the highest concentration of aluminium recorded was 2 mg/l hence it is not a limiting factor to the use of storm runoff water for irrigation. However, aluminium may cause scale deposits to form on boiler tubes. Therefore a concentration of less than 0.1 mg/l has been suggested for good boiler feedwater.

Zinc, lead, mercury and copper were detected only in the first three consecutive storm water runoff samples in concentrations ranging between 0.2 mg/l to 0.1 mg/l (Table 4.2). The rest of the 27 samples contained none of these cations. It is therefore logical

TABLE 4.2: CATIONS - CONCENTRATION IN CONSECUTIVE STORM RUN-OFF

SNO.	Ca	Mg	Na	K	Al	Fe	Mn	Zn	Cd
1	86	44	50	40	2	5	19	0.1	0
2	78	42	44	32	1.9	5	14	0.1	0
3	77	17	42	29	1.9	4	10	0.1	0
4	75	16	40	25	1.8	4	9.6	0	0
5	73	12	40	25	1.7	4	9.5	0	0
6	71	12	40	23	1.2	3.2	9.2	0	0
7	71	9.7	39	21	1	3.1	9	0	0
8	68	9.7	37	21	1	3	7.1	0	0
9	65	9.2	36	20	1	3	7	0	0
10	60	9	36	19	0.8	3	6.5	0	0
11	59	7.8	35	19	0.7	3	6.2	0	0
12	59	7.6	31	18	0.6	2.9	6.2	0	0
13	56	7.5	29	18	0.3	2.5	5.9	0	0
14	48	6.9	28	17	0.1	2.5	5.7	0	0
15	48	6.3	28	16	0.1	2.2	5.6	0	0
16	45	6.3	27	15	0.1	2	5.2	0	0
17	40	6	26	13	0	0.9	4.8	0	0
18	39	5.8	25	10	0	0.9	4.7	0	0
19	37	5.3	24	7	0	0.7	4.5	0	0
20	37	5.1	24	7	0	0.5	4.5	0	0
21	36	4.8	22	6	0	0.5	3.2	0	0
22	34	4.6	21	5	0	0.5	3.1	0	0
23	32	4.2	21	4.7	0	0.4	2.2	0	0
24	30	3.5	20	3	0	0.4	1.8	0	0
25	29	2.9	20	3	0	0.3	1.8	0	0
26	29	2.7	20	2.4	0	0.3	1.7	0	0
27	24	2.1	20	1	0	0.3	1.2	0	0
28	15	0.9	19	1	0	0.1	0.8	0	0
29	8	0.2	11	1	0	0.1	0.8	0	0
30	4.8	0.2	4.8	1	0	0.1	0.1	0	0

TABLE 4.2 :....CONTINUED

SNO.	Pb	Cu	Ag	Mo	Hg	Cr	Se	Ni
1	0.2	0.2	0	0	0.1	0	0	0
2	0.1	0.2	0	0	0.1	0	0	0
3	0.1	0.1	0	0	0.1	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0

to deduce that the first few storms are able to clean out these constituents hence lessening their impact on the quality of runoff water from subsequent storms.

4.3.1.2 ANIONS

The negatively charged ions which were determined in routine analyses of storm water runoff from the city centre included: chloride, sulphate, nitrite, fluoride and phosphate.

a) Chloride

No adverse human health effects result from the presence of large quantities of chloride(600 mg/l). Limits to the maximum concentrations have, however, been set due to taste preferences. Most domestic, agricultural and industrial uses require chloride concentration of less than 250 mg/l (Department of National Health and Welfare, 1979). The highest concentration of chloride obtained during the field study was 43 mg/l while the minimum value recorded was 1 mg/l (Table 4.3). This compares favourably with the limits set for domestic, agricultural and industrial use.

Changes in the chloride concentrations of a water may cause a shift in the biotic community, but no recommendations to protect aquatic life have been set. Hence the effect of the of the storm runoff water from the city centre on aquatic community of the receiving streams cannot be deduced.

However, it is important to note that large amounts of chloride, where calcium and magnesium are also present, increase a water's corrosiveness and may adversely affect metallic equipment. Chlorides are not removed by filtration in conventional physical water treatment methods, and may adversely affect water used in household and commercial food preparations.

b) Sulphate

Moderately high concentrations of sulphate (200-300 mg/l) may be objectionable in water and magnesium sulphate may be cathartic to humans. Although a laxative effect may be experienced when concentrations range between 150 and 500 mg/l, an objective of less than 150 mg/l for drinking water has been proposed and concentrations up to 500 mg/l are acceptable for drinking (Department of National Health and Welfare, 1979).Sulphate concentrations are seldom high enough to affect aquatic life adversely.

The maximum concentration of sulphate recorded during the field study was 120 mg/l while the minimum recorded value was 0.3 mg/l. This can be seen to fall within the recommended range for various uses. However, it is imperative to note that high concentrations of sulphate restricts a water's use as a drinking source. Concentrations in excess of 250 mg/l may restrict the use of a water by certain industries. A hard scale of calcium sulphate may be formed in pipes and boilers. Sulphate can corrode concrete.

c) Nitrite

Nitrite occurs as an intermediate form between ammonia and nitrates (nitrification) or nitrates and nitrogen (denitrification).

Nitrite is much more toxic to man and other animals than nitrates. Public drinking water guidelines specify that nitrite concentrations should not exceed 1 mg/l (Environmental Studies Board, 1973). However, very low concentrations of nitrite (0.01

mg/l) was recorded in storm water runoff and this value persisted throughout the study period (Table 4.3). Therefore nitrite may not be a major hinderance in the use of storm water runoff from the city centre.

d) Fluoride

Small quantities of fluoride have proven to be beneficial in reducing tooth decay; however, excess concentration have resulted in the staining of tooth enamel. Single doses in excess of 250 mg/l have been shown to be toxic to man.

Criteria for drinking waters have been formulated on the basis of the most sensitive water consumers-children-and related to quantity consumed. The maximum limit has been set at 1.5 mg/l (Kenya Bureau of Standards, 1985) for drinking water. To protect plants from detrimental effects a limit of 1.0 mg/l has been proposed for application to acidic soils which can deactivate fluorides (Environmental Studies Board, 1973).

The highest and lowest values of fluoride recorded during the study period were 0.7 mg/l and 0.1 mg/l respectively. This falls within the recommended limits for various uses.

e) Phosphate

Phosphorus is not commonly toxic to man, animals or fish and is an essential element for plant growth. Only the extremely rare form of elemental phosphorus is toxic.

Water quality guidelines have been proposed to eliminate taste and odour problems and difficulties of water treatment which can be associated with phosphorus. A concentration of 0.2 mg/l phosphate (as Po_4) has been defined as the acceptable limit for drinking water (Department of National Health and Welfare, 1969).

TABLE 4.3: ANIONS - CONCENTRATION IN CONSECUTIVE STORM RUNOFF

SNO.	Cl	F	No_2	So_4	Po_4
1	43	0.7	0.01	120	0.02
2	34	0.7	0.01	112	0.01
3	33	0.7	0.01	110	0.01
4	30	0.5	0.01	106	0.01
5	30	0.5	0.01	101	0.01
6	30	0.5	0.01	101	0.01
7	26	0.5	0.01	102	0.01
8	23	0.5	0.01	102	0.01
9	21	0.5	0.01	100	0.01
10	21	0.4	0.01	97	0.01
11	21	0.4	0.01	95	0.01
12	20	0.4	0.01	95	0.01
13	19	0.4	0.01	92	0.01
14	19	0.4	0.01	90	0.01
15	17	0.2	0.01	90	0.01
16	15	0.2	0.01	90	0.01
17	14	0.2	0.01	90	0.01
18	14	0.1	0.01	67	0.01
19	14	0.1	0.01	51	0.01
20	12	0.1	0.01	44	0.01
21	11	0.1	0.01	36	0.01
22	9	0.1	0.01	30	0.01
23	8	0.1	0.01	26	0.01
24	8	0.1	0.01	11	0.01
25	6.5	0.1	0.01	9.4	0.01
26	5	0.1	0.01	0.3	0.01
27	4	0.1	0.01	0.3	0.01
28	4	0.1	0.01	0.3	0.01
29	1	0.1	0.01	0.3	0.01
30	1	0.1	0.01	0.3	0.01

Phosphorus can causes eutrophication in receiving water systems. A general index of maximum desirable concentration is: 0.1 mg/l in flowing water and 0.05 mg/l for water flowing into lakes or reservoirs. This can be seen to compare favourably with the field results since the maximum and minimum concentrations of phosphate recorded during the study was 0.02 mg/l and 0.01 mg/l respectively. Therefore phosphorus is not a limiting factor to the possible harnessing of storm water runoff from the city centre.

4.3.1.3 NONIONIC CONSTITUENTS

Not all the constituents in water are present in dissociated form as ions. Some of the nonionic substances considered in routine analyses of storm water runoff from the city centre are: silica, free carbon dioxide, total suspended solids and permanganate number.

a) silica

The presence of silica in water is not detrimental to humans and aquatic life. The use of water for municipal, domestic, or agricultural purposes is unaffected by silica. However, industry may find silica troublesome in boilers due to formation of siliceous deposits. The highest and lowest concentration of silica recorded in storm water runoff during the study period was 12.4 mg/l and 2 mg/l respectively (Table 4.4).

However, no guidelines specifying concentrations of silica in water have been established.

b) Total Suspended Solids

The Kenya Bureau of Standards requires that there should be no suspended matter in water meant for drinking. The presence of suspended matter in water increases its turbidity. The maximum total suspended solids recorded during the study period was 150 mg/l while the minimum concentration was 10 mg/l (Table 4.4). This is bound to reduce consumer acceptability of storm water runoff on aesthetic grounds.

The suspended matter in storm water runoff can affect aquatic biological communities in the receiving streams. In the management of this water, suspended matter can be removed by sedimentation and filtration processes in conventional water treatment.

No guideline values have been recommended for free carbon dioxide and permanganate number.

TABLE 4.4: NONIONIC CONSTITUENTS - CONCENTRATION IN CONSECUTIVE STORM RUN-OFF

SNO.	TSS	Si	FCD	PN
1	150	12	60	550
2	100	12	56	511
3	85	10	52	492
4	82	9.5	48	460
5	77	9	44	441
6	60	8.7	41	400
7	56	8.3	41	397
8	50	8.1	41	395
9	50	7.7	38	356
10	50	7.4	35	310
11	46	6	30	296
12	44	5.9	30	252
13	40	5	27	226
14	40	5.1	25	210
15	38	4.8	24	205
16	32	4.8	24	187
17	24	4.1	22	158
18	21	4	22	126
19	21	4	14	118
20	19	4	14	110
21	16	3.7	14	103
22	14	3.1	9	95
23	14	3	8	71
24	10	3	6	65
25	10	3	6	59
26	12	3	4	43
27	11	2.8	4	35
28	10	2.5	4	32
29	10	2	4	32
30	10	2	4	32

4.3.1.4 PROPERTIES

Both of the constituents of water, ionic and nonionic impart certain quality characteristics which may be termed "properties". The most significant properties of storm water runoff which relate to quality and were considered in the routine analysis are discussed below:

a) Total Hardness

Hardness is principally determined by the sum of calcium and magnesium. The presence of other constituents, such as iron, manganese and aluminium also contribute to total hardness. The range of hardness can be outlined as in Table 4.5.

TABLE 4.5: HARDNESS OF FRESH WATER

Hardness as Calcium Carbonate in mg/l	Degree of Hardness
0-30	Very soft
31-60	Soft
61-120	Moderately soft
121-180	Hard
> 180	Very hard

Source: Water Quality Sourcebook, 1979.

The degree of hardness of water may have a detrimental economic impact; water with a hardness less than 120 mg/l calcium carbonate can be deemed desirable for most uses, but only if hardness exceeds 500 mg/l can the water be labelled undesirable for both industrial and domestic uses (Department of National Health and Welfare, 1969).

