ANTHROPOGENIC IMPACTS ON FLOW REGIME AND WATER QUALITY OF NGONG RIVER IN NAIROBI

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as the University Supervisors.

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DEDICATION

This work is dedicated to my Late Father, Mr. Joseph Simon Kinyari, for the best inheritance he provided by educating me and my siblings. Our lives will surely be a reflection of the selfless love that you had for us. This work is also dedicated to all those with dreams of a restored Nairobi with Clean rivers.

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ABBREVIATIONS

BOD$_5$ - Five day test for Biological Oxygen Demand

GPS - Global positioning system

GIS - Geographic Information System

DEST - Dandora Sewerage Treatment plant

ET - Evapotranspiration

NEMA - National Environmental Management Authority

WHO - World Health Organisation

mg/l - milligram per litre

FAO - Food and Agriculture Organisation

µs/cm - microsiemens per centimetre

EC - Electrical Conductivity

DO - Dissolved Oxygen

TSS - Total Suspended solids

TDS - Total Dissolved solids

HSD - Honestly Significant Difference

NCWSC - Nairobi City Water and Sewerage Company

SCS - Soil Conservation Service

masl - metres above sea level

APPENDIXES

ABSTRACT

Water resource management involves the monitoring and management of water quality and water quantity. This research project was designed after several extensive case studies that revealed lack of adequate information on interaction between water quantity and quality of Ngong River. Many of those research investigations indicate that the river is highly polluted and almost no information about water quantity is presented.

This report is compiled based on water quality and water level data collected from five flow measuring stations set up along the Ngong River and four sewer stations for a period of 5 months (July to December, 2006). The stations namely: Kibera, Nairobi Dam Outlet, Mombasa Road crossing, Outering Road crossing and Njiru Bridge. The sewer stations were located at Kibera, Enterprise road, Imara Daima and Outering Road. Water levels were determined daily for a period of five months and the data was converted into discharge by use of Manning's equation. Daily rainfall data was collected and the SCS Curve number method was used to estimate direct runoff depths within Ngong river basin.Water quality assessment was done for a wide range of physical and chemical water quality parameters. Microsoft Excel and SPSS version 10 software were used for statistical analysis. Results were screened against NEMA, FAO and WHO standards, and were compared across the five sampling stations in the dry and wet seasons to assess suitability for domestic and irrigation use.

Flow in the Ngong River increases downstream with the lowest average flow rates experienced at the Kibera (0.090m^3/s) and Nairobi Dam outlet (0.856 m^3/s) stations. Mombasa Road station had an average flow of 5.452 m^3/s. Higher flows were recorded downstream at Outering Road (6.283 m^3/s) and Njiru (7.003 m^3/s) stations.

Direct runoff contribution from areas above Kibera and Nairobi Dam Outlet station was 7% and 78%, of the measured water yields, respectively. Water yields at the downstream stations is contributed by other sources other than direct runoff which were identified as extra water from wastewater discharges of overflowing manholes and open drains, and stormwater runoff.

The highest pollutant concentrations found in Ngong river water were heavy metals (lead and cadmium), nitrate and residues (suspended and dissolved solids). There were reduced levels of EC, Nitrates, TSS and TDS during the wet weather whilst increasing levels of lead and cadmium reported. Lead values increased in the wet season ranging from 0.39-0.46mg/l. The heavy metal levels recorded at all stations were below the FAO guidelines for irrigation water - 5mg/l for lead and 0.5mg/l for Cadmium. Sewer water contaminant loading of TSS and TDS were found to be decreasing during the wet weather. BOD_5 values of these sewers waters were high ranging from 103-500mg/l. These high values are above the NEMA effluent discharge standard which allows for only treated wastewaters to be discharged in water courses. Heavy metal levels increased during the wet season with lead values ranging from 0.39-0.44mg/l and cadmium values ranging from 0.08-0.12mg/l.

Downstream river stations recorded increased levels of water quality parameters against constant discharge rates implying that Ngong River cannot sustain its assimilative capacity as it is heavily polluted. Ngong River at Kibera station can be described as adequate since water sampled complied with WHO and NEMA standards for most parameters except for Nitrates. According to FAO irrigation water standards, Ngong River is fit for irrigation however this should be cautioned due to the long-term effects on the soils and crops. Frequent water quality monitoring programs combined with the enforcement of NEMA criteria and guidelines on effluent discharges, improvement of sewer infrastructure, protection of riparian areas, control of direct waste discharges, decreasing surface run-off distances and, the creation of pervious areas for increased infiltration, can be adopted to restore the hydrological system of the Ngong River.

CHAPTER 1

1.0: GENERAL INTRODUCTION

1.1 Background of Study

The Ngong River also known as Motoine River is one of the three main rivers, whose sources are Motoine swamp and Dagoretti forest to the north of Nairobi city, that flow within the Nairobi River basin. The Ngong River basin comprises of diverse land use types namely: forests, farmlands, and built-up areas (roads and buildings), which diversely affect the river water quality and quantity adversely.

The Ngong River has been studied intensely over the past two decades to assess the water quality. Most results indicate that the levels of pollution are rising progressively (Wandiga et al, 2005). This is attributed to population growth leading to increased demand for expansion of urban, agricultural and industrial activities. Krhoda (2002) names the core sources of pollution as: uncontrolled disposal of human excreta at Kibera, Mukuru and Dagoretti-Satellite informal settlements; the disposal of solid waste, blockages and or breakages of sewage lines within Industrial Area and, the discharge of untreated waste-water from large-scale and cottage (*Jua-Kali*) industries.

Natural phenomena such climate, geology (DWAF, 1995, Boorman, 2003), including the spatiotemporal variation of water-flow, i.e. the flow regime (Nilsson and Renofalt, 2008), are factors that influence river water quantity and quality. Seasonal events such as floods and low water-flow relate to diverse environmental conditions. Further, urbanization and industrialization cause water quality to be affected by anthropogenic activities at both point and non-point sources of pollution.

Radwan *et al* (2003) described the relation between BOD_5, DO and ammonia parameters. Degradation of the organic matter expressed as BOD_5 gives rise to an equivalent consumption of oxygen. Degradation of BOD_5 is also a source of nutrients (NH4-N) that can be oxidized and that give rise to additional oxygen consumption.

An important aspect that has not been dealt with much until recently is how flow variation interacts with variations in the physicochemical characteristics of water, especially when these are affected by waste discharge and non-point source pollution (Palmer et al. 2005a).

1.2 Problem Statement

The Ngong River is now considered an open sewer and an environmental health hazard (Kahara, 2002). However, most of the urban poor population living in informal settlements (slums) depend on this river as a source of water for domestic use and urban farming. Even though a number of pollution studies have been done on this river (Ohayo-Mitoko 1996, Wandiga 1996, Olago & Aketch 2000, Issaias 2000, Kithaka 2001, Kahara 2002), little has been done to evaluate the sewer water quality. Overflowing manholes were identified as one of the major point pollution sources along the Ngong River.

Improved understanding of hydraulic and water quality conditions is limited to the availability of observed field data. Ngong River is ungauged with little historical to almost no flow monitoring. There is need to observe the flow situations when water quality variables become limiting to ecosystem processes due to existing human interactions such as alterations in channel characteristics and pollution sources.

1.4 Research Objective

1.4.1 General Objective

The general objective is to document the hydrology of Ngong River and evaluate the effects of anthropogenic activities on its water quality.

1.4.2 Specific Objectives

- To document the hydrology of Ngong River for a period of 5 months starting from July to December 2006 and identify watershed characteristics that influence the river hydrology.
- To establish seasonal variations of Ngong River water quality and assess the quality of raw sewage discharged into the river as a result of pipe breaks or deliberate extraction of sewer water for irrigation.
- To evaluate the influence of river discharge on water quality.

1.5 Scope of Study

This study is about the quantity and quality of Ngong River water. The river channel is ungauged and thus five flow measuring stations were set up at convenient sites along the entire river course. The study targeted sewer lines that pass along the river. Sewer samples were collected at stations with overflowing manholes and those with open channels carrying untreated wastes discharging directly into the river.

River water levels were converted into flow data using Manning’s n formula. An attempt was made to establish the proportion of rainfall runoff that contributes to the flow within the Ngong River basin using the curve number method.

Sewer and river water samples were collected during the dry and wet seasons and analysed for a wide range of water quality parameters to establish seasonal water quality variations. On a weekly basis, river water was anaylsed for three parameters (DO, Ammonia and BOD_5) to evaluate their trends with discharge.

1.6 Study Area

1.6.1 Location of study area

Ngong River is one of three main rivers flowing through the Nairobi city, which is located approximately between 1° 10' - 1° 20' S and 36° 40' - 37° 50' E (Figure 1.1). The river originates from Motoine dam which is in Dagoretti Area and flows through the Kibera settlements into the Nairobi Dam which has a surface area of 356,179 m^2 (Kahara,2002).The river leaves the dam and crosses the Mombasa road in Nairobi West area. It flows through the Industrial area and Mukuru informal settlements crossing Enterprise Road and Outering Road. Ngong River continues on to the Kangundo road at Njiru bridge upto its confluence with the Nairobi River at Ruai in Embakasi Division.

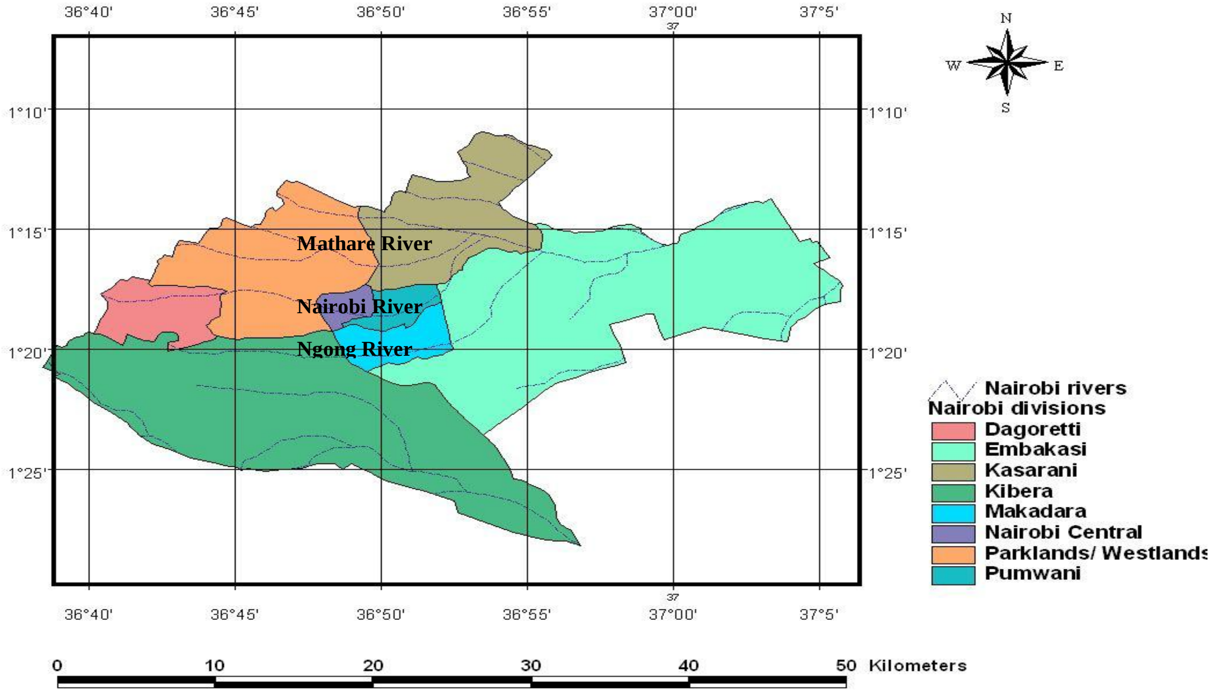


Figure 1.1: Map of rivers flowing within the Nairobi City

1.6.2 Topography of the study area

The topography of Ngong River drainage basin is relatively high in the west reaching an elevation of 1,980 masl near Riu Swamp, and falling to 1,820 masl at the Ngong River Bridge along Ngong Road. The elevation falls further to 1,525 masl at the confluence of the Ngong and Nairobi River. Krhoda (2002) observed that the basin may be divided into four sections: the upstream stretch of the Nairobi Dam, the Dam and its outlet and, the stretch from the Dam outlet to the confluence with Nairobi River. Figure 1.2 shows the longitudinal profile of Ngong River from Kibera to Njiru flow measuring and sampling stations.