The maximum and minimum hardness values recorded during the study period were 360 mg/l and 42 mg/l respectively (Table 4.8). From this table, it can be seen that most of the storms received in the city centre generated runoff water which was soft to moderately soft (Table 4.5). Generally, hardness of storm water runoff from the city centre is not a major limiting factor, if the water was to be put to beneficial use.

Hard water results in the formation of scale on boilers and pipes and also increases soap consumption which affects both domestic and industrial cleaning and laundering activities.

b) Total Alkalinity

Alkalinity is a measure of water's capacity to neutralize an acid. It indicates the presence of carbonates, bicarbonates and hydroxides and less significantly, borates, silicates, phosphates and organic substances.

Waters with high alkalinity are undesirable because of the associated excessive hardness or high concentration of sodium salts. Guidelines on water quality have been established to ensure capability of water treatment processes to maintain a chemical balance of water; and to alleviate corrosive or encrusting properties; and to eliminate human health problems such as gastro-intestinal irritation.

Alkalinity in the range of 30 to 500 mg/l is generally acceptable (Department of National Health and Welfare, 1969) and for treatment control, it is desirable that there be no sudden variation in the alkalinity (Environmental Studies Board, 1973). To protect the aquatic environment, guidelines stipulate that alkalinity must be maintained at natural background levels with no sudden variations (Environmental Studies Board, 1973).

From the field data (Table 4.8), the maximum alkalinity recorded was 140 $mgCaCo_3/l$ while the minimum value recorded was 25 $mgCaCo_3/l$. This ranges within the acceptable guideline values indicating that alkalinity does not adversely limit the usefulness of storm water runoff from the city centre as a source of water supply.

c) Hydrogen-ion Concentration (pH)

pH indicates the balance between the acids and bases in water and is a measure of the hydrogen ion concentration in solution. A pH range from 6.5 to 8.5 pH units is acceptable in drinking water (Department of National Health and Welfare, 1969). A pH greater than 8.3 interferes with the disinfection process of drinking water.

The pH of the water may influence the species composition of an aquatic environment and affect the availability of nutrients and the relative toxicity of many trace elements. For the protection of the aquatic environment, the pH should be within the range of 6.5 to 9 units. An identical range has been suggested for aesthetic uses. From the field data (Table 4.8), pH can be seen to be a highly variable parameter. For the thirty samples analyzed, the pH ranged from 7.4 to 6.2 units. The acidity of storm runoff water can be accounted for by the high acidity of rain water received in the city (Table 4.6). Therefore storm runoff water will require pH adjustment if it has to be put to beneficial use.

d) Conductivity

Conductivity is a numerical expression of a water's ability to conduct an electrical current. It provides a good indication of the changes in a water's composition, especially in its mineral concentration.

No guidelines have been established to regulate conductivity since the high values are found to correlate with Total Dissolved Solids, which have outlined objectives. This is supported by the field data (Table 4.8).

e) Colour

The colour of water is attributable to the presence of organic and inorganic materials. Mineral components such as iron and manganese and organic matter imparts colour to water.

Colour is not normally considered a serious pollution problem, although it may be detrimental in that it interferes with the passage of light, thereby impeding the photosynthesis of aquatic plants. Domestic, industrial and recreational uses of a water may be affected by its colour. For aesthetic considerations and to prevent possible staining of clothes, food and fixtures the acceptable limit for true colour in public drinking water is 15 mg/l (Department of National Health and Welfare, 1969).

TABLE 4.6: WATER QUALITY CHARACTERISTIC OF RAINFALL WITHIN THE CITY CENTRE

PARAMETERS	UNIT	RESULTS
pH	pH scale	6.8
Colour	mgpt/l	<5
Turbidity	N.T.U	4
Permanganate No.	mgO_2/l	12
Conductivity	μs/cm	71
Iron	mgFe/l	0.1
Manganese	mgMn/l	0.2
Calcium	mgCa/l	3.2
Magnesium	mgMg/l	<0.1
Sodium	mgNa/l	0.9
Potassium	mgK/l	2.5
Total Hardness	mgAl/l	8
Total Alkalinity	mg$CaCO_3$/l	20
Chloride	mg$CaCO_3$/l	3
Fluoride	mgF/l	<0.1
Nitrite	mgN/l	<0.1
Sulphate	mgSO_4/l	8.9
Orthophosphate	mgPO_4/l	0.02
Total Dissolved Solids	mg/l	43
Free Carbon Dioxide	mg/l	4
Chemical Oxygen Demand	mgO_2/l	2
Biochemical Oxygen Demand	mgO_2/l	2

The storm runoff water from the city centre is highly coloured (Table 4.8) since the maximum and minimum values obtained for the thirty consecutive storms are 1750 mgpt./l and 25 mgpt./l respectively. Therefore the raw storm water runoff is objectionable from aesthetic point of view based on colour. This can however be remedied by sedimentation and filtration during the treatment process.

f) Turbidity

Turbidity is a measure of the suspended particles such as silt, clay, organic matter and microscopic organisms in water which are usually held in suspension.

Turbidity can affect aquatic biological communities by reducing photosynthesis of submerged, rooted aquatic vegetation and algae; this reduced plant growth may in turn suppress fish productivity.

Turbidity, unless related to asbestiform minerals, does not affect the safety of a drinking water, but does alter its consumer acceptability. Although water with a turbidity of 5 NTU or less is acceptable for drinking, a value less than 1 NTU is the recommended level (Department of National Health and Welfare,1969). Turbidity also affects recreational uses of water and recommendations for water with direct recreational contact range from 5 to 50 NTU (Department of the Environment, 1972).

Like colour, the turbidity of storm water runoff from the city centre is extremely high (Table 4.8), with the maximum and minimum values recorded being 4600 and 190 NTU respectively. This is well out of the range of guidelines recommended for various uses. Conversely, prior to harnessing this water, thorough sedimentation and filtration must be undertaken during the treatment process.

g) Oxygen Demand

The ability of substances to utilize, either directly or indirectly, the dissolved oxygen in water for their eventual stabilization is termed oxygen demand. The two major types considered in this study are (i) Biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

i) Biochemical Oxygen Demand

BOD of a water is the amount of oxygen required to oxidize the organic matter by aerobic microbial decomposition to stable inorganic form.

BOD is not a pollutant itself, but is a measure of organic pollution. A BOD load can pose a threat to the aquatic environment by depressing the dissolved oxygen concentrations to levels that affect aquatic organisms. Water with high BOD values may be unsuitable for irrigation purposes, since they may restrict plant growth.

No specific guidelines for BOD have been proposed, but waters with BOD Levels less than 4mg/l are deemed reasonably clean. Waters with levels greater than 10 mg/l thus are considered polluted since they contain large amounts of degradable organic materials.

BOD for storm water runoff is considerably high (Table 4.8); a sign of organic pollution. Therefore before use, this water will require thorough aeration.

ii) Chemical oxygen demand

COD is a measure of the amount of oxygen required to chemically oxidize the organic matter in water. Although both COD and BOD indicate the potential dissolved oxygen demand in water, there is not necessarily a correlation between these two measures. The use of water with high COD values for irrigation may restrict plant growth especially on poorly drained soils. The tolerance in feed-waters for low-and high-pressure boilers are 5 mg/l and 1.0 mg/l respectively. COD may reduce dissolved oxygen levels, thus affecting the survival of aquatic organisms, but no water quality guidelines for COD have been proposed.

Like BOD, COD for storm water runoff from the city centre is extremely high (Table 4.8). COD levels in this water can also be regulated through aeration.

h) Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is an index of the amount of dissolved substances in water. The presence of such solutes alters the physical and chemical properties of water. The range of dissolved solids is variable (Table 4.7).

Significant contributions to TDS load of storm water runoff from the city centre is anthropogenic in the form of municipal effluent and aerosols fallout.

Basic guidelines on the concentration of TDS which have been established relate to taste and palatability rather than to detrimental health effects on man and aquatic biota. TDS concentrations of 500 mg/l or less have been designated as an objective level for drinking water provided none of the dissolved constituents exceed their particular guidelines (Department of National Health and Welfare, 1979).

TABLE 4.7: TOTAL DISSOLVED SOLIDS-SALINITY RELATIONSHIPS

Total Dissolved Solids mg/l	Degree of salinity
0-1000	Fresh; non saline
1001-3000	Slightly saline
3001-10,000	Moderately saline
10001-100,000	Saline
> 100001	Brine

Source: Water Quality Sourcebook, 1979.

Industrial users of water usually prescribe TDS concentrations to be less than 1000 mg/l, but this is quite variable among individual users and their particular requirements (U.S Geological Survey, 1970). It is evident from the field data (Table 4.8) that the maximum and minimum TDS values recorded during the study period were 900 mg/l and 80 mg/l respectively. However, only the first six storms had values greater than 500 mg/l. Therefore TDS in most of the storm water runoff is within desirable levels for domestic and industrial uses.

TABLE 4.8: PROPERTIES OF CONSECUTIVE STORM RUN-OFF

SNO.	TH	TA	TSD	COD	BOD	pH	CoL	Tur	Con
1	360	140	900	1250	130	7.2	1750	4600	650
2	264	98	725	1240	126	7	1700	4400	630
3	212	96	632	1200	122	7.1	1500	4200	600
4	178	94	580	1180	120	6.8	1250	4000	595
5	160	92	549	1017	120	7	1000	3800	575
6	140	82	513	1005	116	7.4	750	3500	550
7	120	74	476	980	111	6.3	700	3300	550
8	110	72	453	965	106	6.2	620	3100	530
9	110	56	428	960	105	6.8	610	3100	530
10	100	56	408	957	102	6.8	580	2900	505
11	96	44	387	952	100	6.8	550	2750	500
12	91	36	367	946	98	7	535	2555	475
13	87	36	354	940	94	7	500	2150	460
14	80	36	333	938	91	7.1	485	2000	465
15	80	35	328	931	90	7.2	480	1700	420
16	80	35	320	930	90	7.2	445	1655	415
17	76	33	304	925	88	7.2	425	1600	400
18	68	31	265	920	85	7.4	410	1600	370
19	63	31	237	900	84	6.8	400	1500	320
20	60	31	225	850	84	6.3	350	1125	315
21	54	31	205	830	80	6.2	300	1000	290
22	51	30	188	758	80	6.2	200	900	275
23	50	30	179	670	79	6.2	150	700	245
24	50	29	157	639	74	6.3	150	625	240
25	49	27	149	372	70	6.8	150	600	200
26	49	26	137	357	68	6.3	115	525	185
27	45	26	124	250	62	6.2	90	500	175
28	45	25	111	190	50	6.2	70	500	120
29	42	25	90	100	45	6.2	70	210	100
30	42	25	80	92	7	6.2	30	190	84

4.3.2 BACTERIOLOGICAL QUALITY

Bacteria and other micro-organisms are present in the aquatic environment. Because of problems in detecting disease-causing bacteria and viruses, the microbial safety of water is determined indirectly. normal intestinal bacteria are used as indicators of the degree of pollution by enteric wastes, and therefore, entero-bacterial pathogens.

In this study, the bacterial quality of storm water runoff is expressed in terms of MPN of coliform organisms and faecal coliforms (Table 4.9). The bacteriological quality standard for drinking water in Kenya is shown in table 4.10. This does not compare favourably with bacterial examination results obtained for six consecutive samples of storm runoff from the city centre (Table 4.9).

High counts of coliform bacteria, especially faecal coliform as revealed by storm runoff from the city centre indicates the presence of animal wastes, which may also support pathogenic organisms. Therefore the raw storm runoff is unsuitable for domestic, agricultural and industrial applications because according to the water quality source book:

a) Bathing water quality should not contain more than 200 faecal coliforms per 100 millilitres

b) Irrigation waters should not contain more than 20 faecal coliforms per 100 millilitres and

C) Brewing, soft drinks, and food processing industries should not have coliform bacteria counts greater than those of drinking water (Table 4.10).