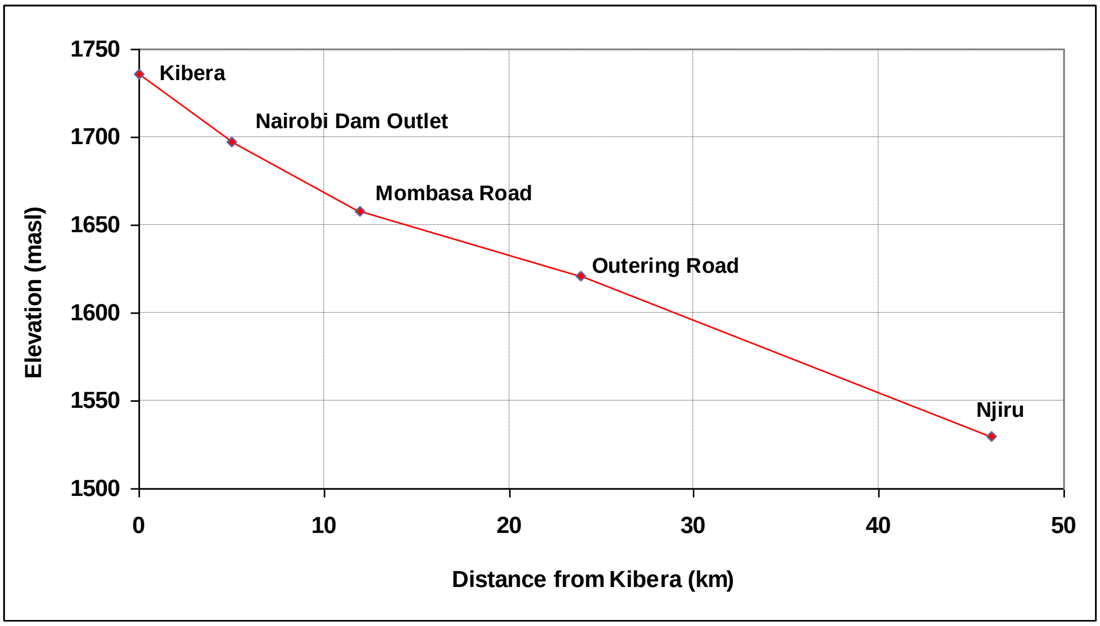


Figure 1.2: Longitudinal Profile of Ngong River from Kibera to Njiru

1.6.3 Climate and hydrology of the study area

Climatologically, statistics derived from the Kenya Meteorological Station at Dagoretti, show that the Ngong River basin receives mean annual rainfall ranging from 1000 mm to 1200 mm. Figure 1.3 shows daily rainfall collected during the study period. Nairobi climate is characterized by the existence of definite wet and dry seasons, and the absence of any large seasonal change in temperature. The Kenya Meteorological Department has subdivided the climate into four seasons: Mid-December to Mid-March as warm, sunny and dry weather, Mid- March to May is the main rainy season, June to Mid-October as cool, rather cloudy (especially July-August) and dry, Mid-October to Mid-December is a secondary rainy season. The basin has daily maximum temperatures that range from 21.4^{0}C during the month of August to 25.6^{0}C in March. Minimum daily temperatures range from 11.6^{0}C to 15. ^{0}C. Relative humidity ranges from a daily maximum of 88% in May to a daily minimum of 36% in April. Monthly evaporation ranges from a minimum of 89mm in July to a maximum of 191mm in March.

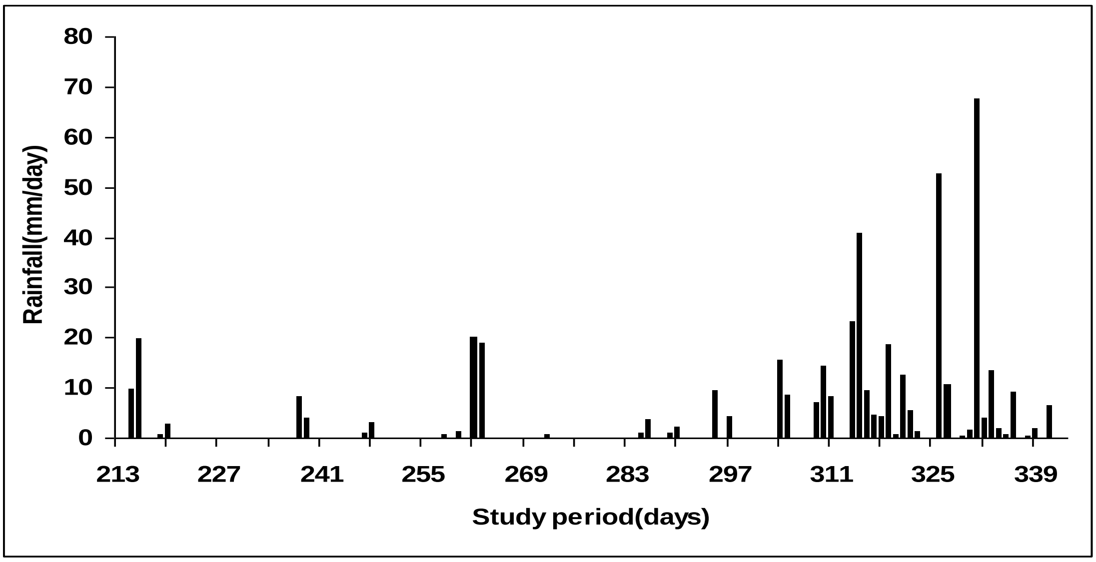


Figure 1.3: Rainfall Distribution during the Study Period

(Source: Data obtained from Kenya Meteorological Department, Dagoretti Station)

The Ngong River flows through a series of four man-made dams before crossing the Ngong Road Bridge and two larger dams at Race Course area. A small tributary (Mbagathi stream) joins the river after the Nairobi Dam flowing across Mombasa road. Water from the Nairobi Dam is lost through base-flow and underground recharge and according to Kahara (2002), the rate of loss is estimated at 0.5 m^3/s, overflow at the spillway as 0.2 m^3/s and dam evapotranspiration rate as 711,289 m^3 per annum.

1.6.4 Land Use in the study area

Ngong River is heavily used in the settled Dagoretti area. As the river flows towards Nairobi city, farmers in the valley impound its water for irrigation, dairy farming among other domestic uses. The river starts receiving agrochemical pollution as it flows through Dagoretti area and Ngong forest. Urban farming has been observed at the edges of the Nairobi Dam outlet, which is filled with sediments and solid wastes. The same is observed along the riparian river course. Commercial activities such as car washing, roadside tree nurseries and small-scale cottage industries, thrive downstream of the Dam outlet.

Direct sewage input influences the volume of the river water negatively as it traverses through Industrial Area, the Mukuru informal settlement and Outering Road areas. Garage workshops and large industries have been observed discharging their effluent directly into the river as it passes through these areas areas. There is reduced human activity with minimum agriculture along banks as the river approaches the confluence with Nairobi River.

A recent post-classification comparison of landuse/cover changes of Nairobi by Mundia and Aniya (2006) observed that the urban/built-up areas have increased from 14 km^2 in 1976 to 62 km^2 in 2000. Agricultural fields occupied 49 km^2 in 1976 and have increased substantially to 88 km^2 in 2000 which comprised of small-scale crop gardens near the central part of the city, along roadsides and on flood plains, and in high density residential areas to the eastern side of the city and peri-urban agriculture where the land holdings are large enough to allow cultivation and livestock keeping for commercial purposes.

Informal/Squatter settlements which are located on flood plains, in abandoned quarries, on steep banks of river valleys, host an estimated that 50 per cent of Nairobi's 3 million people (Lamba, 1994).

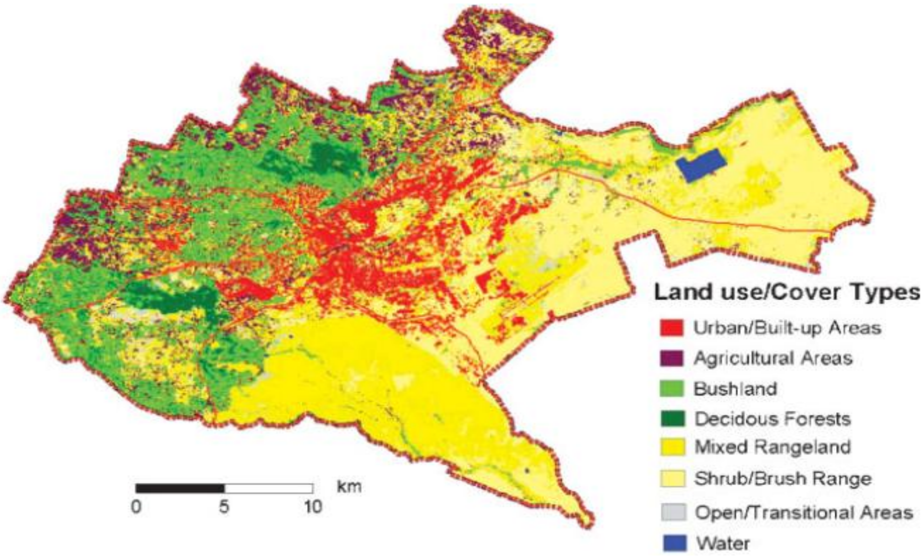


Figure 1.4: Land use/cover map of Nairobi

Source: Mundia and Aniya (2006)

CHAPTER II

2.0: LITERATURE REVIEW

2.1 Urban Hydrological Regimes

The hydrological regime of many rivers in urban areas has been impacted by rapid urban population growth and industrialisation. Processes like infiltration have been replaced by massive runoffs and frequent flooding occurrences. The prevalence of a built up environment has seen the replacement of vegetated channels with concrete drains. Paved pathways have replaced soil or earth paths.

River channel characteristics is determined through the establishment of several variables, the most important being the river discharge which is most commonly determined by the stage-discharge method where stage is measured at regular time intervals manually or with a recording instrument and the discharge is determined at various water levels using a current meter. Discharge can also be determined using flumes or weirs installed in the river channel. There are methods or estimating discharge based on hydraulic equations like Manning's and Chezy. The simplest method is the Manning's equation which, although developed for conditions of uniform flow in open channels, may give an adequate estimate of the non-uniform flow which is usual in natural channels (Meybeck et al., 1996).

The Manning equation (Chow, 1959) states that:

$$Q = \frac{1}{n} R^{\frac{2}{3}} s^{\frac{1}{2}}$$

Where:

Q = discharge (m^3/s)

R = hydraulic radius (m) and = A/P

A = cross-sectional area (m^2)

P = wetted perimeter (m)

S = slope of gradient of the stream bed

n = roughness coefficient

Other variables important in determining river water quantity include: Mean surface runoff which is a function of the water regime of the plant cover in terms of evapotranspiration (ET), the ability of the soil to hold water (infiltration capacity), and the ability of the plant cover to intercept moisture. The infiltration rate is zero on the pavement but unlimited on undisturbed forest floors. A change of land cover from lower to higher ET will lead to a decrease in annual stream flow (Pouraghniaei, 2002).

Reduced impervious surfaces due to precipitation infiltration lead to the increased height of flood or peak discharges during heavy storms. Large population increases, which result in urbanization, also increase the amount of impervious surfaces. Due to these factors events of higher peak discharge, in streams, are expected in affected areas, (Marchbanks, 2000)**.**

2.2 Challenges in River Water Quality Management

Unsafe water, coupled with a lack of basic sanitation, kills at least 1.6 million children under the age of five years annually. More than 40% of the world population (approximately 2.6 billion people) lacks access to modern toilet facilities and defecate in open and or unsanitary places (WHO/UNICEF Joint Monitoring Programme, 2006), resulting in human waste deposits in river systems.

Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and odour) characteristics. In a healthy environment, the water quality supports a rich and diverse community of organisms as well as protects public health.

Many countries are increasingly recognising a water quality as a major factor in the water crisis problem. Historically, poor water quality has been principally associated with public health concerns through the transmission of water-borne diseases, which are still leading problems in Africa and in other parts of the developing world (Ongley, 1999).

The contribution of degraded water to the water crisis is also measured through the loss of beneficial uses such as: aesthetic (recreation), economic (fishing, electricity generation, transport and irrigation), ecological (biodiversity), water for consumption (supply for domestic and industrial uses), and conveying waste-water discharges (treated or untreated). Rivers and canals have become the treatment facilities as they carry out natural remediation (Pearce *et al*,1998). To maintain these values and their sustainable use, water quality standards must be met. Table 2.1 shows the typical water quality standards developed by NEMA for sources of domestic water in Kenya.