TABLE 4.9: BACTERIOLOGICAL EXAMINATION OF STORM RUNOFF

Storm Number	MPN of Coliform Organisms	Faecal Coliform
1	≥2400 micro-organisms/100 mls	≥ 2400 micro-organisms/100 mls
2	≥2400 micro-organisms/100 mls	≥ 2400 micro-organisms/100 mls
3	≥2400 micro-organisms/100 mls	≥ 2400 micro-organisms/100 mls
4	≥2400 micro-organisms/100 mls	≥ 2400 micro-organisms/100 mls
5	≥2400 micro-organisms/100 mls	≥ 2400 micro-organisms/100 mls
6	≥2400 micro-organisms/100 mls	≥ 2400 micro-organisms/100 mls

Since the storm runoff is discharged in the receiving streams feeding the main Athi River, this is bound to affect the recreational use of its water for instance swimming. If the storm runoff from the city centre has to be used for irrigation, domestic and industrial applications or safely disposed through the sewerage network, then its proper treatment (chlorination) is paramount in order to achieve the bacterial quality recommended for each use and to protect the aquatic ecosystem especially for recreational purposes incase of direct disposal into the receiving streams.

However, for marginal quality uses such as fire fighting, washing vehicles, building construction and cooling factory machines, no bacterial quality guidelines have been formulated, though the water will still have to be chlorinated since these uses exposes it to human beings.

TABLE 4.10: BACTERIOLOGICAL QUALITY

Piped Supplies	Number per 100 ml
Treated water entering the distribution	Faecal coliforms 0; 3 coliform organisms in any one sample, 0 in any two consecutive samples, 0 in 98 per cent of yearly samples
Untreated water entering the distribution system	Faecal coliform 0; 3 coliform organisms organisms in any one sample, 0 in any two consecutive samples, 0 in 98 per cent of any yearly samples
Water in distribution system	Faecal coliform 0; 3 coliform organisms in any one, 0 in any two consecutive samples, 0 in 95 per cent of yearly samples
Unpiped Supplies	Faecal coliforms 0 Coliform organisms 10
Bottled drinking water	Faecal coliform 0 Coliform organisms 0
Emergency supplies of water	Faecal coliforms 0 Coliform organisms 0

Source: Kenya Bureau of Standards.

4.4 SUMMARY

The city centre generates large quantities of surface runoff during rainfall periods. Analytical results have revealed that this storm runoff water is not as heavily contaminated as would have been expected. Furthermore certain quality parameters such as cadmium, silver, molybdenum, nickel, and selenium were not detected. Zinc, lead, copper and mercury were only detected in the first three storms indicating that the first few storms have a cleaning effect on the city centre.

The quality parameters which were found to exist in considerably high concentrations as to cause concern in the management of storm runoff water from the city centre are: iron, manganese, Total Suspended Solids, Total Dissolved Solids, oxygen demand, colour and turbidity. However, all these quality parameters can be regulated through conventional water treatment except oxygen demand (BOD and COD) which requires aeration.

It is also apparent from the analytical results that all the physicochemical quality parameters (except pH which is a highly variable parameter) decrease with subsequent storms. This implies that each storm reduces the contamination of the next storm (see figures 7-20). Figures indicates at which point the storm runoff water can be harvested for domestic, agricultural and industrial uses considering the guidelines recommended [appendix 1(a)-(f)]. They also show from which point the storm runoff water becomes harmful to flora and fauna of the receiving streams.

Because of the poor bacteriological quality of this storm runoff water, it is imperative, that it is thoroughly disinfected either before harvesting or disposing into the receiving streams as the case may be.

Fig 6 : Calcium concentration in consecutive storms

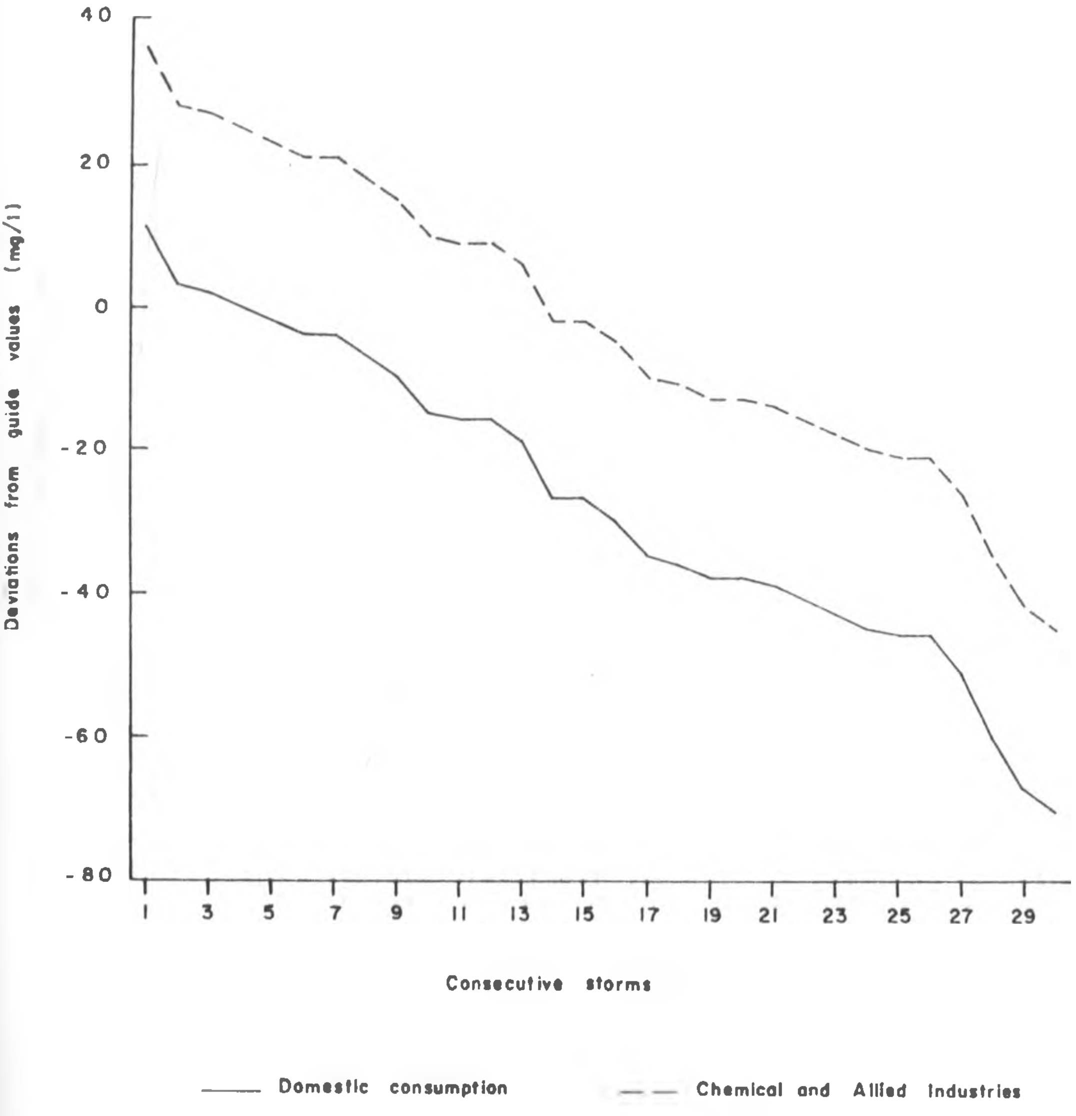


Fig. 7 : Magnesium Concentration In Consecutive Storms

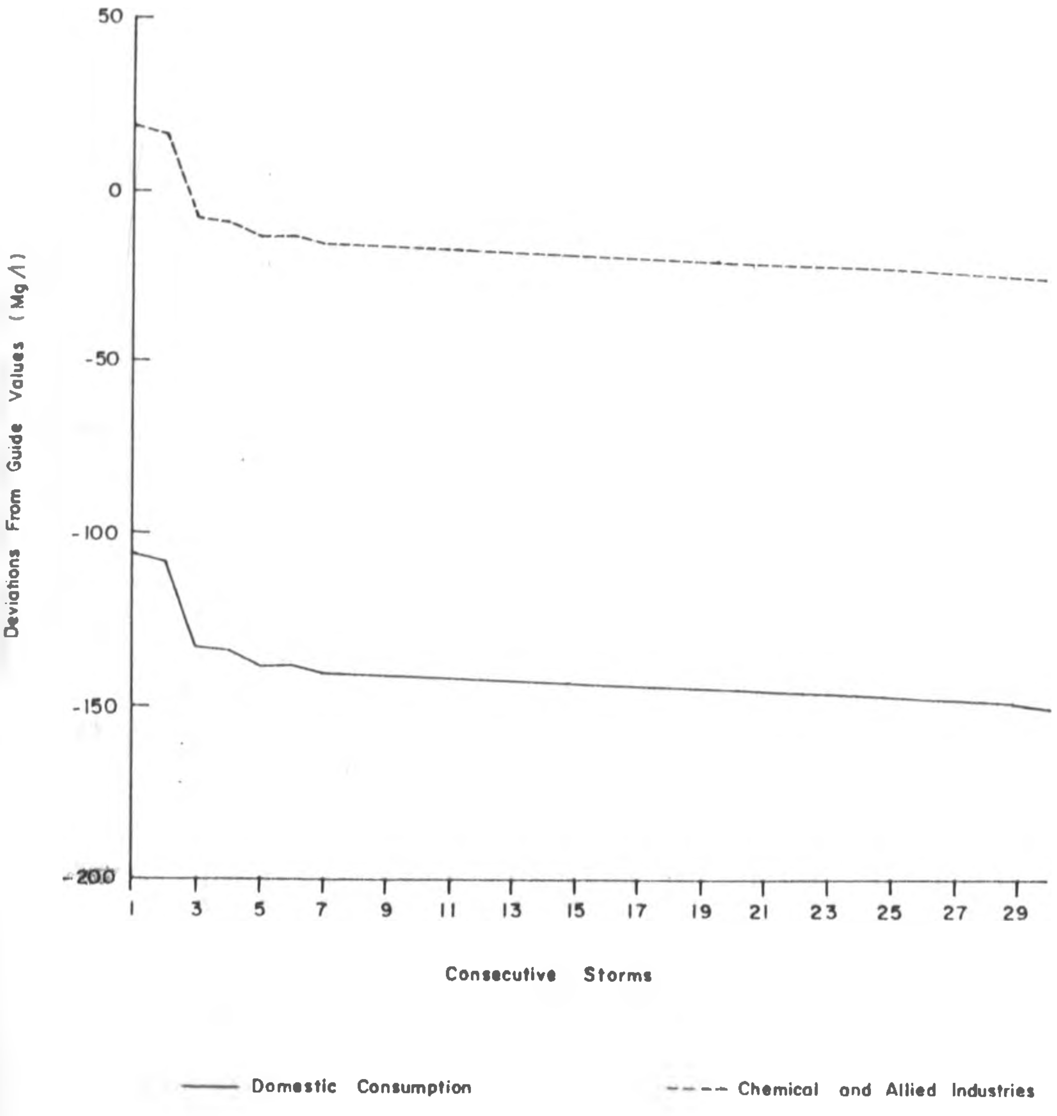


Fig 8 : Sodium concentration in consecutive storms

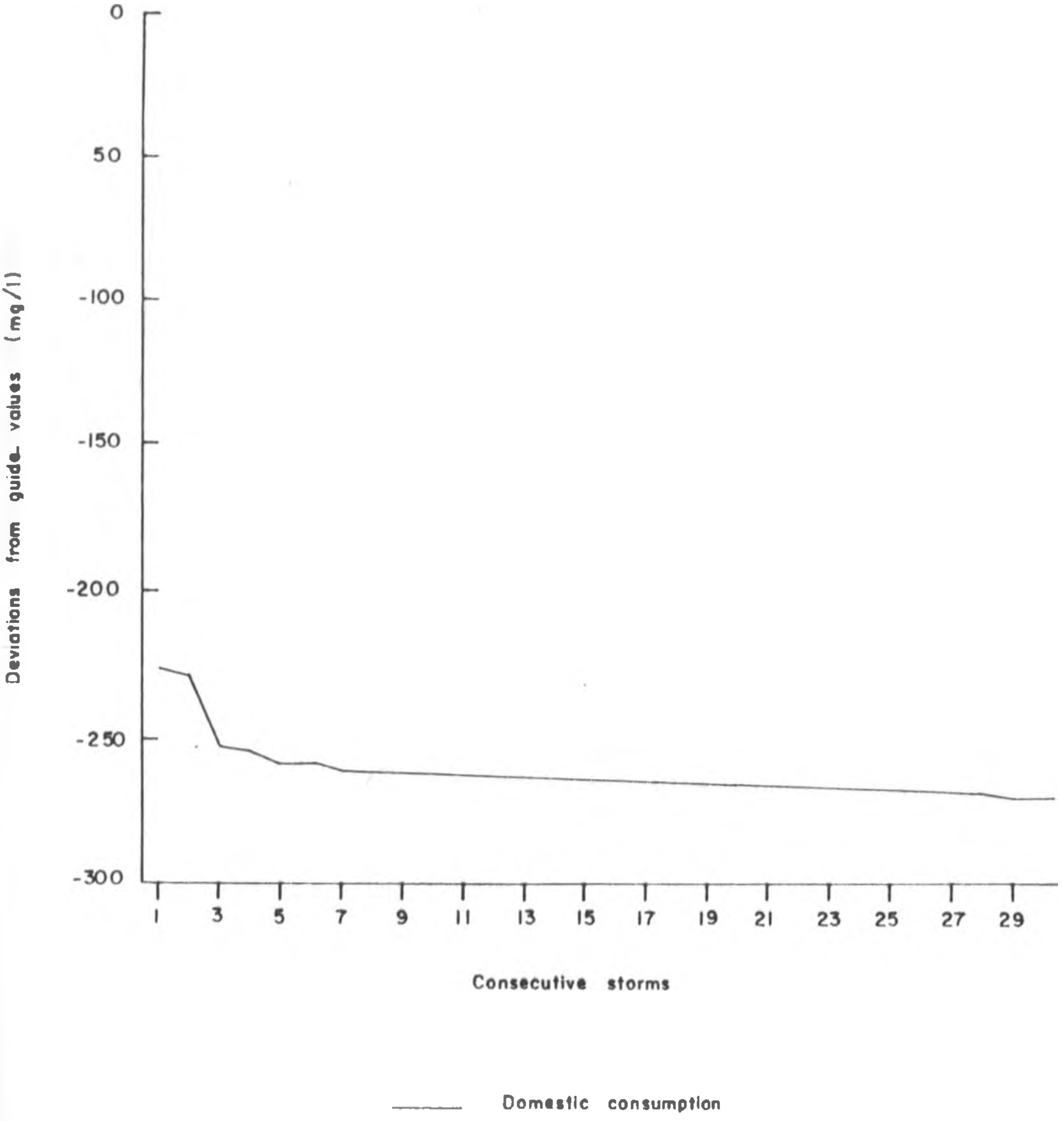


Fig. 9 : Iron concentration in consecutive storms.

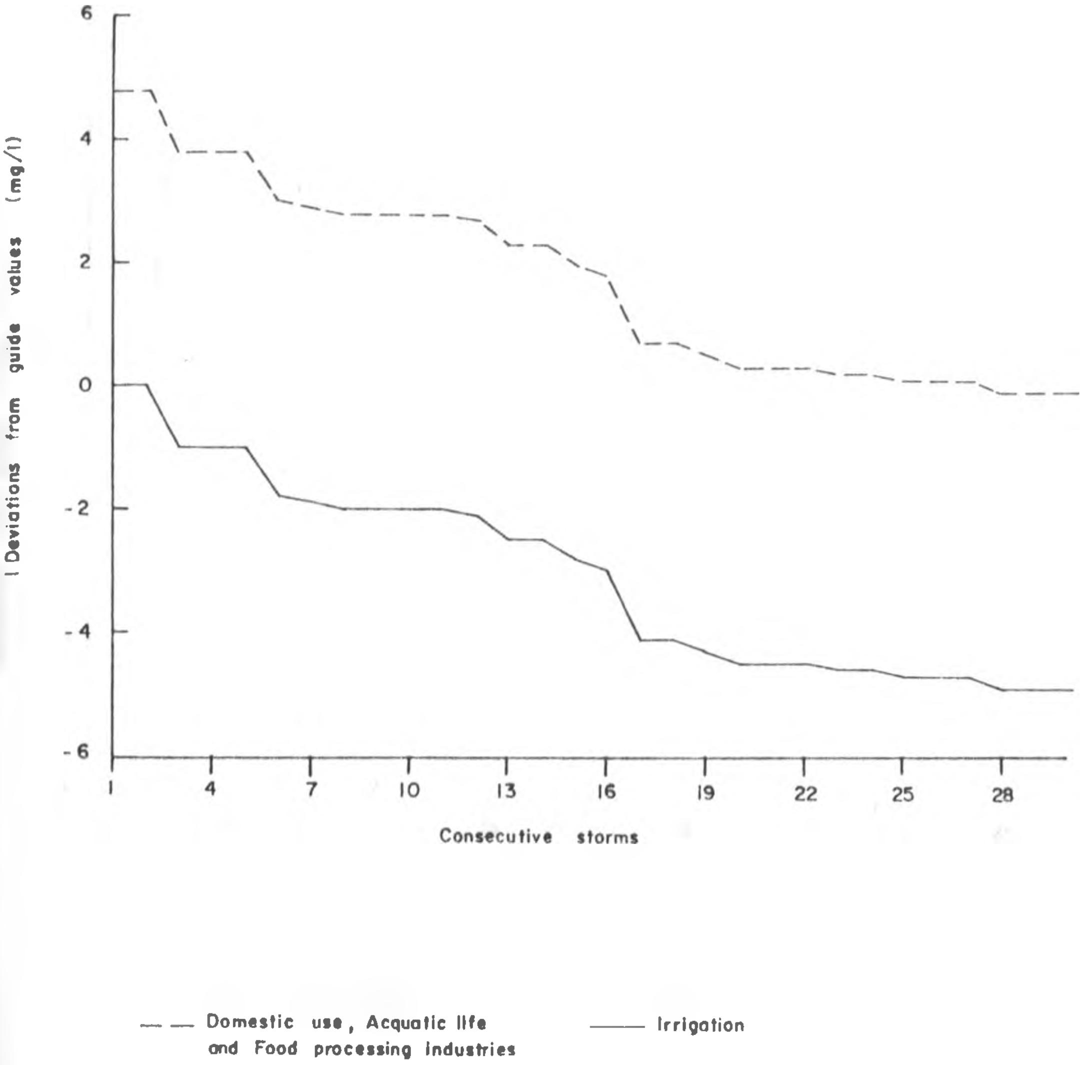


Fig. 10 : Manganese concentration in consecutive storms.

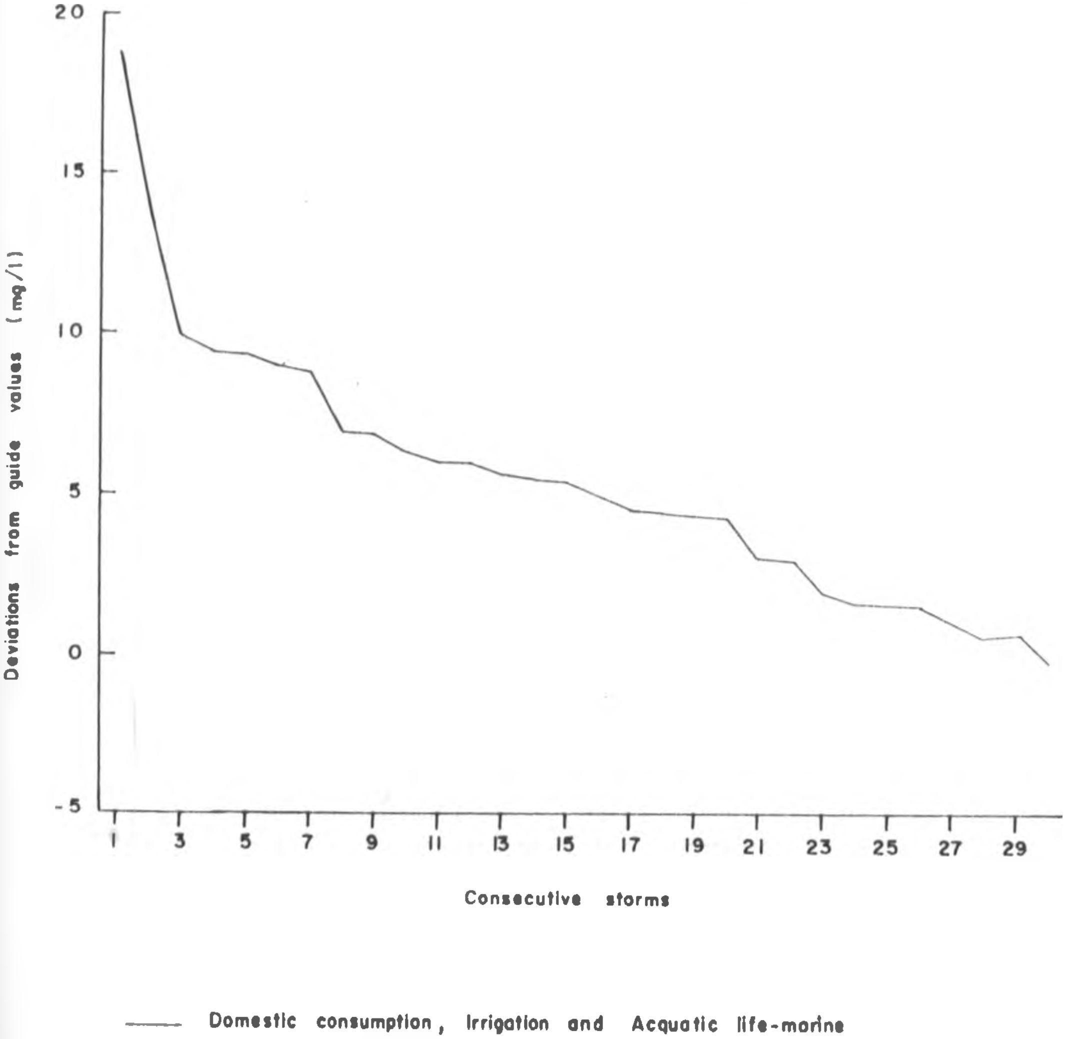


Fig. 11: Alluminium concentration in consecutive storms.