Table 2.1: NEMA water quality standards for sources of domestic water

Parameter	**Units**	**Guide Value (maximum allowable)**
pH	pH value	6.5-8.5
Suspended Solids	mg/l	30
Nitrate-NO3	mg/l	10
Ammonia-NH3	mg/l	0.5
Nitrite-NO2	mg/l	3
Total Dissolved Solids	mg/l	1200
E.coli	Per ml	NIL
Fluoride	mg/l	1.5
Phenols	mg/l	NIL
Arsenic	mg/l	0.01
Cadmium	mg/l	0.01
Lead	mg/l	0.05
Selenium	mg/l	0.01
Copper	mg/l	0.05
Zinc	mg/l	1.5
Alkylbenzyl sulphonates	mg/l	0.5
Permanganate value	mg/l	1.0

Source: EMCA Water quality requlations (2006)

Natural processes like rock weathering, climate changes, including the growth and decomposition of biota also affect water quality. However, anthropogenic activities are the main sources of water pollution. Anthropogenic pollution sources are divided into two main categories: point and non-point/diffuse sources. Discharges from sewage treatment works, industrial waste-water outlets, solid waste disposal sites, animal feedlots and quarries can be described as point sources. Non-point source pollutants, which are mostly of agricultural origin enter surface waters with run-off or infiltrate into ground-waters. Table 2.2 illustrates the major pollution sources and the resultant types of pollutants released into the receiving water bodies.

Table 2.2: Major pollution sources

Pollutant Category	**Natural Occurrences**	**Domestic Sewage**	**Industrial Wastes**	**Small scale Agriculture**	**Large scale Agriculture**	**Urban Runoff**
Pathogens	X	X	X		x	x
Decomposable organic matter		X	X		x	x
Toxic metals	X		X			x
Suspended solids/sediments	X	X	X	X	x	x
Nutrients	X	X	X	X	x	x
Salts			X		x	x
Toxic Organic Chemicals			X	X	x	
Heat	X		X			

Modified after: Davis M.L and Cornwell D.A, 1998. Introduction to Environmental Engineering. International Edition WCB/McGraw-Hill.

The effect of a point source on the receiving water body is dependent on population or size and type of activity, waste discharge, capacity of the water body to dilute the discharge, ecological sensitivity of the receiving water body and intended water uses (Meybeck et al. 1996).

Nutrient enrichment of surface water as a result of runoff from agricultural land in particular, is the most challenging problem in environmental management (Duda, 1993; Carpenter et al., 1998). Whilst the impact of point source pollution can be minimized with proper management of wastes and land use activities, it is difficult and resource intensive to reduce the contributions of non-point pollution sources to water quality degradation in a given watershed (Dekissa, 2004). A common approach to controlling point source discharges, such as those from storm-water outfalls, municipal waste-water treatment plants or industries, is to impose standards specifying maximum allowable pollutant loads or concentrations in their effluents (UNESCO, 2005).

2.3 Sewer Water Quality in Nairobi

Nairobi has a combined sewer system that carries Domestic, Industrial, Infiltration/Inflow and Storm water. About 80% of the waste-water produced in Nairobi is treated and analysed at the Dandora Sewerage treatment works (DEST) in Ruai. The other 20% is treated at Kariobangi Sewerage works, at Kahawa and in other small plants (NCWSC, 2006).

The BOD_5 level of raw sewage inflow at the DEST works is reported to be about 173 mg/l, which is well above the recommended effluent discharge BOD_5 levels of 30mg/l into surface waters. Raw sewage is likely to cause heavy metal pollution on River water in the case of manhole overflows before the waste-water reaches the treatment works. Table 2.3 shows heavy metal levels contained in sewer water measured at the DEST works.

Table 2.3: Nairobi Sewage heavy metal concentrations measured at DEST

Metal	Raw Sewage	Final Effluent	% Removal
Iron (mg/l)	5.866	0.315	95.53
Manganese(mg/l)	2.57	0.132	95.74
Chromium(mg/l)	0.613	0.097	86.61
Cadmium(mg/l)	0.145	0.002	98.85
Lead(mg/l)	0.558	0.018	98.85
Copper(mg/l)	0.096	0.001	97.39
Zinc(mg/l)	1.255	0.023	98.84

Source: NCWSC, (2006).

2.4 Interaction of Flow Regime and Water Quality

Poff et al. (1997) defined "flow regime" as that flowing water which affects ecosystems in different ways depending on the season and the level of discharge. The key issue for optimizing water quality management is identifying the flow situations when water quality variables become limiting to ecosystem processes (Palmer et al. 2005b). A certain amount of pollutants in a stream can vary in importance depending on the actual discharge and on how much it becomes diluted.

Table 2.4 shows examples of extreme discharge conditions and the adverse effect on ecosystem processes from a hydrograph perspective as extracted from literature.

Table 2.4: Effect of extreme discharge conditions on water quality variables

Water quality variables	Low flows	High flows
Pollutants	Concentrations can reach toxic levels	Can be washed out from adjacent, otherwise unflooded uplands; dilution reduces but does not eliminate risk for toxicity
Drugs	PPCP:s (Pharmaceuticals and Personal Care Products) can become toxic; natural estrogens can feminize fish	
Nutrients	Can lead to eutrophication and acidification;N levels can become toxic	Removed from watercourse by downstream transport, uptake by riparian vegetation and denitrification
Salts	Can lead to acidification, mobilization of toxic metals and invasion of salt tolerant Species	
Organic matter and sediments		Considerable addition that increases turbidity, which reduces primary productivity and may increase acidity and threaten fish production Organic matter can reduce pH Sedimentation of transported inorganic matter restructures channel
High temperature	Lowers oxygen content, makes contaminants more toxic, lowers productivity	
Low temperature	Surface ice cover leads to reduced oxygen Open water and temperatures rising from below to above 0°C lead to melting anchor ice that can jam up and produce local floods and upland ice that damage riparian and upland biota	If high flows occur during periods with low temperatures and surface ice, water can be forced on top of the ice, often leading to floods, or the ice cover may break up and run the risk of jamming

Source: Online publication by Nilsson C. and Malm Renöfält B. (2008)

CHAPTER III

3.0: NGONG RIVER HYDROLOGY

3.1 Introduction

Urbanisation results in increased built-up or impervious areas in watersheds. As a result, the infiltration capacity of watershed is reduced and hence less recharge of ground water aquifers. Surface run-off from the impervious areas goes into storm sewers, which then discharge into streams, causing flooding. In this manner, the Ngong river watershed has been interfered with and the natural stream channel characteristics being modified leading to flooding and erosion along stream banks.

Proper interpretation of the significance of water quality variables in a sample taken from a river requires knowledge of the discharge of the river at the time and place of sampling. For adequate interpretation of water quality data, it is necessary to have hydrologic data such as velocity of flow and river discharge (Meybeck *et al*., 1996).

Stream flow data for Ngong River is unavailable. Wandiga *et al*., (2005) reported the average flow velocity of 0.7m/s in the river. According to Krhoda (2002), storm water runoff from paved surfaces contributes significantly to the waters of the Nairobi dam. Due to the presence of densely populated iron-roofed structures at Kibera station, a high proportion of the watershed is impervious. The remaining space, constituting footpaths, is heavily trampled and behaves as a paved surface. Furthermore, waste-water from the non-sewered Kibera and Mukuru informal settlements contributes to the stream flow at the Nairobi Dam.

3.1.1 Objective

To document the hydrology of Ngong River for a period of 5 months starting from July to December 2006 and identify watershed characteristics that influence the river hydrology.

3.2 Materials and Methods

3.2.1 River Reach Subdivision

Five gauging stations along Ngong River were selected from the upper reaches just downstream of Motoine forest to the lower end of the River shortly before its confluence with Nairobi River. The stations were namely: Kibera, Nairobi Dam outlet, Mombasa Road, Outering Road and Njiru. The stations represent the average conditions between one site and the succeeding one.

The sites were selected as they adequately capture the effects of different land uses on River quantity and quality within the Ngong River catchment. Kibera station was specifically picked to assess the effects of Motoine forest and agricultural activities on the upper reaches of Ngong River. The Nairobi Dam outlet station would capture the likely effects of the Kibera informal settlements. Mombasa Road station is located in a well sewered residential area. The Outering Road station describes the influence of the bustling Industrial Area and Mukuru Informal settlement. Njiru station captures the river’s effects in highly populated residential areas. GPS co-ordinates of each station were collected and GIS shapefiles of identified land uses were overlaid to generate a map of the study area.

3.2.2 River Channel Surveys

The five stations were surveyed to determine river channel dimensions and slope. In each station a 30m section was identified whose characteristics would be representative of the ambient conditions of that section.

Channel cross-sectional dimensions were measured using an engineering tilting leveling instrument using the collimation method. The tilting level has two spirit bubbles: a circular bubble on the upper plate, which achieves approximate leveling by means of three foot screws, and a telescope/tube bubble that is leveled for each sighting by the tilting screw.

After leveling, the instrument is adjusted to eliminate parallax, traversing its vertical axis and the two peg (collimation) adjustment to ensure the line of collimation (line of sight) is horizontal when the bubble is central. This is done by adjusting the leveling screw nearest to the line of the telescope and staff. Three survey trials were carried out along the selected 30m cross-section at each gauging station. The trial with the least error value was taken to represent the River channel shape and size. Appendix 1 shows collimation method recordings taken at each station.

3.2.3 Flow Measurement

Ngong River is ungauged and thus no prior river flow data exits. In order to determine stream-flow, the channel cross section at each station was surveyed using an engineer's level to obtain cross-sectional areas and perimeters. Longitudinal profiles were also surveyed to determine channel slope. A stable reference station in the streambed was identified from which the water level could be measured.

Five field assistants, trained to take and record water level measurements in a field book, measured water levels daily at 9.00am using a portable graduated steel rule and suspended tape measures placed against each reference station for a period within the months of July to December, 2006. Where the water was shallow, the trained assistant waded into the stream holding the steel plate that they placed at identified stable reference point. The graduated steel plate was placed on the floor of the channel along the flow direction and the depth measurements read and recorded. In deep water (more than 1m), the suspended tape measures were lowered from a bridge. Appendix 2 shows the raw water level readings collected at each station.

The values obtained were converted into discharge data using Manning's equation. Manning's equation (Chow, 1959) was applied to calculate discharge. Manning's equation is given as:

$$Q = \frac{1}{n} R^{\frac{2}{3}} s^{\frac{1}{2}}$$

Where: Q = discharge in m^3/s, n is Manning's roughness coefficient and S is bed slope. The hydraulic radius $R=A/P$ where A is wetted cross-sectional area, P is wetted perimeter

Figure 3.1: Training field assistant on water level reading

3.2.4 Estimation of Manning's Roughness Coefficient (n)

The Manning's *n* values for channels is determined by evaluating the effects of certain roughness factors in the channels for prevailing channel conditions along a longitudinal reach of the channel. The Ngong River channel was divided into subsections and roughness coefficients are determined for each subsection using the step-step guide outlined by Arcement and Schneider (1989).

The computation of channel roughness involved assigning a base roughness (nb) and adjustments for various roughness factors (channel irregularities, alignment, obstructions, vegetation, and meandering) to determine the total n value for each sub-section. The *nb* values and adjustment factors were selected from Tables 1 and 2, which were extracted from Aldridge & Garett (1973). This information is contained in Appendix 7.

Cowan's (1956) procedure was used to estimate the effects of these factors to determine the value of *n* for a channel which is:

$n = (nb + n1 + n2 + n3 + n4)m$

where:

nb =a base value of *n* for a straight, uniform, smooth channel in natural materials

n1 =a correction factor for the effect of surface irregularities

n2 = a value for variations in shape and size of the channel cross section,

n3 =a value for obstructions

n4 =a value for vegetation and flow conditions

m=a correction factor for meandering of the channel.

3.2.5 Runoff Curve Number Method

The SCS Runoff Curve Number Equation is actually a relationship between runoff volume and rain volume described in SCS publication, (1986). The following basic equation was used to estimate the total rainfall runoff within the Ngong river basin during the study period.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Q is the runoff depth, P is the rainfall depth, and S is the watershed storage. All units are depth, in mm. Rainfall depths were obtained from the Kenya meteorological Department. The S term was determined indirectly from tables relating qualitative land use information to a runoff index called the Curve Number (CN). CN tables follow (SCS, 1972). The CN is related to S with the following equation:

$$S = \frac{25400}{CN} - 254$$

3.3 Results and Discussion

3.3.1 Ngong River Channel Cross-sections

Location of the flow measurement stations set up during this study are shown in the generated map in Figure 3.2 below.