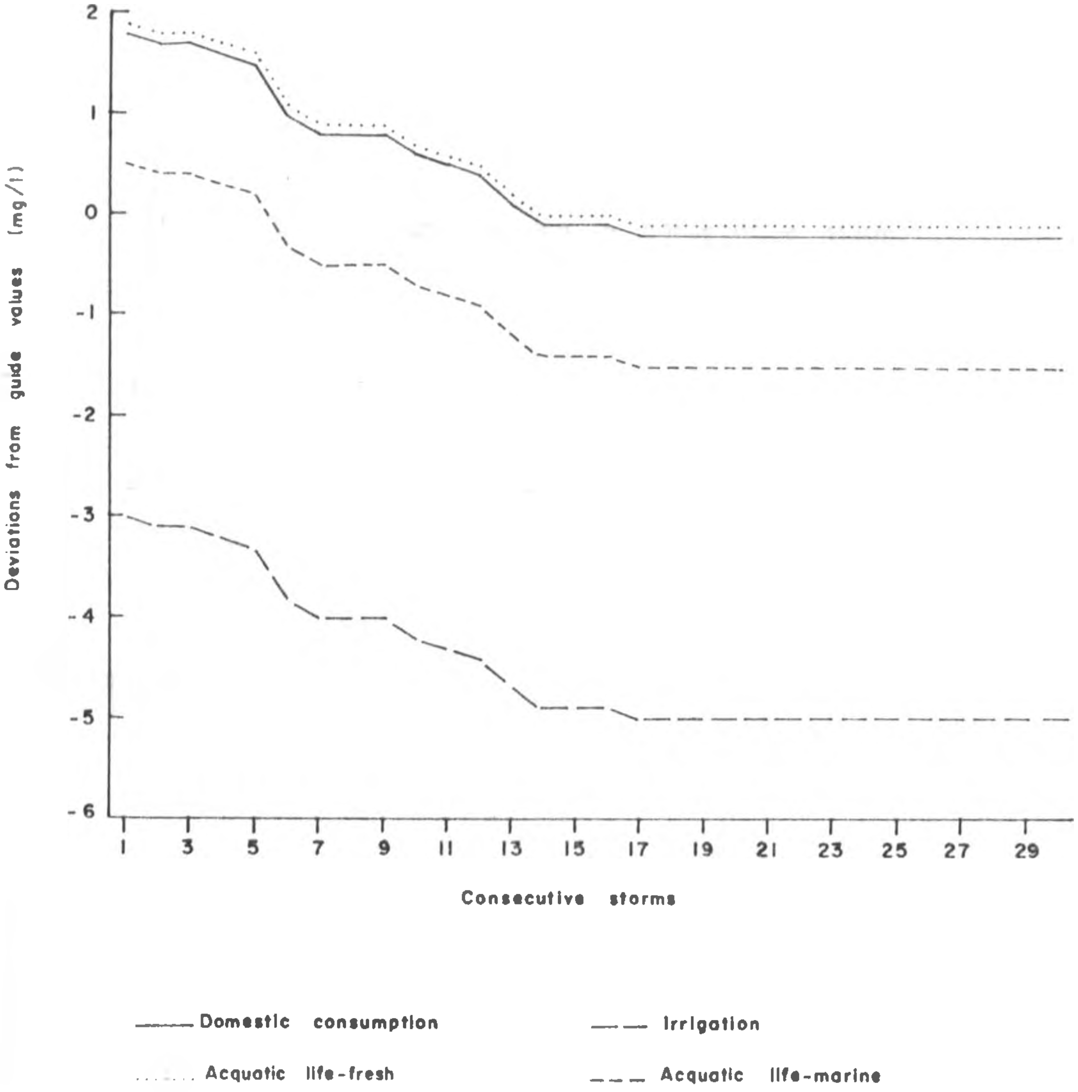


Fig. 12 : Copper concentration in consecutive storms

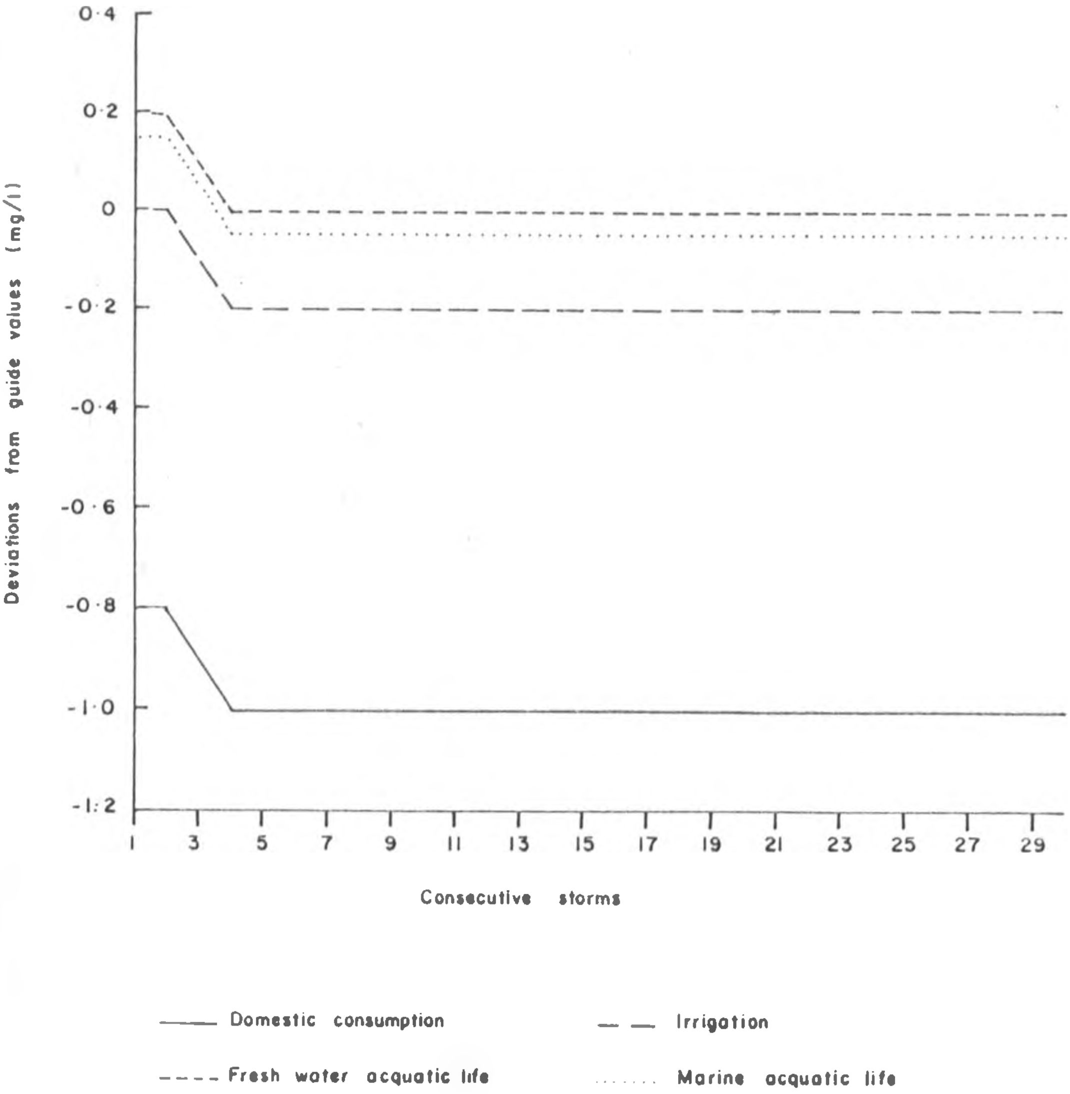


Fig 13: Lead concentration in consecutive storms.

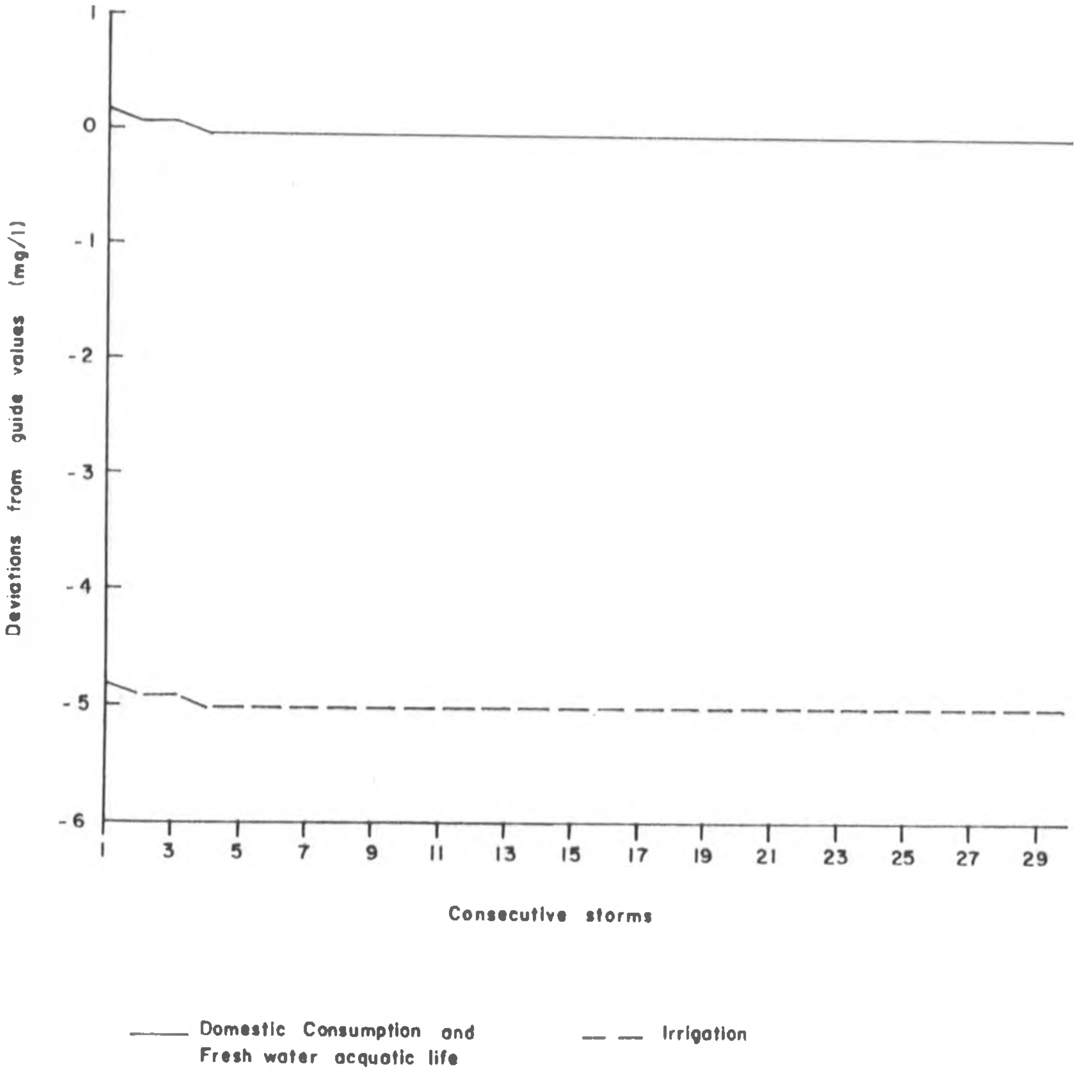


Fig. 14 : Zinc concentration in consecutive storms.