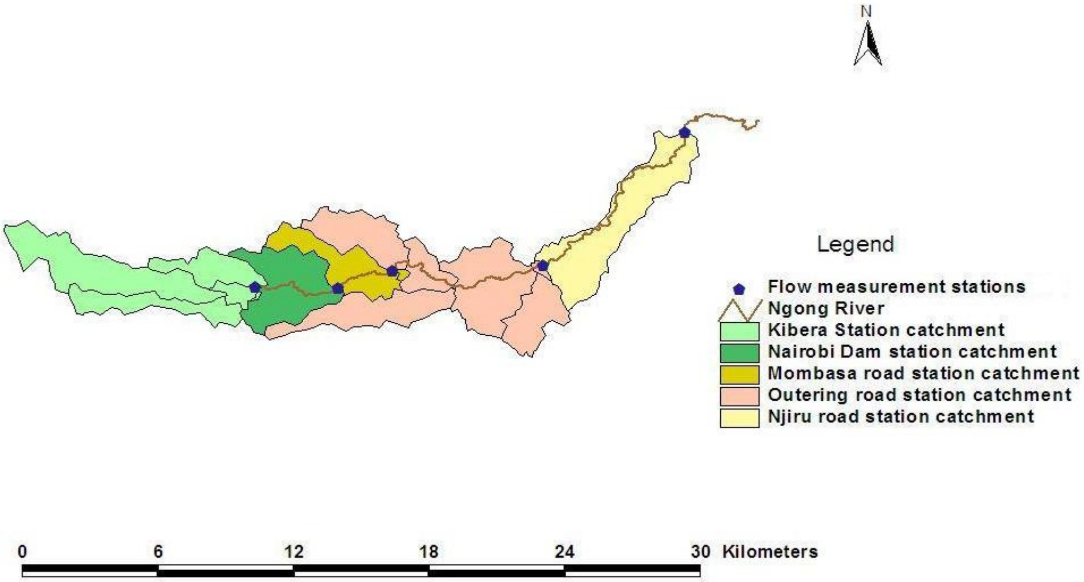


Figure 3.2: Flow measurement stations

The channel size, and shape of channel cross sections, varied downstream with the Kibera to Nairobi Dam inlet cross-section characterised by unshaped, meandering, V-shaped cross-sections. Downstream of the Nairobi Dam and starting with the weir, the river channel is wide and shallow. Concrete linings can be seen as it flows through the Mombasa Road crossing into Industrial Area. For the most part, the concrete lined channels are in good condition except downstream of Mombasa Road station, where the channels have developed cracks that have provided areas for vegetative growth. Also, areas under bridges have been turned into dumping sites for garbage.

As Ngong River approaches the Outering Road station up to its confluence with Nairobi River, the channels continue to re-excavate into parabolic meandering channels marked by riparian vegetation. Figures 3.3 to 3.7 show the cross-sectional profiles of the five flow measuring stations along the Ngong River reach.

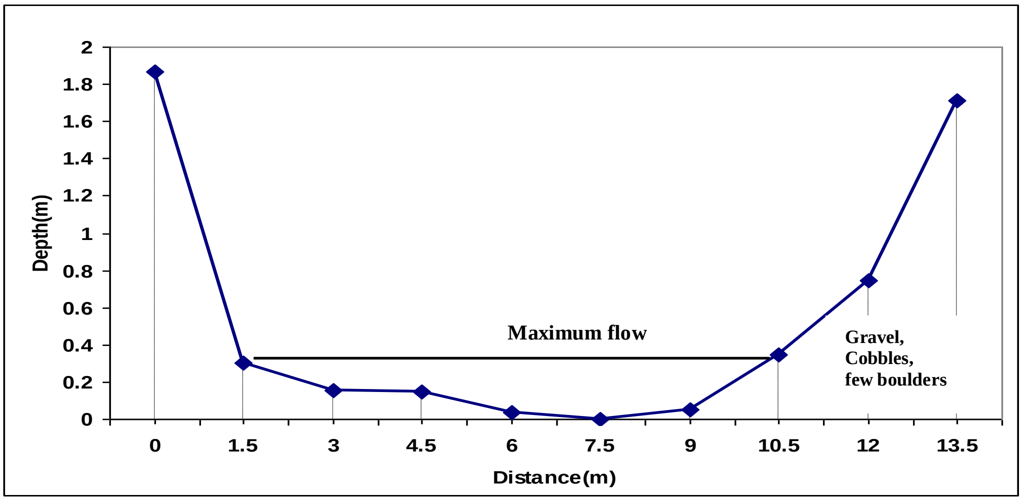


Figure 3.3: Kibera Station cross-section

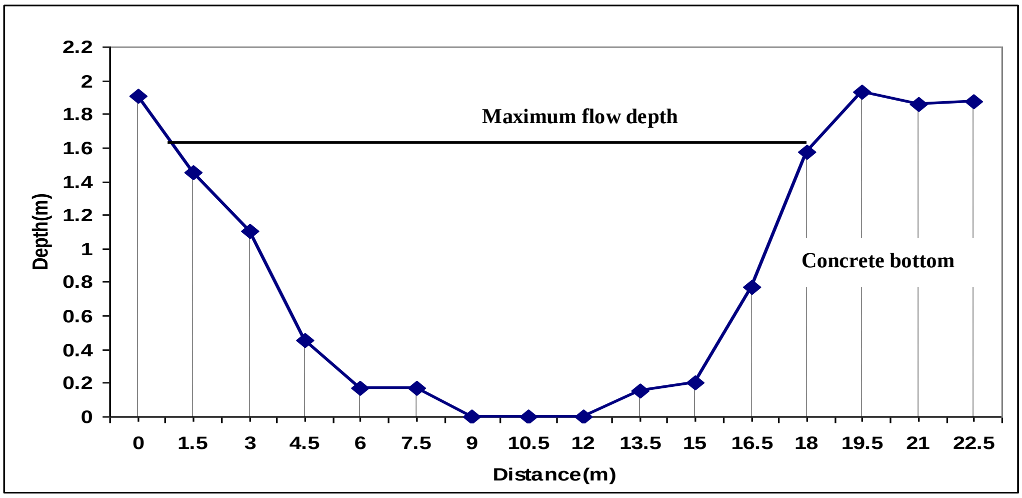


Figure 3.4: Nairobi Dam outlet Station cross-section

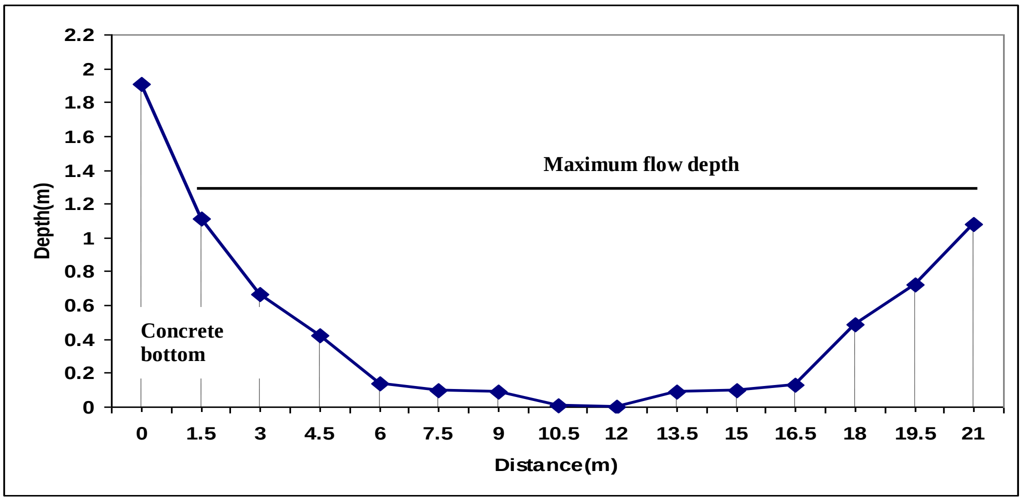


Figure 3.5: Mombasa Road Station cross-section

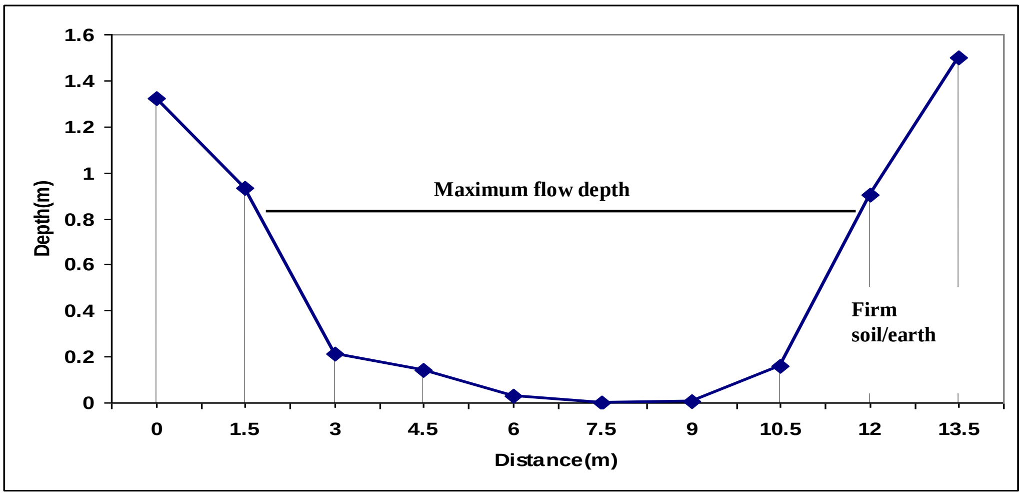


Figure 3.6: Outering Road Station Cross-section

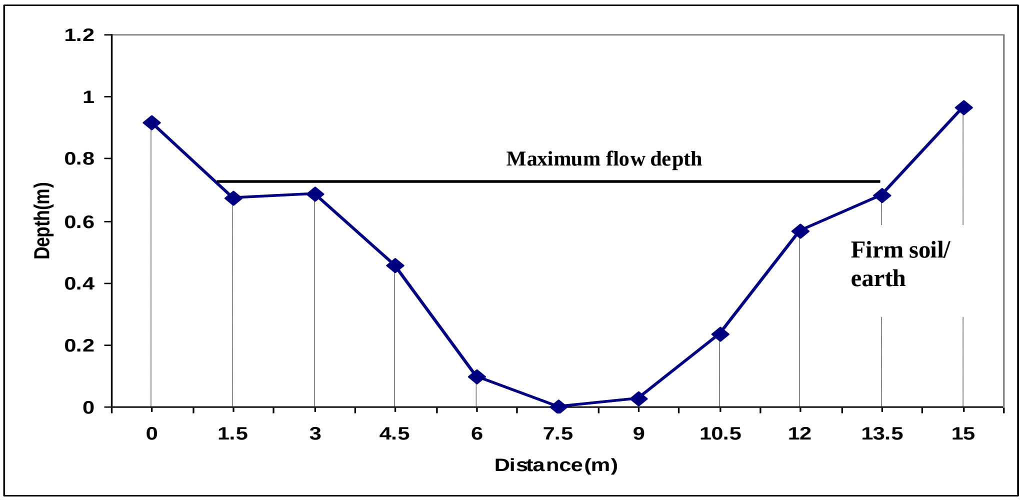


Figure 3.7: Njiru Bridge Station Cross-section

Longitudinal profiles obtained for a 30 metre stretch at each of the five flow measurement stations were used to estimate channel slopes as shown in Table 3.1 below. The difference between the lowest points of the river bed were recorded and used to establish the slope of the channel using the collimation method where the difference of the reducing levels of the lowest points were divided by the 30m longitudinal stretch. The values in Table 3.1 were used in the Mannings' formula to determine the discharge.

Table 3.1: Longitudinal slope at sampling stations

Station	Slope (m/m)
Kibera	0.0207
Nairobi Dam outlet	0.0165
Mombasa Road	0.0059
Outering Road	0.0195
Njiru Bridge	0.0195

3.3.2 Manning's Roughness Coefficient

As each cross section was not representative of the entire reach, the Ngong River channel was divided into cross-sections and Manning's n values assigned to each subsection. Channel irregularities, alignment, obstructions, vegetation, and meandering were the main factors considered to estimate the roughness of the channel. The Manning's n- values estimated ranged from 0.012-0.068 shown in Table 3.2 below.