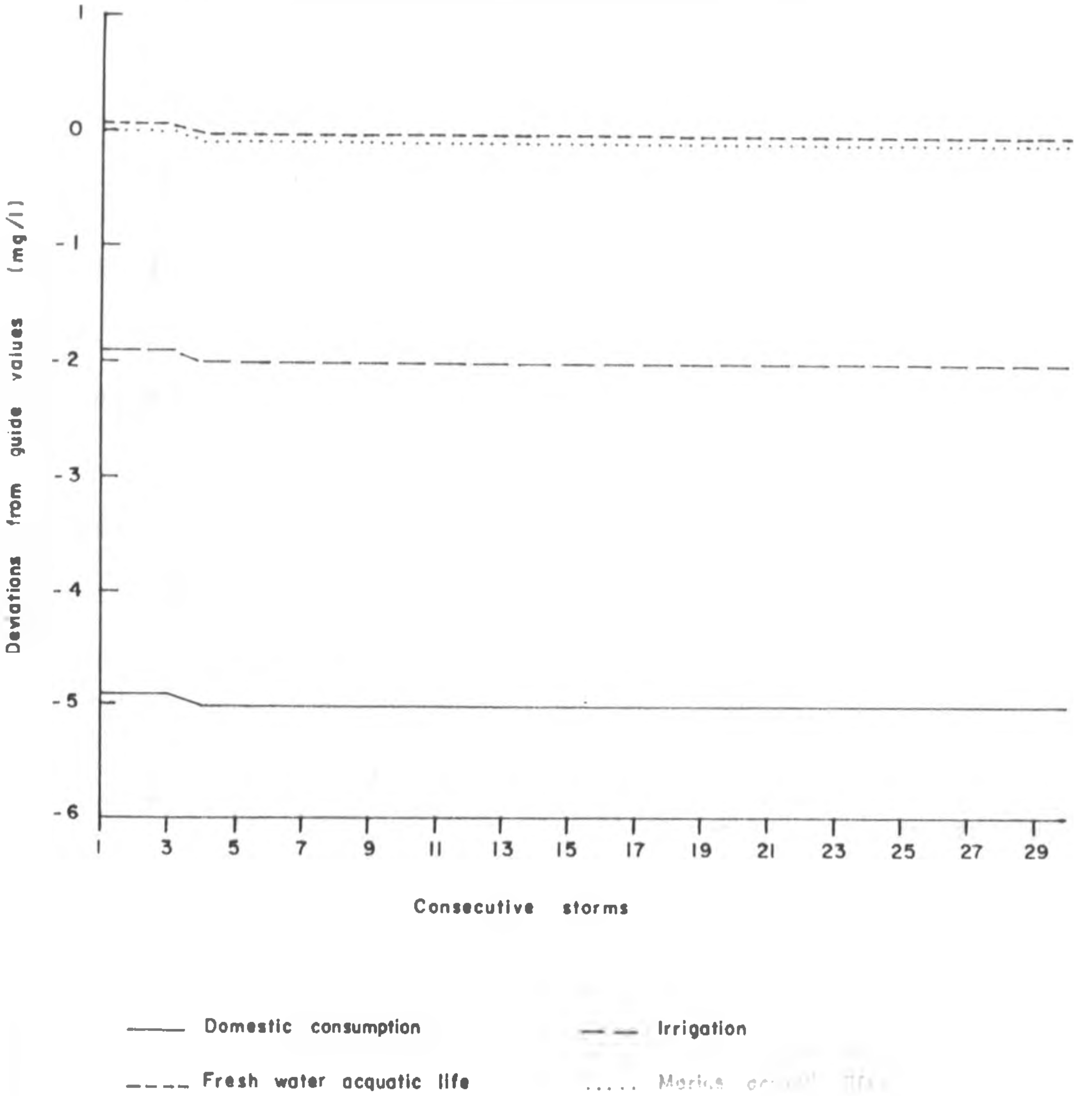


Fig 15 : Cadmium concentration in consecutive storms

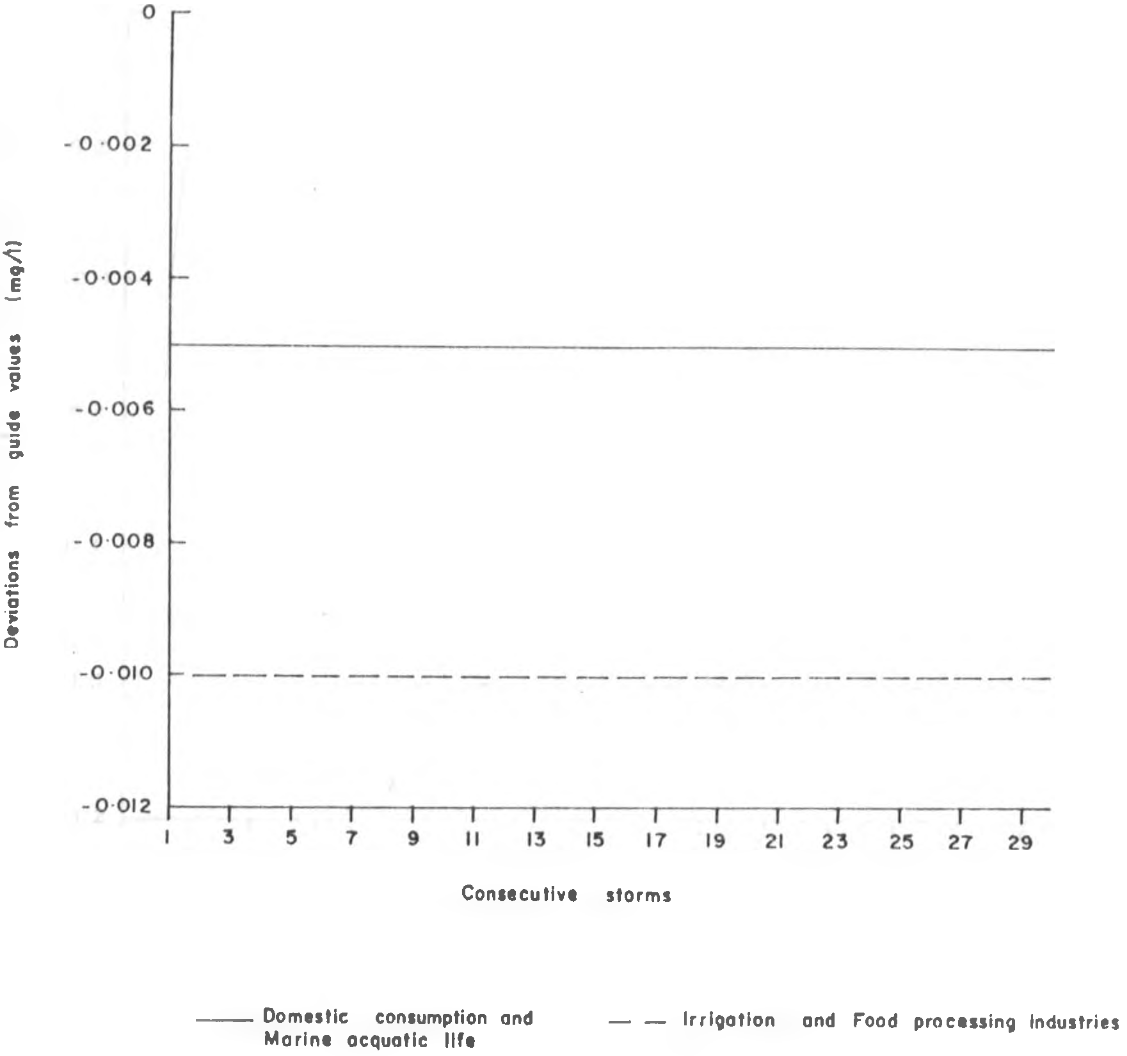


Fig.16 : Mercury concentration in consecutive storms

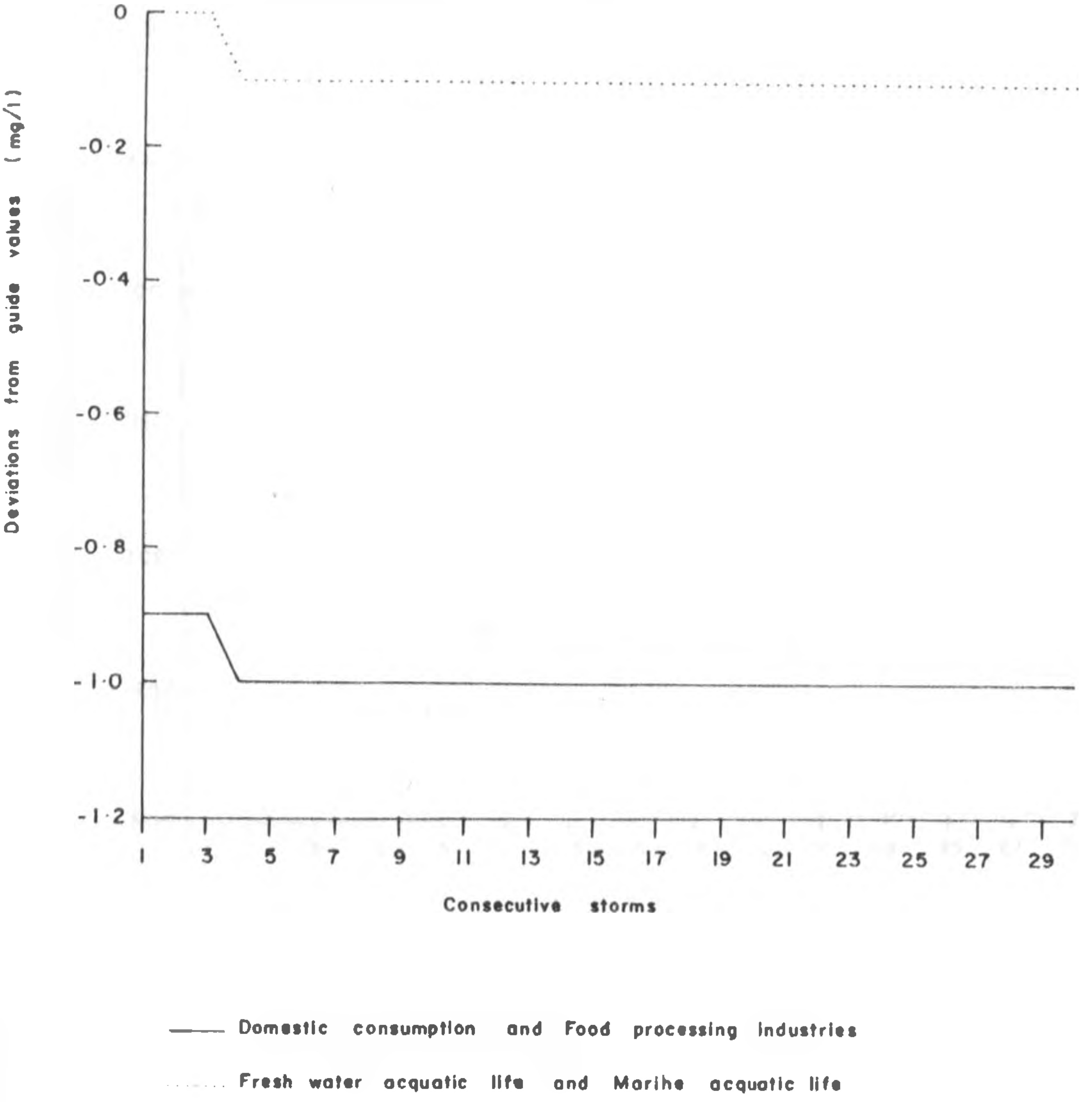


Fig. 17 : Chloride concentration in consecutive storms.

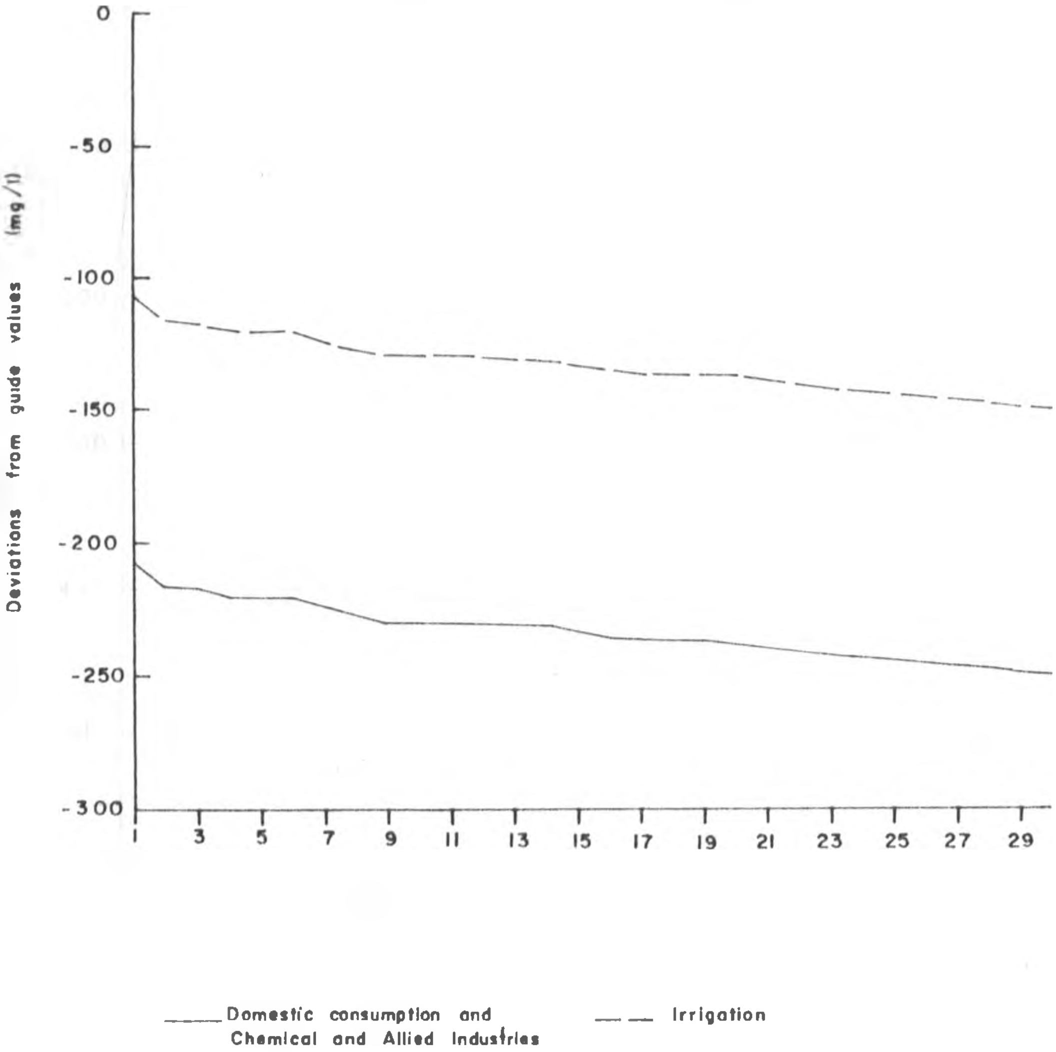


Fig. 18 : Sulphate concentration in consecutive storms.