Table 3.2: Calculated n value for channel cross-sections

Station	Base n value (nb)	Degree of irregularity (n1)	Variation in channel size and shape (n2)	Obstructions (n3)	Vegetation (n4)	Meandering (m)	n
Kibera	0.030	0.006	0.010	0.020	0.002	1.0	0.068
Nairobi Dam outlet	0.012	0.000	0.000	0.000	0.000	0.0	0.012
Mombasa road	0.012	0.000	0.000	0.000	0.000	0.0	0.012
Outering Road	0.028	0.001	0.001	0.002	0.010	1.15	0.0483
Njiru Bridge	0.028	0.001	0.001	0.002	0.010	1.15	0.0483

3.3.3 River Flow Rates

Flow rates at the Kibera cross-section during the project duration reached a maximum of 0.598m^3/s with an average discharge of 0.090m^3/s. At the Nairobi Dam outlet maximum discharge was 4.447m^3/s with the average being 0.856m^3/s. Maximum discharge measurement at the Mombasa Road Station was found to be 24.755m^3/s with the average at 5.452m^3/s. Flow at Outering Road station reached a high of 19.753 m^3/s and an average of 6.283m^3/s. The highest mean discharge was recorded at Njiru station where the average value was 7.003m^3/s. Table 3.3 provides the minimum, maximum and mean discharge rates of the five gauging stations.

Table 3.3: Ngong River flow rates during study period

Station	Minimum discharge (m^3/s)	Maximum discharge (m^3/s)	Mean discharge (m^3/s)
Kibera	0.013	0.598	0.090
Nairobi Dam outlet	0.074	4.447	0.856
Mombasa Road	0.567	24.755	5.452
Outering Road	3.309	19.753	6.283
Njiru Bridge	2.647	18.535	7.003

Discharge data calculated for the study period from 19th July 2006 to 7th December 2006 was plotted against time to produce hydrographs as presented in Figure 3.8 to 3.12. Day 1 is the first day of January while day 213 to day 345 the duration the flow depths were recorded. The hydrographs show low but constant discharge rates at all the stations from July to November and a sharp rise in discharge due to rains that occurred in November. A decrease in discharges was noted as the month of December started. The response to a rainfall event is almost immediate since the contributing catchment of the river is small with areas upstream of Kibera station being 26.22km^2 and the total catchment area contributing to the river flow is 101.16km^2.

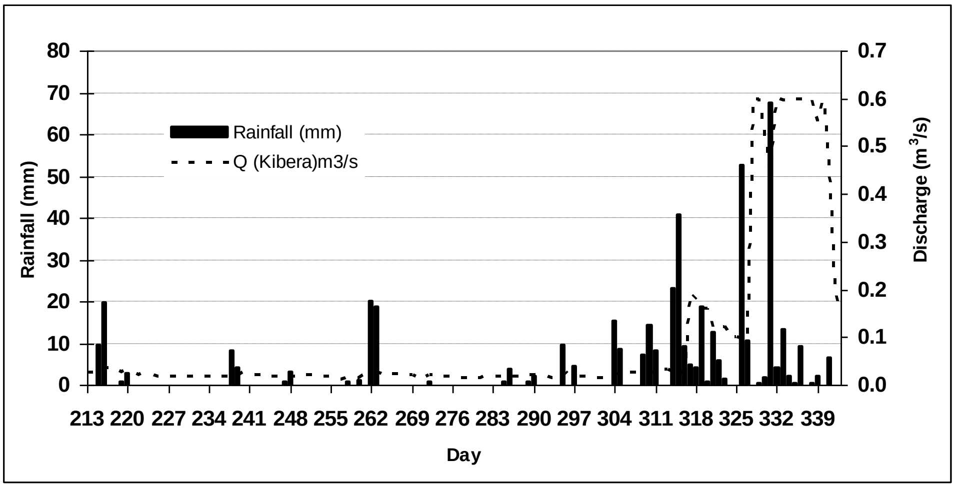


Figure 3.8: Kibera Station Hydrograph

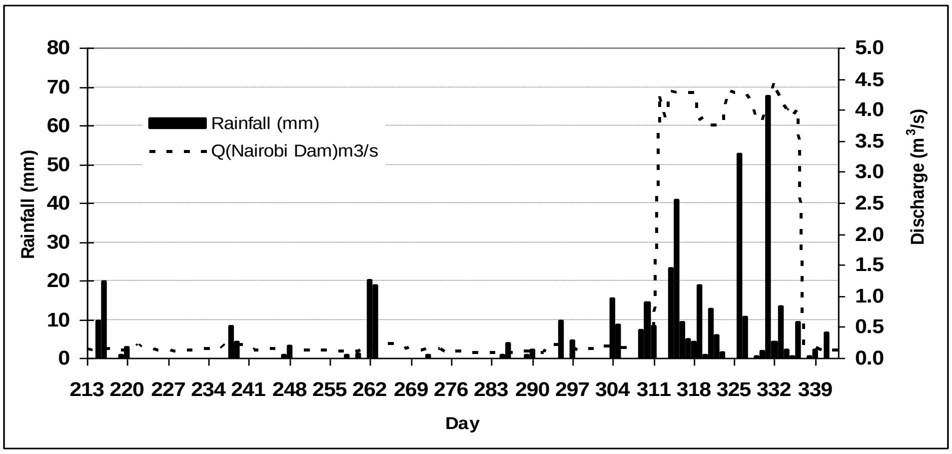


Figure 3.9: Nairobi Dam outlet hydrograph

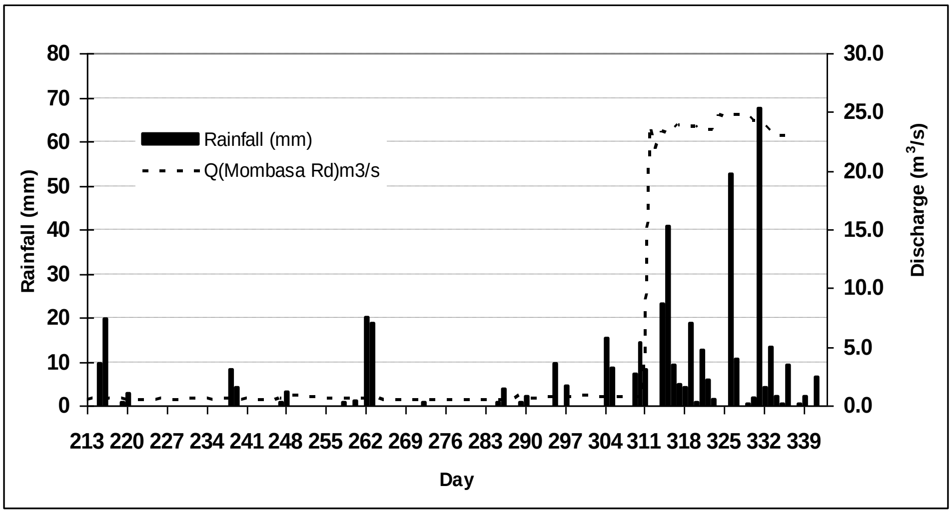


Figure 3.10: Mombasa road station hydrograph

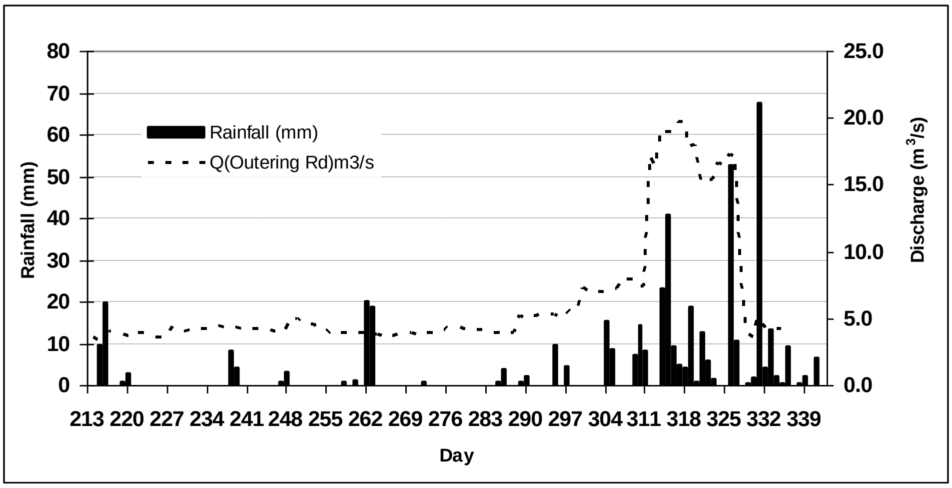


Figure 3.11: Outering Road station hydrograph

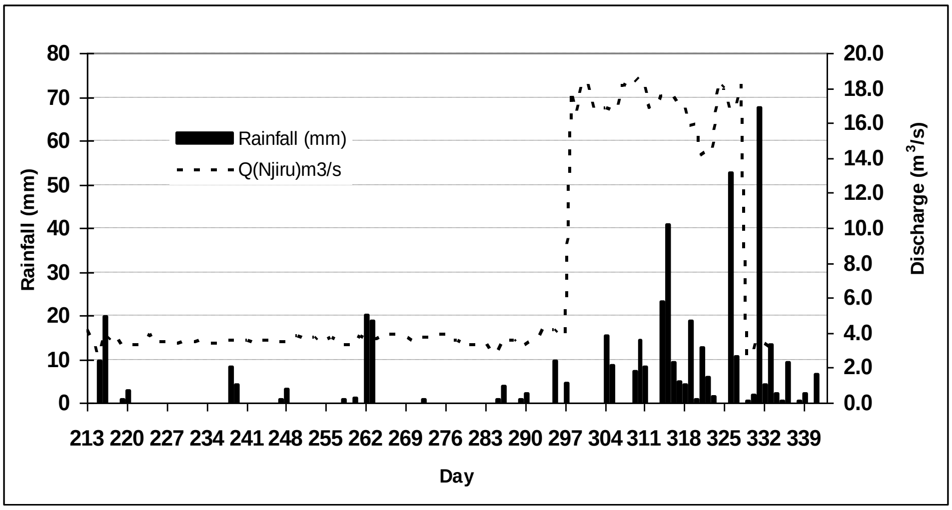


Figure 3.12: Njiru Bridge station hydrograph

The low discharge rates were observed during at the Kibera station despite presence of the Motoine Dam and Motoine forest upstream of that station. This may be attributed to the abstraction of water for irrigation and domestic uses upstream of the station. Figure 3.13 shows evidence of water use at Kibera station.

Figure 3.13: Photograph showing domestic water use at Kibera Station

Flow at the Nairobi Dam outlet is extremely fast as it falls through a trapezoidal weir that regulates the flow from the Dam. The Dam is designed to recharge Ngong River in dry seasons, storing extra water in the wet season. There is however little increase in the flow rate as the outlet is filled up with soil sediments, solid waste dumped from the Kibera informal settlement, as well as infested by Water Hyacinth (*Eicchornia crassipes*), common reeds and bulrushes. The low flow rates at Mombasa Road gauging station can be attributed to the car-washing and roadside tree nursery activities along the river or dam banks.

Even though the channel subsections of Outering Road and Njiru stations are wider, they carry more water as a result of direct sewage discharges from open drains and overflowing manholes that course flow into the River. The River water along this reach is used by farmers who have taken up the riparian areas to grow basic subsistence crops (urban agriculture).

The SCS curve number was used to estimate the depth of direct runoff. The curve numbers for areas above each station are shown in Table 3.4 below. The total rainfall received over the study period was 455mm. Direct runoff from areas contributing above the Kibera and Nairobi Dam outlet is larger than the water yields at these stations due to upstream abstractions and storage at the Dam respectively. The water yields at Mombasa Road, Outering Road and Njiru stations are influenced by sources other than direct precipitation-runoff that occurs within the watershed.

Table 3.4: Contribution of Direct Runoff on Ngong River Flow

Catchment Area	Km^2	CN	Estimated Direct runoff (mm) over study period	Measured Water yield (mm) over study period	Percent contribution (Water yield /Direct runoff*100)
Kibera	26.23	74	504	39	8% (Abstraction by upstream activities)
Nairobi Dam Outlet	37.83	82	344	268	78%(Storage effect of Nairobi dam)
Mombasa Road	46.02	89	266	1280	481% (Extra water sources include storm runoff from well paved areas and Mbagathi stream flow)
Outering Road	83.95	88	273	789	289% (Extra water sources from wastewater discharges, upstream flows)
Njiru	101.16	85	303	727	240% (Extra water sources from wastewater discharges, upstream flows)

3.4 Conclusion and Recommendations

Discharge at the Kibera station was found to be very small (mean value of 0.090m^3). There was evidence water use for domestic purposes and upstream abstraction by small holding farming at this station. Mombasa road station responds greatly to wet weather with a maximum discharge of 24.755m^3/s recorded. Though, for the most part of the study the flows were low. The river at this station is vulnerable to flooding since it fills to its capacity due to the dam recharge, small Mbagathi stream and runoff from the well drained residential areas in the area during the wet weather.

Downstream stations have high flow rates through the study period with Outering road station recording an average of 6.283m^3/s and Njiru an average value was 7.003m^3/s. Direct runoff contribution to the water yield at Kibera and Nairobi dam outlet stations can be improved by controlled abstractions in Motoine area and restored recharge capacity of the Nairobi dam. The downstream stations (Mombasa Road, Outering Road and Njiru) show the effect of anthropogenic activities on water yields rather than natural water cycle processes like direct precipitation and runoff. More studies could be done to establish accurate amounts and other sources of extraneous water contribution to Ngong River flow.

Extraneous water sources have been identified as: storm run-off from roads and pathways, sewer wastewaters (which constitutes of sanitary water and storm water) from overflowing manholes located adjacent to the Ngong River course, open drains carrying faecal matter and grey-water from informal settlements existing along this river and, the direct discharge of industrial waste-waters. Sewer flows should be monitored along the sewer pipeline to screen cases of overloading as well prevent overflows into the river. Currently sewer water inflows are only measured at the Ruai Waste-water Treatment, which is approximately 40km from the Nairobi Area. Improved sanitation services within informal settlements through provision of sewerage infrastructure will provide residents with enhanced options to faecal waste and grey water disposal.

Permanent gauging stations should be set up along existing bridges that are conveniently located along Ngong River to establish discharge data. Encroachment into the river's cross sections is evident with subsistence farming being practiced along the riparian areas. The modification of the valleys has led to decreased river capacity enhancing the risk of flooding. The recent law enacted by the Ministry of Environment of securing 30m riparian way-leaves along Nairobi Rivers should be accompanied by hydrological studies to determine extents of river channel meanders as well as verify impoundments that can be utilised for controlled productive uses.

CHAPTER IV

4.0: NGONG RIVER AND SEWER WATER QUALITY

4.1 Introduction

Natural water bodies serve many uses including the transport and assimilation of waterborne wastes. But as natural water bodies assimilate these wastes, their quality changes (UNESCO, 2005). Blockages, inadequate carrying capacity and leaking pipes often lead to sewage overflows into nearby streams. Sewer lines are constructed next to streams to take advantage of the continuous, gradual slopes of stream valleys (Pouraghniaei, 2002).

The Ngong River basin continues to experience rapid urbanization through the addition of road and housing infrastructure. This translates to growing populations, new water supply and increased pressure on existing waste-water systems. Subsequently, more waste-water is being discharged into local streams.

The Nairobi River Basin Initiative programme of UNEP established a pollution-monitoring programme in 2001 to provide scientific information on the status of the Motoine /Ngong River and form the basis of subsequent monitoring of the effects of interventions on the River regime (UNEP/NRBP, 2006).

Typically, water quality surveys comprise of: on-site measurements, the collection and analysis of water samples, evaluation of results against standards and reporting of the findings. WHO water quality standards are the global reference. They are complemented by other world standards such the EU drinking water standards (1998), FAO (1992) and the National Environmental Management and Co-ordination Act EMCA (2006). Existing statistical methods used in water quality monitoring studies, use the concept of “statistical significance” (i.e. p-values) to validate the information produced, be it comparison of means/medians (e.g. upstream/downstream averages), evaluation of trends, or determination of standards compliance (Martin, 2000).

4.1.1 Study Objectives

This study is about water and sewer quality analysis done to establish seasonal variation of Ngong River water quality and the suitability of the water for domestic use. The quality of sewer water was also measured to assess suitability for discharge into water courses and for use in irrigation. The specific objectives were:

- To establish the seasonal variation of Ngong River water quality.
- To establish the variation of sewer water discharge quality along Ngong River.

4.2 Materials and Methods

The sampling design used was an Upstream Downstream survey where the number, location and sampling pattern of the sampling site were defined with sampling stations being chosen sufficiently over the entire river length to cater for spatial variations.

4.2.1 River and Sewer Water sampling

Five river water sampling stations were selected out of a field reconnaissance, which was guided by the UNEP Nairobi River Basin project strategy that had identified 20 stations along the river for long-term water quality monitoring (UNEP, 2006).

The rationale behind the choice of stations for the study was:

- The sampling stations were set up in the upper reaches of the river in order to: monitor the background characteristics of the water. Middle reaches were set up to monitor specific sources of contamination (i.e. forest/agricultural areas, informal settlements, residential areas, industrial area) and, in the lower reaches in order to check the dilution effect due to self-purification of the river.
- River segments with uniform channel characteristics and straight sections of flowing water thus avoiding areas with stagnant water, solid waste deposits and dam outfall.
- River sections where water is sufficiently mixed for only a single sample to be required.
- Accessibility and Cost effectiveness for collection and analysis

For sewer water samples, the sanitary sewer laid within the Ngong River basin was selected. With the help of experienced Nairobi Water and Sewerage Company personnel, four sewer sites were selected from upstream of the Ngong River to its confluence with the Nairobi River. Burst or overflowing sewers, those seen directly influencing the River water quality, including those used for waste-water farming were selected. The four selected sites were namely: Kibera, Enterprise Road, Imara Daima and Outering Road. Kibera and Imara Daima serve domestic areas while Enterprise Road and Outering Road sewers serve both Domestic and Industrial areas. Grab samples were taken at each sewer station.

The sample size was estimated based on the fact that the flow depth was shallow with no variations in depth and width at each sampling station. Flow depth along the entire River length ranged from 5cm to 1m and thus a grab sample would give a good representation for the overall sampling population. Three water samples were collected at right angles to the flow of the stream on straight stretches of the stream at each station as shown in Figure 4.1. Water quality sampling and analysis procedures were based on the methods recommended in a guide published by WHO/UNEP (1996).

During sampling date, time, exact location, temperature, pH, and conductivity were noted in a field notebook before leaving the sampling station. The three samples were collected at each station in 1L plastic bottles, placed in cooler boxes with freezer packs and transported an accredited and well equipped laboratory at the Kenya Water Institute (KEWI).At the laboratory samples were stored at 4^0C before analysis.

River and Sewer water sampling was done once in the drier month of July and once in the wet month of December. River water samples were collected weekly during the study period for analysis of three parameters.

The extent of sewer line within the Ngong River basin was digitized with the help of NCWSC technical personnel. GPS coordinates of each river and sewer sampling station were collected and point based map generated.

Figure 4.1: Photograph shows river water sampling at Njiru station.

4.2.2 Water Quality Analysis Methods

Field test kits were used to analyse river and sewer water samples for pH, Electrical Conductivity and Temperature as shown in Figure 4.2. For quality assurance, triplicate samples were taken at each station to ensure precision in laboratory methods and analysed using the same method, equipment and reagents, to ensure that the results would be subjected to the same bias.

River and sewer water characterization of physical-chemical parameters comprising of: pH, Electrical Conductivity (EC), heavy metals (Lead, Cadmium and Chromium), Temperature, Turbidity, Total Suspended Solids (TSS), Total Settleable Solids, Total Dissolved Solids (TDS), Alkalinity, Magnesium, Calcium, Sodium, Total Hardness, Chloride, Bicarbonates, Carbonates, BOD_5 and Dissolved Oxygen (DO), were carried out following procedures described in a manual of standard methods for examination of water and waste-water (Lenore *et al*., 1998).

Weekly analysis of BOD_5, Dissolved Oxygen (DO), and Ammonia was conducted using manual for Standard Methods for the Examination of Water and Waste-water (APHA, 1992). River and sewer water samples were digested samples and then analyzed for total lead, chromium and cadmium content, following Atomic Absorption Spectrometry (AAS) method as described by Van Loom (1980) and using the Atomic Absorption Spectrophotometer, Model Varian SpectrAA-10. Comparative analysis of means per station in both seasons was conducted using SPSS version 12 software.

Results from triplicate analyses were used to calculate a relative range value. Appendix 3 presents water quality laboratory results for dry and wet season tests. All parameters were screened against WHO (1993), EMCA (2006), FAO (1992) water quality and effluent discharge standards. Graphs depicting the dry and wet season trends in parameter levels were drawn (see Appendix 4 and 5).

.

Figure 4.2: Photograph showing onsite water parameter testing

4.3 Results and Discussions

Appendix 4, 5, 6 show graphical descriptions of water quality parameters measured during the dry and wet season river and sewer water.

4.3.1 Description of Study Area

Five River water stations and four sewer water sampling stations were selected along the Ngong River basin which is about 42.3 km long and narrow as show in the study area map (Figure 4.3).

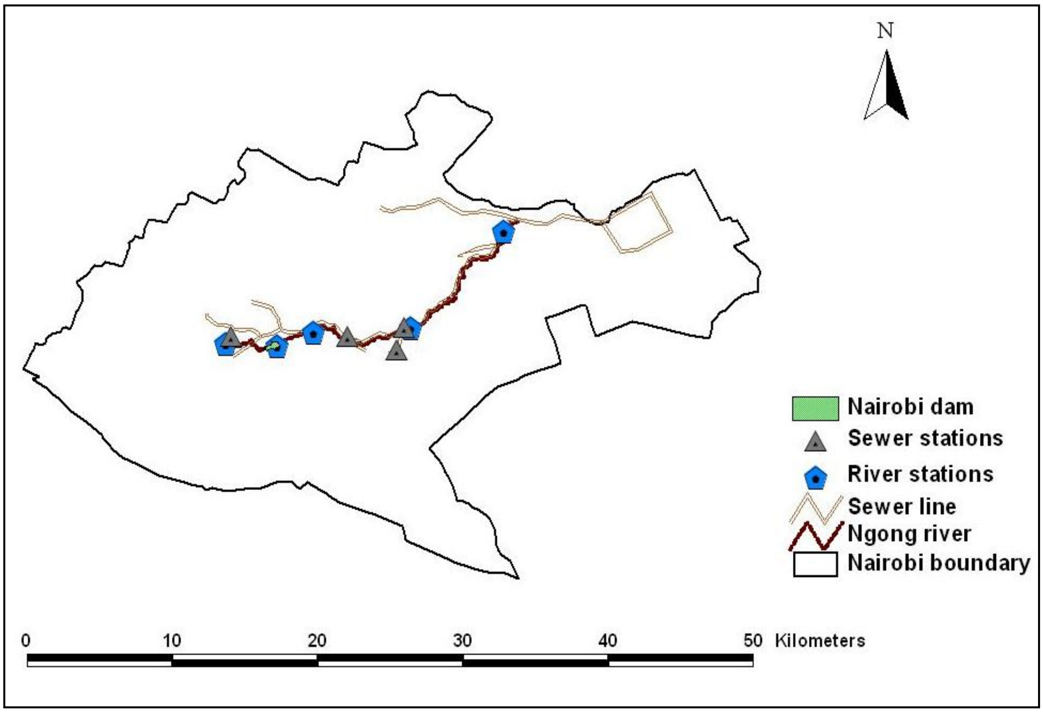


Figure 4.3: Map showing locations of water sampling stations

Ngong River, which rises from Riu Swamp, is used upstream for irrigation agriculture, dairy farming and other domestic uses. As it flows downstream through the Kibera informal settlements urban farming is observed along the edges of the Nairobi Dam station. Some sections of the Dam have gradually silted up and the same is observed along the riparian river course. From the Nairobi Dam outfall, until the Mombasa Road bridge crossing, Ngong River passes through well sewered residential areas. At this point, the water is clear but reverts to its characteristic grey-black colour as it flows through Industrial Area, Mukuru informal settlements, the Outering Road station up till its confluence with Nairobi River just after the Njiru Bridge station. (See Figure 4.4)

Figure 4.4: Photograph showing water quality at Outering Road station

A number of sewer lines were found to be faulty due to overflows (see Figure 4.5), caused by increasing effluent volumes resulting from rapid population growth and intentional blockage for irrigation by poor urban farmers as the water which, has high nutrient value, is readily available throughout the year.