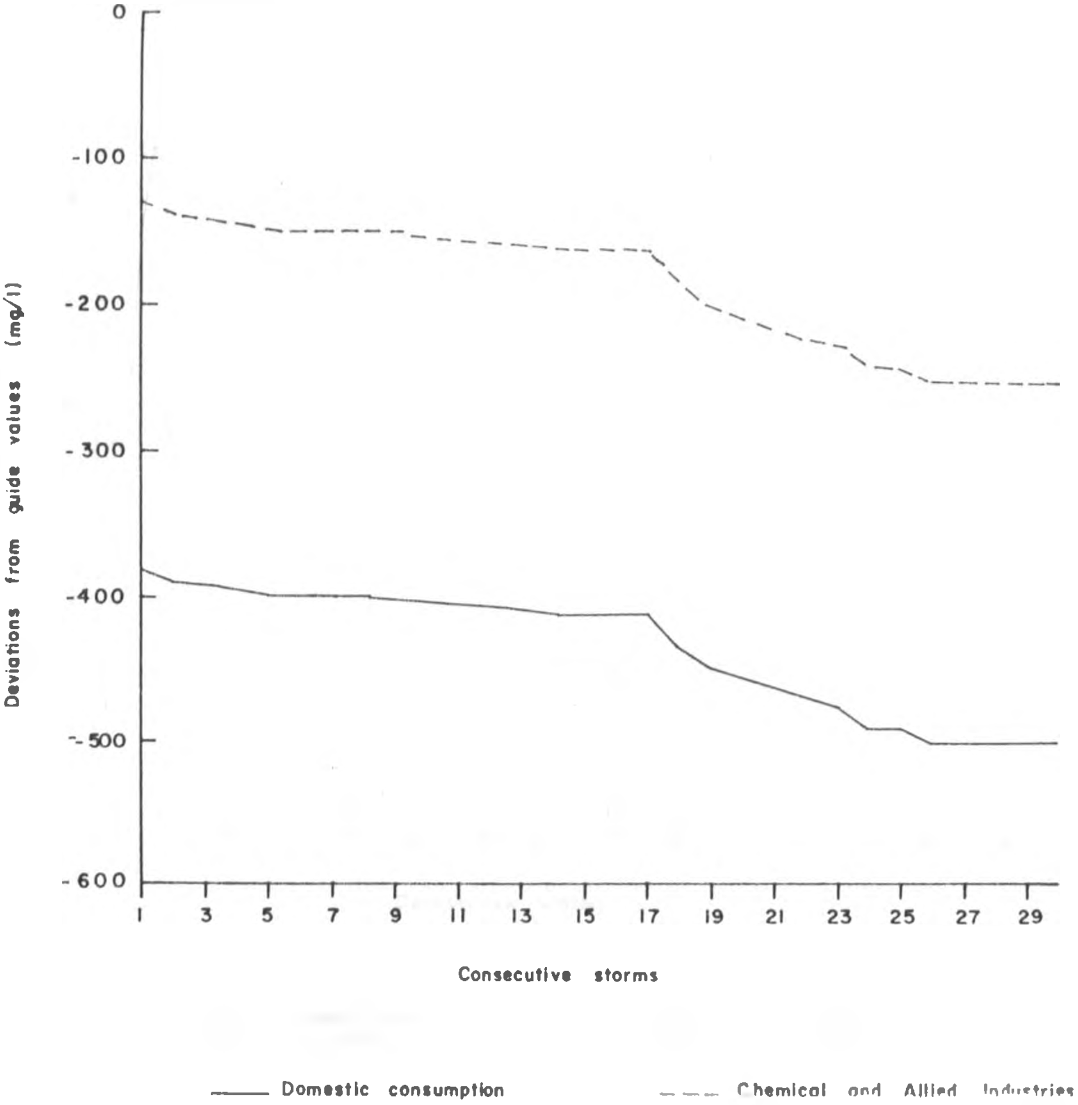


Fig 19 : Fluoride concentration in consecutive storms.

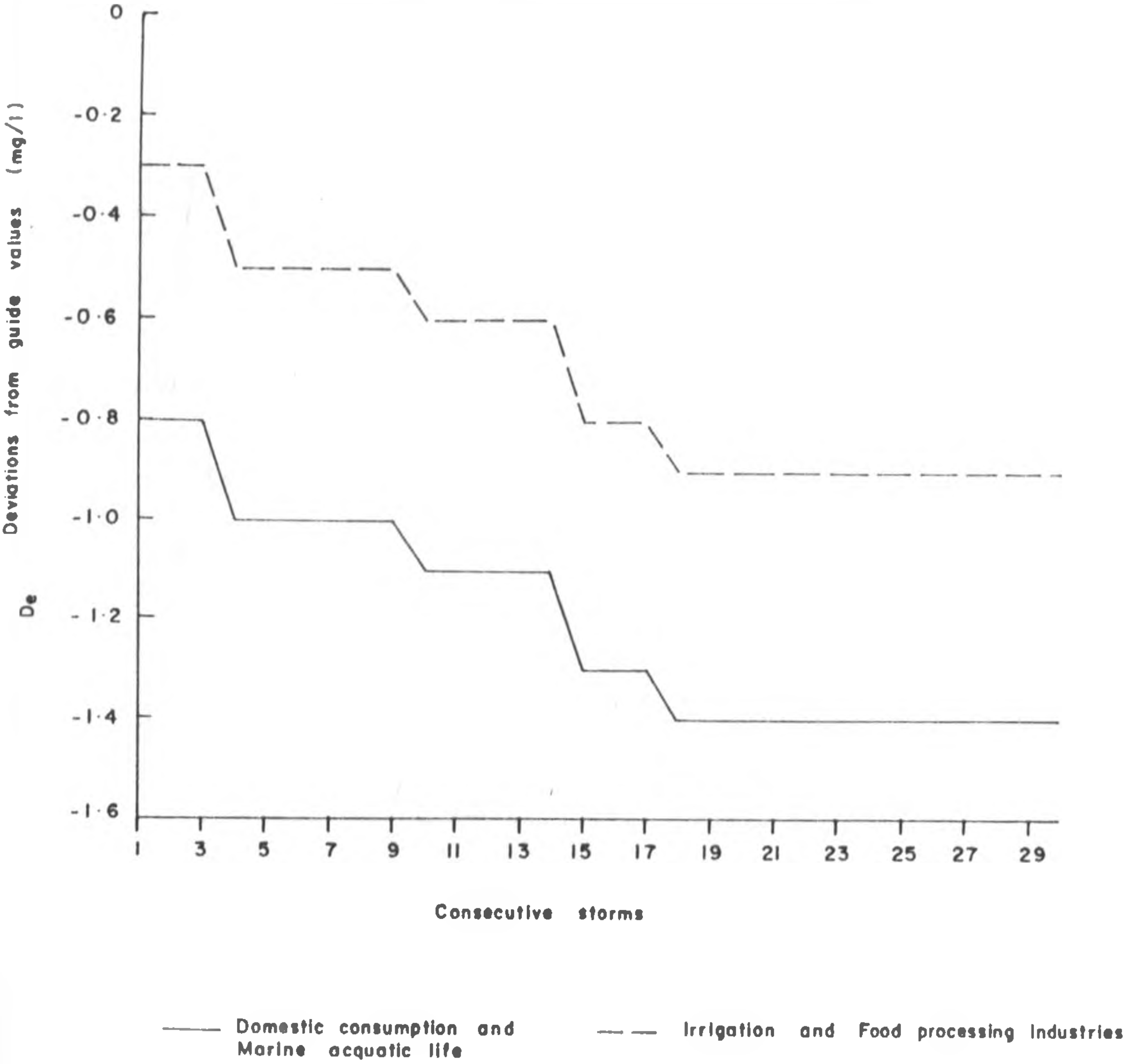
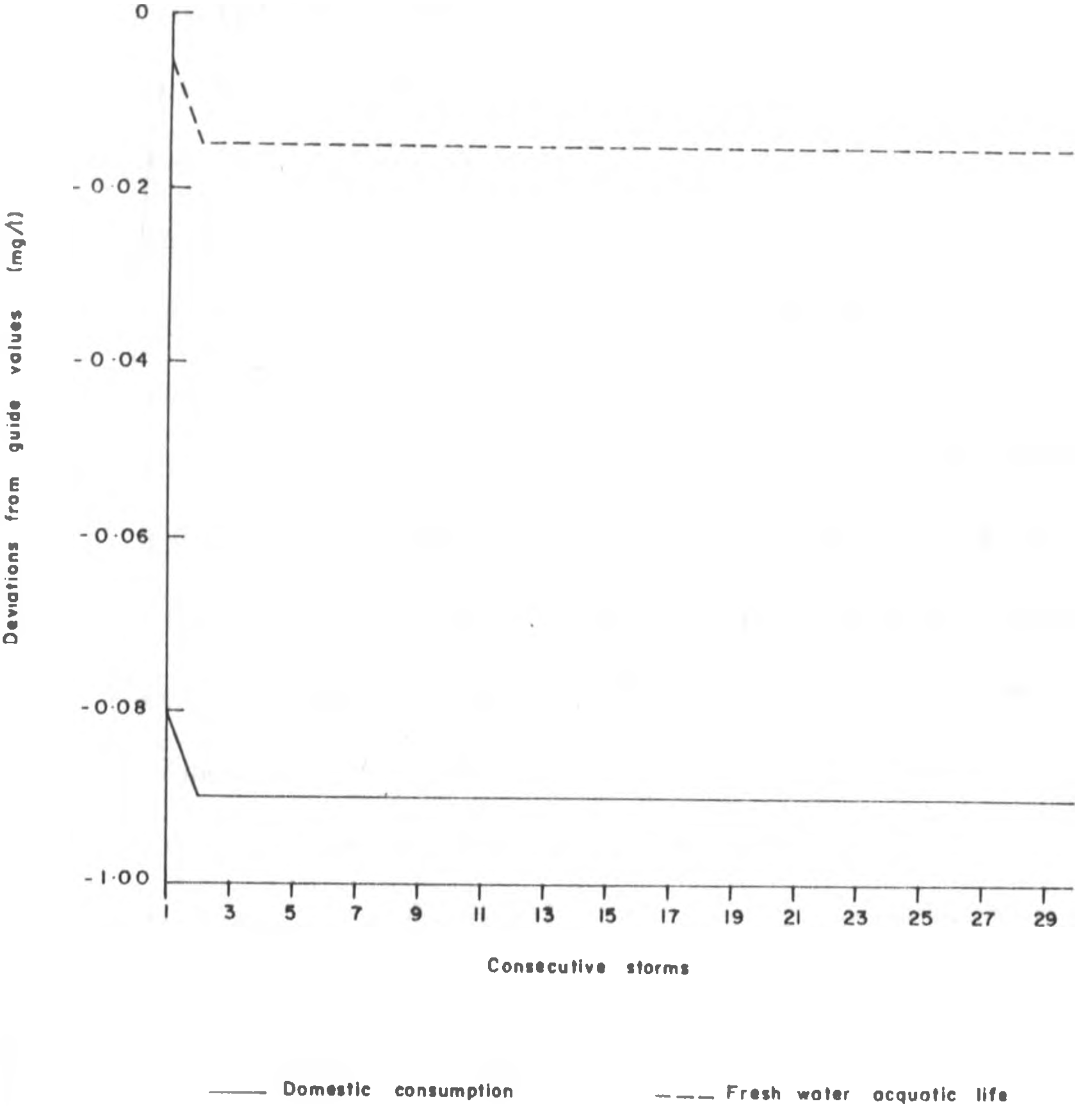


Fig 20. Phosphate concentration in consecutive storms.



CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

i) Over 90% of rainfall received in the city centre is conveyed as runoff because of the large impervious surface.

ii) The current storm-water drainage system within the city centre is not able to cope with the surface runoff generated especially during heavy storms.This is one of the main causes of flooding within the city centre.

iii) Despite the high turbidity, colour, Total Suspended Solids and oxygen demand, storm water runoff from the city centre is not heavily contaminated.

iv) Contaminants in storm water runoff generally decrease with consecutive storms except the pH and bacterial count. This could be attributed to the high variability of these quality parameters.

v) The quality characteristics of storm water runoff from the city centre compare favourably with designated guidelines for domestic, industrial and irrigation use, and protection of aquatic ecosystems for most of the storms. That is, for most quality parameters, the storm water runoff does not vary significantly from designated guidelines for these uses.

vi) The bacteriological quality of storm runoff water is very poor.

vii) Cadmium, silver, Chromium, molybdenum and selenium were not detected in any of the thirty runoff water samples.

viii) Zinc, lead, copper and mercury were detected in the first three runoff water samples only.

ix) Surface runoff from the city centre is not heavily contaminated with heavy metals.

5.2 CONCLUSIONS

In the light of the above findings, it is evident that large quantities of surface runoff is generated from the city centre during the rainy season. However, the present storm drainage network is not capable of efficiently conveying this water hence the recurrent floods. Therefore any attempt to effectively manage the flood water within the city centre should consider the redesigning of the drainage network.

Even though the storm runoff water is not heavily contaminated with heavy metals, its bacteriological quality is poor. Consequently, any attempt at treating this water for either safe disposal or abstraction should ensure thorough chlorination. Since Turbidity, Total Suspended Solids and oxygen demand in the storm runoff are high relative to guideline values for various uses, their removal is also significant.

In order to lessen treatment costs, the storm runoff (which is more contaminated) from the initial storms should be treated partially and then disposed off into the receiving streams or channelled to the sewerage system for purposes of dilution .The subsequent storms can then be thoroughly treated and harnessed for various uses as the quality (based on the efficiency of treatment) may allow.

5.3 RECOMMENDATIONS

Based on the major findings of this study, the following recommendations have been made:

a) RECOMMENDATIONS FOR POLICY MAKERS

i) The drainage system within the city centre should be redesigned in order to cope with the rapid changes taking place in this area which are continuously increasing the impervious area.

ii) Cleaning of the drainage network especially during the dry spell should be enforced as a way of minimizing clogging of the drains.

iii) The gutter system on the buildings within the city centre should be effectively linked to the drainage network in order to harness all the rain water falling on the buildings.

iv) Local urban storm water quality guidelines should be devised for the purposes of managing this water.

v) The storm water runoff from the city centre should be stored, treated and then utilized for uses requiring marginal quality water. However, incase the treatment plant developed is efficient enough, then the resultant treated storm water runoff can be used for domestic, irrigation and industrial purposes. This will go a long way in supplementing the already strained water supply within the city.

vi) Any major construction site must have properly designed sediment traps in order to minimize the amount of sediments carried into the drainage network.

vii) Garbage dumps should regularly be removed from the city centre since they contribute to the clogging of the storm drains and are also a major source of pollution.

viii) The best solution to the urban runoff problem is to detain the stormwater in small volumes as near to its source as possible, and then to release it slowly to natural stream channels, the groundwater system or a central storage system. Because most of the storm runoff generated in urban areas originates on impervious surfaces such as rooftops and parking lots, one obvious method of runoff control is the storage of the water in these very areas. For instance, many new flat-topped buildings in the CBD are designed to hold upto three inches of water on their roofs. In a developed area like Nairobi's CBD, roofs occupy over 50% of the built-up area, so roof storage can control a major portion of the storm runoff hence the need for an efficient connection of the gutter system to the storm sewer system. Large parking lots can also be designed to store conveniently as much as three inches of water, and even pedestrian malls and plazas can be designed to provide one inch of ponding.

ix) Detention storage may also be privided underground. Metal or concrete tanks can be installed below ground, and overflow from storm sewers is diverted into them. The water may drain back to the sewer after the storm, or if heavily polluted (as is the case in the initial storms), it may be diverted to the sanitary sewer system for treatment.

x) Stormwater can be allowed to recharge groundwater which augments dry weather streamflow. However, careful exploration of the local geology is necessary before recharge is allowed to ensure that the stormwater does not pollute shallow aquifers being used for water supply.

xi) There is need to establish stormwater quality monitoring stations covering all the landuse types within the city. This will go a long way in ensuring that the quality of this water is under strict surveillance.

xii) There is need to intensify the meteorological network within the city in order to obtain representative and reliable data especially of rainfall for accurate forecasting and storm water design.

b) RECOMMENDATIONS FOR FUTURE RESEARCHERS

i) Water quality characteristics of storm runoff generated from other urban landuse types within the city (e.g residential, industrial and recreational) should be investigated with a view to developing an integrated storm drainage system for the whole city.

ii) Spatial-temporal variation of water quality characteristics of rainfall over the city should be studied since it has a bearing on the quality of storm runoff.

iii) A comprehensive study should be carried out to establish the specific sources of contaminants in the storm runoff water from the city centre.

iv) There is need for a detailed study on flood frequency and risk analysis within the city to enable the formulation of effective mitigation measures.

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APPENDIX 1(a): MAXIMUM ACCEPTABLE LEVELS IN WATER USED FOR DOMESTIC CONSUMPTION

PARAMETER	LEVEL
Iron, as Fe	LE 0.3 mg/l
Manganese, as Mn	LE 0.05 mg/l
Calcium, as Ca	LE 200 mg/l
Magnesium, as Mg	LE 150 mg/l
Sodium, as Na	LE 270 mg/l
Aluminium, as Al	
Total Hardness, as $CaCO_3$	
Total Alkalinity, as $CaCO_3$	GE 30 mg/l
Chloride, as Cl	LE 250 mg/l
Fluoride, as F	LE 1.5 mg/l
Nitrite, as N	LE 1 mg/l
Sulphate, as SO_4	LE 500 mg/l
Phosphate, as P	LE 0.1 mg/l
Total Suspended Solids	NONE
Total Dissolved Solids	LE 500 mg/l
pH	6.5-8.5
Colour	LE 15 TCU
Turbidity	LE 5 NTU
Zinc, as Zn	LE 5 mg/l
Cadmium, as Cd	LE 0.005 mg/l
Lead, as Pb	LE O.05 mg/l
Copper, as Cu	LE 1 mg/l
Mercury, as Hg	LE 1

APPENDIX 1(b): GUIDELINES FOR IRRIGATION OF ACIDIC SOILS/CONTINUOUS USE (ALL SOILS)

PARAMETER	LEVEL
Iron, as Fe	LE 5 mg/l
Manganese, as Mn	LE 0.2 mg/l
Aluminium, as Al	LE 5 mg/l
Chloride, as Cl	LE 150 mg/l
Fluoride, as F	LE 1 mg/l
Zinc, as Zn	LE 2 mg/l
Chromium, as Cr	LE 0.1 mg/l
Cadmium, as Cd	LE 0.01 mg/l
Copper, as Cu	LE 0.2 mg/l
Lead, as Pb	LE 5 mg/l
Molybdenum, as Mo	LE 0.01 mg/l
Nickel, as Ni	LE 0.2 mg/l
pH	GE 4.5
Total Dissolved Solids	LE 500 mg/l
Selenium, as Se	LE 0.02 mg/l

APPENDIX 1(c): GUIDELINES FOR THE PROTECTION OF FRESHWATER AQUATIC LIFE

PARAMETER	LEVEL
Aluminium, as Al	LE 0.1 mg/l
Copper, as Cu	LE 0.005 mg/l
Chromium, as Cr	LE O.04 mg/l
Iron, as Fe	LE 0.3 mg/l
Lead, as Pb	LE 0.03 mg/l
Mercury, as Hg	LE 0.1
Nickel, as Ni	LE 0.025 mg/l
Phosphate, as P	LT 0.025
Zinc, as Zn	LE 0.03 mg/l
Total Alkalinity, as $CaCO_3$	GT 20 mg/l
Total Suspended Solids	LE 25 mg/l

APPENDIX 1(d): GUIDELINES FOR THE PROTECTION OF MARINE AQUATIC LIFE

PARAMETER	LEVEL
Iron, as Fe	LT 0.3 mg/l
Manganese, as Mn	LE 0.1 mg/l
Aluminium, as Al	LE 1.5 mg/l
Fluoride, as F	LT 1.5 mg/l
Copper, as Cu	LT 0.05 mg/l
Chromium, as Cr	LE 0.1 mg/l
Cadmium, as Cd	LE 0.005 mg/l
Zinc, as Zn	LT 0.1 mg/l
Mercury, as Hg	LE 0.1
Nickel, as Ni	LT 0.1 mg/l
Silver, as Ag	LT 0.005 mg/l
Selenium, as Se	LT 0.01 mg/l
pH	6.5-8.5

APPENDIX 1(e): GUIDELINES FOR CHEMICAL AND ALLIED INDUSTRIES

PARAMETER	LEVEL
Total Alkalinity, as $CaCO_3$	LE 150 mg/l
Calcium, as Ca	LE 50 mg/l
Chloride, as Cl	LE 250 mg/l
Colour	LE 20 TCU
Total Hardness, as $CaCO_3$	LE 250 mg/l
Iron, as Fe	LE 0.3 mg/l
Magnesium, as Mg	LE 25 mg/l
Manganese, as Mn	LE 0.1 mg/l
pH	6.5-8.5
Silicon, as SiO_2	LE 50 mg/l
Sulphate, as SO_4	LE 250 mg/l
Total Suspended Solids	LE 15 mg/l
Total Dissolved Solids	LE 750 mg/l

APPENDIX 1(f): GUIDELINES FOR FOOD PROCESSING INDUSTRIES

PARAMETER	**LEVEL**
Total Alkalinity, as $CaCO_3$	LE 150 mg/l
Cadmium, as Cd	LE 0.01 mg/l
Chloride, as Cl	LE 250 mg/l
Chromium, as Cr	LE 0.1 mg/l
Colour	LE 5 TCU
Fluoride, as F	LE 1 mg/l
Total Hardness, as $CaCO_3$	LE 150 mg/l
Iron, as Fe	LE 0.2 mg/l
Manganese, as Mn	LE o.2 mg/l
Mercury, as Hg	LE 1
pH	6.5-8.5
Silicon, as SiO_2	LE 50 mg/l
Total Suspended Solids	LE 10 mg/l
Total Dissolved Solids	LE 500 mg/l

APPENDIX 2: ORGANIC CONSTITUENT OF HEALTH SIGNIFICANCE

	SUBSTANCE	LIMIT(Mg/l)
1	Benzene	10
2	Chlorinated Alkanes and Alkenes	
	i) Carbon tetrachloride	3
	ii) 1,2-Dichloroethane	10
	iii) 1,1-Dichloroethylene	0.3
	iv) Tetrachloroethylene	10
	v) Trichloroethylene	30
3	Chlorophenols	
	i) Tentachlorophenol	10
	ii) 2,4,6-Trichlorophenol	10
4	Polynuclear Aromatic Hydrocarbons	
	i) Benzo (a) Pyrene	0.01
5	Trihalomethanes	
	i) Chloroform	30
6	Pesticides	
	i) Aldrin/Dieldrin	0.03
	ii) Chlordane(total)	0.3
	iii) 2,4 D	100
	iv) DDT(total)	1
	v) Heptachlor and heptachlor Epoxide	0.1
	vi) Hexachlorobenzene	0.01
	vii) Lindane	3
	viii) Methoxychlor	30