Figure 4.5: Photographs showing sewer burst and tampered manholes

4.3.2 River Water Quality levels

Tables 4.1 and 4.2 shows results of river water quality analysis. In the dry and wet seasons, water parameters at Ngong River that were above guide/maximum allowable standards were as follows:

4.3.2.1 Electrical Conductivity

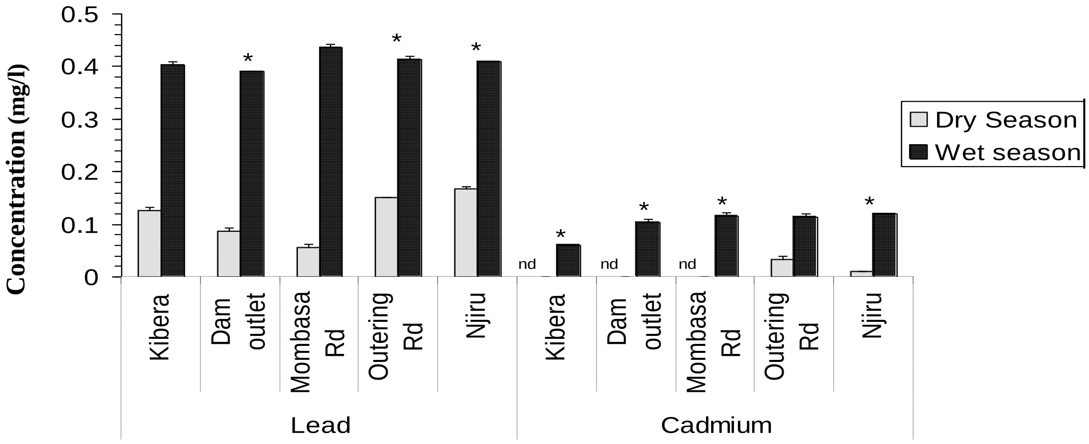
This is the measurement of the ability of water to conduct an electric current. The greater the content of ions in the water, the more current the water can carry. This is often used as an alternative measure of dissolved solids. Conductivity is reported in terms of microsiemens per centimeter (µS/cm). Ions are dissolved metals and materials, which may limit the suitability of water as a drinking source and irrigation supply. Each station sampled along the river recorded high EC values during the dry season, above the WHO guide value of 250µS/cm (see Table 4.1 for EC means). In the wet season EC values at Kibera were the lowest at 213µS/cm. The other stations downstream of Kibera station had high EC values, the highest being 828µS/cm at Outering Road station. Waters with high EC values may interfere with the clarity, colour and taste of manufactured products.

4.3.2.2 Heavy Metal Levels

Lead levels make the entire Ngong River unfit for drinking water purposes when compared to WHO and NEMA drinking water maximum allowable standards of 0.01mg/l and 0.05mg/l respectively during the dry and wet season. Lead value was highest at Njiru station in the dry season at 0.17mg/l but highest at Outering Road with a value of 0.46mg/l. Nairobi Dam outlet registered the lowest lead values at 0.09mg/l in the dry season and 0.39mg/l in the wet season. Refer to Table 5.1 and 5.2 for lead values at each river water sampling station. However, according to FAO (1992), lead levels in the river water are suitable for irrigation as the maximum contaminant level is set at 5mg/l. Irrigation of soils using these waters should be cautioned as it leads to the long-term accumulation of heavy metals in the soils and subsequent uptake by plants, resulting in chronic effects both in livestock and humans. Possible sources of lead include iron and steel production, building and construction, pipe-work and for pigmentation in paints, ceramics, catalysers and preservatives used by large and cottage industries located along the river.

Cadmium values ranged from 0-0.03 mg/l in the dry season and 0.06-0.12 mg/l in the wet season. The cadmium levels were highest at Outering Road (0.12mg/l) against WHO recommended value of 0.003mg/l and NEMA 0.01mg/l. Cadmium levels in Ngong River do not restrict its use for irrigation when screened against the FAO guide value of 0.5mg/l. Cadmium finds its way into the environment through waste-waters of industries and through discharges from iron and steel industries. Other sources of cadmium contamination are combustion of tyre, oils and plastics.

Cadmium levels were not high because it either precipitates as carbonate or is absorbed into humic substances and particulate matter, especially bottom sediments. Effects of untreated waste-water containing cadmium from the Imara Daima sewer is seen downstream at the Outering Road station. The effect of rainfall to cadmium occurrence at all stations could be either through surface run-off or rainwater containing atmospheric cadmium.



nd- not detectable with the analytical method used

*-indicates 0.05 level of significance of dry and wet season means at each station

Bars indicate Standard deviation of means

Figure 4.6: T-test results for lead and cadmium equality of mean levels (river)

A T-test carried to out to assess the equality of means in the five stations showed there exists a significant difference in lead values at three stations, with the exception of Kibera and Mombasa Road stations – in the dry season (Figure 4.6). This means that one of the three samples collected at each station for a particular season (dry or wet), could best describe the parameter level at that station. During the dry season cadmium was not detected at Kibera, Nairobi Dam outlet and Mombasa Road stations. Cadmium values at the Outering Road station did not vary significantly during the dry and wet seasons.

Chromium was not detected at any station. This could be due to its nature as it largely exists in suspended solids and is found in elevated levels in sediments close to anthropogenic sources of pollution. This agrees with Parker and Jananner (1977) who established that chromium in suspended solids constitutes upto 65% of the total chromium in most waters.

4.3.2.3 Nitrates

The entire Ngong River contained high nitrate levels above the recommended values of NEMA 10mg/l and WHO at 50mg/l. In the dry season, the Outering Road station was found to have the highest nitrate levels at (176.0mg/l).High levels at Kibera station were measured at (137.33mg/l) during the wet weather as a result of runoff from the agriculutrral fields upstream of the station. Mombasa road station had the lowest levels in both seasons (Table 4.1 and 4.2). A general reduction of nitrate values in the wet season was observed. Nitrate is the primary form of nitrogen, a nutrient used by plants to stimulate growth. Excessive amounts of nitrogen may result in phytoplankton or macrophyte proliferations. At high levels, it is toxic to infants.

4.3.2.4 Dissolved Oxygen

DO levels in the dry season decrease at Nairobi Dam outlet station below the WHO guide value of >5mg/l. In the wet season, there were peaks in DO levels at Kibera (6.67mg/l) and Mombasa Road (6.576mg/l) stations. The lowest levels were recorded at Outering Road station (1.60mg/l). Low levels of Dissolved Oxygen facilitate the release of nutrients from the sediments thus affecting the solubility, availability of nutrients, and productivity of aquatic ecosystems. DO levels decrease downstream due to high organic matter contained in upstream waters. The Kibera station complied with the allowable DO guide values during the two sampling and analysis tests.

4.4.2.5 Biological oxygen demand

BOD_5 test is carried out to establish the pollution strength of the waters when discharged in a water course. There is no BOD guide value for river waters since the river system receives treated wastewaters from wastewater treatment plants which can be assimilated within the system as it flows downstream through self purification. However once the river receives raw wastewater over a long period it loses its assimilative capacity and becomes an open sewer system.

For this case high BOD values were reported along all stations implying that the river waters can best be described as effluent waters. The lowest BOD levels were reported at Kibera station (46.67mg/l) during the wet season showing some form of dilution at this station. Downstream of the Kibera station BOD values increase as the river receives more organic wastes. The highest BOD levels were measured at Outering station (463.33mg/l) as a result of effluent discharges from the industrial areas and residential settlements (formal and informal).

4.3.2.6 Total Suspended Solids (TSS)

NEMA maximum allowable value for TSS is 30mg/l. There is a general increase in TSS levels reported during the dry season at Mombasa Road station (59.67 mg/l) and 946.67 mg/l at Njiru station. However in the wet season, TSS was lowest at Mombasa Road (21.67mg/l) and highest at Nairobi Dam outlet (210mg/l). High concentrations of TSS increase turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspected anthropogenic sources that contribute to increased TSS levels are: industrial effluents, and domestic waste-water discharges.

4.3.2.7 Total Dissolved Solids (TDS)

The values of TDS have a general increase along the Ngong River profile but decrease to some extent in the wet season. The highest TDS levels recorded at Outering Road (484.67mg/l wet season) and Njiru (503.33mg/l dry season) would restrict the use of water at these stations for irrigation as guided by FAO standards of 450mg/l. Interestingly, WHO and NEMA drinking water standards of 1000mg/l and 1200mg/l respectively, are much less stringent compared to the FAO irrigation standards. High concentrations of TDS limit the suitability of water as a drinking source and irrigation supply.

Table 4.1: River water quality parameter levels (Dry Season)

Parameter	Unit	WHO DW Standards	NEMA DW Standards	FAO IW Standards	Kibera	Dam Outlet	Mombasa Road	Outering Road	Njiru Bridge
pH	pH scale	<8	6.5-8.5	6.5-8.5	7.24	6.70	7.39	6.63	7.25
Temperature	°C	-	-	-	19.80	18.77	27.33	22.10	22.80
EC	µS/cm	250	-	-	328.67a	698.33a	595.33a	759.67a	838.00a
Lead	mg/l Pb	0.01	0.05	5.00	0.13ab	0.09ab	0.06ab	0.15ab	0.17ab
Cadmium	mg/l Cd	0.003	0.01	0.50	0.00	0.00	0.00	0.03ab	0.01ab
Alkalinity	mg/l CaCO$_3$	-	-	-	12.67	28.67	14.67	27.73	28.00
Total Hardness	mg/l CaCO$_3$	150-500	-	-	77.33	173.33	108.00	112.00	104.67
Calcium	mg/l CaCO$_3$	-	-	400	20.53	43.47	30.80	36.27	34.00
Magnesium	mg/l mg	-	-	-	6.83	16.03	7.63	5.23	4.80
Nitrates	mg/l NO$_3$.	50.00	10.00	-	132.00ab	158.40ab	96.80ab	176.00ab	149.60ab
B.O.D$_5$	mg/lO$_2$	-	-	-	160.00	283.33	293.33	373.33	240.00
DO	mg/l O$_2$	>5	-	-	6.07	4.13a	3.23a	2.57a	2.50a
TSS	mg/l	-	30.00	-	20.33	22.67	59.67b	276.67b	946.67b
TDS	mg/l	1000.00	1200.00	450	197.20	419.00	357.20	455.80c	503.33c
Chloride	mg/l CI	250.00	-	-	48.00	80.00	55.33	64.00	113.00
Bicarbonates	mg/lCaCO$_3$	-	-	-	34.67	28.67	14.67	37.33	28.00
Sodium	mg/l Na	200	-	70	30.43	60.00	44.20	55.83	42.50
Potassium	mg/l K	-	-	-	7.53	28.00	25.00	27.00	23.00

a = indicates measured values above WHO drinking water standards (1993)

b = indicates measured values above NEMA water quality regulations-domestic water sources (2006)

c = indicates measured values above FAO irrigation water standards (1992)

Table 4.2: River water quality parameter levels (Wet Season)

Parameter	Unit	WHO DW Standards	NEMA DW Standards	FAO IW Standards	Kibera	Nairobi Dam Outlet	Mombasa Road	Outering Road	Njiru Bridge
pH	**pH scale**	<8	6.5-8.5	6.5-8.0	6.70	6.75	7.73	6.83	7.10
Temperature	**°C**	-	-	-	20.30	21.37	22.37	26.77	23.50
EC	**µS/cm**	250	-	-	213.00	492.67a	471.33a	828.00a	597.33a
Lead	**mg/l Pb**	0.01	0.05	5.00	0.40ab	0.39ab	0.44ab	0.46ab	0.43ab
Cadmium	**mg/l Cd**	0.003	0.01	0.50	0.06ab	0.10ab	0.12ab	0.12ab	0.11ab
Alkalinity	**mg/l $CaCO_3$**	-	-	-	346.67	391.33	221.33	325.33	312.67
Total Hardness	**mg/l $CaCO_3$**	-	-	-	50.67	99.33	90.67	108.67	99.56
Calcium	**mg/l $CaCO_3$**	-	-	400	20.33	34.00	28.67	9.00	23.89
Magnesium	**mg/l Mg**	-	-	-	1.00	3.67	5.00	21.33	10.00
Nitrates	**mg/l NO_3.**	50.00	10.00	-	137.33ab	94.00ab	49.00b	50.33ab	64.44ab
B.O.D$_5$	**mg/lO_2**	-	-	-	46.67	253.33	186.67	463.33	301.11
DO	**mg/l O_2**	>5	-	-	6.67	3.20a	6.57	1.60a	3.79a
TSS	**mg/l**	-	30.00	-	146.00b	210.00b	21.67	121.67b	117.78b
TDS	**mg/l**	1000.00	1200.00	450	138.67	292.33	280.33	484.67c	352.44
Chloride	**mg/l CI**	250.00	-	-	22.33	55.00	103.67	60.33	73.00
Bicarbonates	**mg/lCaCO_3**	-	-	-	313.33	391.33	154.67	325.33	290.44
Sodium	**mg/l Na**	-	-	70	19.67	34.67	29.33	56.67	40.22
Potassium	**mg/l K**	-	-	-	6.00	16.33	19.33	11.67	15.78

a = indicates measured values above WHO drinking water standards (1993)

b = indicates measured values above NEMA water quality regulations-domestic water sources (2006)

c = indicates measured values above FAO irrigation water standards(1992)

A desktop literature review carried out by the University of Nairobi, Chemistry Department under the UNEP Nairobi River Basin Project Phase III, describes water quality trends as observed at various sampling stations along the Ngong River from 1969-2004. The review shows the occurrence of self-purification mechanisms along the Ngong River, from the source up to Mombasa Road bridge, a fact previously observed by Wandiga (1996) and Issaias (2000). Within the Nairobi Dam outlet, pollutants and turbidity decrease due to slow movement and the retention of water. Pollution levels after the Nairobi Dam outlet tend to increase, particularly as the river passes through Industrial Area and downstream towards Outering Road and then Njiru Bridge station.

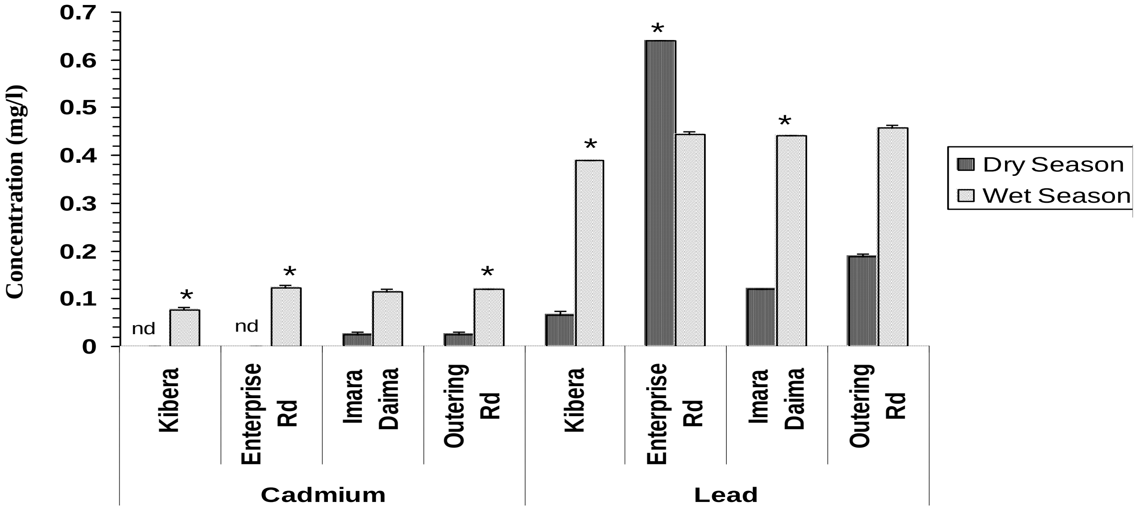
4.3.3 Sewer Water Quality

Table 4.3 and 4.4 show the general characterization of effluent parameters and conformity to the local NEMA discharge standards. Parameters that were above recommended values are discussed below.

4.3.3.1 Heavy Metals Levels

Discharged sewer water showed high lead values above the NEMA effluent discharge standard of 0.01mg/l. Highest values were recorded at Enterprise Road sewer at 0.64mg/l with the lowest showing at Kibera (0.07mg/l) during the dry weather season. In the wet season, there was an increase at all the sewer stations with Outering Road sewer having the highest levels at 0.44mg/l. Levels at Kibera sewer increased to 0.39mg/l in this season. (See Figure 4.7)

Cadmium levels were highest at Imara Daima and Outering Road at 0.02 mg/l in the dry season against a NEMA recommended value of 0.01mg/l. No cadmium was reported at Kibera and Enterprise Road in the dry season however, in the wet season, the levels recorded in these stations were above recommended values (0.01mg/l).



nd- not detectable with the analytical method used

*-indicates 0.05 level of significance of dry and wet season means at each station

Bars indicate Standard deviation of means

Figure 4.7: T-test results for lead and cadmium mean equality levels (sewer)

The mean levels of cadmium samples collected at Imara Daima do not vary significantly at 0.05 level of significance for the dry and wet seasons. Lead values of samples collected at Outering Road have a 95% probability of similarity within both seasons.

No chromium was detected at any sewer sampling station.

4.3.3.2 Other Parameters

Tables 4.3 and 4.4 show that TSS levels of sewer waters are high above NEMA guide value of 30mg/l for all stations in both seasons. The values were highest at Enterprise Road (786.67mg/l) and Outering Road (663.33mg/l) sewers. TDS was found to be highest at Enterprise sewer at 2550mg/l while the guide value is 1200mg/l for effluent discharge. BOD_5 levels were above NEMA guide value of 30mg/l, the highest being recorded at Enterprise at 500mg/l in the dry season. BOD_5 values remain high during the wet season with the highest levels being observed at Kibera (463mg/l).

Table 4.3 Sewer water quality parameter levels (Dry season)

Parameter	Unit	NEMA Effluent Discharge Standards	Kibera	Enterprise road	Imara Daima	Outering
pH	**pH scale**	6.5-8.5	6.96	5.92	7.58	6.67
Temperature	**°C**	±3 °C ambient temp	20.10	20.23	22.40	23.60
EC	**µS/cm**	-	1245.67	4216.67	1017.33	537.00
Lead	**mg/l Pb**	0.01	0.07d	0.64d	0.19d	0.12d
Cadmium	**mg/l Cd**	0.01	0.00	0.00	0.02d	0.02d
Alkalinity	**mg/l $CaCO_3$**	-	47.33	23.33	24.67	30.00
Total Hardness	**mg/l $CaCO_3$**	-	290.00	64.67	68.67	57.33
Calcium	**mg/l $CaCO_3$**	-	63.00	21.13	24.67	16.97
Magnesium	**mg/l Mg**	-	32.50	2.93	1.83	3.77
Nitrates	**mg/l NO_3.**	-	149.60	93.30	114.40	102.10
B.O.D_5	**mg/lO_2**	30.00	280.00d	500.00d	213.33d	326.67d
DO	**mg/l O_2**	-	2.73	4.90	2.73	3.70
TSS	**mg/l**	30.00	376.67d	786.67d	295.00d	663.33d
TDS	**mg/l**	1200.00	747.40	2550.00d	610.07	322.07
Chloride	**mg/l CI**	-	139.00	1640.67	53.33	40.00
Bicarbonates	**mg/l$CaCO_3$**	-	47.33	23.33	18.00	30.00
Sodium	**mg/l Na**	-	88.33	382.67	39.60	65.00
Potassium	**mg/l K**		64.33	31.67	14.33	21.00

d= indicates measured values above NEMA water quality regulations-Effluent Discharge (2006)

Table 4.4: Sewer water quality parameter levels (Wet Season)

Parameter	Unit	NEMA Effluent Discharge Standards	Kibera	Enterprise Road	Imara Daima	Outering Road
pH	**pH scale**	6.5-8.5	7.46	6.48	7.05	6.91
Temperature	**°C**	±3 °C above ambient temp	21.27	24.10	25.37	23.73
EC	**µS/cm**	-	790.00	702.33	543.00	856.33
Lead	**Mg/l Pb**	0.01	0.39d	0.44d	0.41d	0.44d
Cadmium	**Mg/l Cd**	0.01	0.08d	0.12d	0.11d	0.11d
Alkalinity	**Mg/l $CaCO_3$**	-	283.33	246.67	213.33	373.33
Total Hardness	**Mg/l $CaCO_3$**	-	117.33	68.00	75.33	120.67
Calcium	**Mg/l $CaCO_3$**	-	35.67	28.00	26.67	30.00
Magnesium	**Mg/l Mg**	-	7.00	0.00	2.00	11.00
Nitrates	**mg/l NO_3.**	-	91.00	96.33	91.33	53.67
B.O.D_5	**Mg/lO_2**	30.00	463.33d	430.00d	103.33d	140.00d
DO	**Mg/l O_2**	-	2.91	2.23	2.13	1.60
TSS	**mg/l**	30.00	67.33d	110.00d	102.00d	120.00d
TDS	**mg/l**	1200.00	484.00	457.33	330.33	517.67
Chloride	**Mg/l CI**	250.00	70.67	50.67	66.67	60.33
Bicarbonates	**Mg/l$CaCO_3$**	-	283.33	246.67	213.33	373.33
Sodium	**Mg/l Na**	-	53.33	61.67	43.33	50.00
Potassium	**mg/l K**		22.67	14.33	10.00	12.33

d= indicates measured values above NEMA water quality regulations-Effluent Discharge (2006)

4.3.4 Time Series Data

Weekly sampling and analysis was done for Ammonia, BOD_5 and DO parameters. Appendix 6 shows the trends observed for the three parameters from the month of July to December 2006.

Table 4.5: Analysis of variance of river water quality parameters

Site	Mean		
	Ammonia	**Dissolved Oxygen**	**BOD_5**
Kibera	.87201[a]	5.75718[a]	19.19952[a]
Dam Outlet	23.44166[b]	1.81299[b]	126.26235[b]
Mombasa Rd	21.72716[b]	5.95972[a]	43.77430[a]
Outering Rd	25.25338[b]	.69991[c]	225.66951[b]
Njiru	39.61783[b]	.64447[c]	230.82802[b]

Means within the same column do not differ at 0.05 level of probability if followed by same letter using the Tukey HSD post hoc test.

The BOD_5 levels observed at Outering Road and Njiru stations show the likely influence of similar factors which include organic waste-waters from the Industrial Area and high density residential areas upstream of these stations (see Table 4.5). Mombasa Road and Kibera station continued to show DO values above 5mg/l.

Ammonia levels increase above the NEMA guide value for ammonia (0.5mg/l) after the Kibera station through out the study period. Ammonia at high concentrations is toxic to aquatic life. It contributes to eutrophication of water bodies. This results in prolific algal growths that have deleterious impact on other aquatic life, drinking water supplies, and recreation. Likely sources include the direct discharge of raw waste-water from Industrial Area and high density residential areas, and to a less extent the effect of agricultural run-off at Kibera station.

4.4 Conclusions and Recommendations

The highest pollutant concentrations found in Ngong river water were heavy metals (lead and cadmium), nitrates, TSS and TDS. There were reduced levels of EC, Nitrates, TSS and TDS during the wet weather whilst lead and cadmium increased. Lead values increased in the wet season ranging from 0.39 to 0.46mg/l. During the dry season cadmium was not detected in Kibera, Nairobi dam and Mombasa road stations but in the wet season cadmium was detected in all stations with values ranging from 0.06 to 0.12mg/l.

There is no general trend exhibited with the weekly sampling of DO, Ammonia and BOD_5, however peaks in BOD concentrations were observed in the month of November with Outering station recording 463.33mg/l and 301.11mg/l at Njiru station which shows that the river water at these points are highly polluted. Waters at Kibera station can be described as adequate since they complied with WHO and NEMA standards for most parameters except for Nitrates with levels of upto 137.33mg/l being reported. Downstream of the Kibera station the river exhibits a dark greyish colour which explains the high levels of suspended solids contained in the water. According to FAO irrigation water standards, Ngong River is fit for irrigation however this should be cautioned due to the long-term effects on the soils and crops.

Sewer water parameter loading of TSS and TDS were found to be decreasing during the wet weather. These values are above the NEMA effluent discharge standards which allows for only treated wastewaters to be discharged in water courses. Heavy metal levels increased during the wet season with lead values ranging from 0.39-0.44mg/l and cadmium values ranging from 0.08-0.12mg/l. This means that the runoff waters getting into the sewer line contain lead and cadmium contents which increase the heavy metal loading of sewer waters.

The Nairobi sewer line is a combined sewer which carries both sanitary and storm waters. The construction of small waste-water treatment plants and improved sewer infrastructure through repair and/or replacement of old sewer pipes within the Nairobi river basin will reduce pollutant loading in the sewer line as it progresses towards the Ruai Waste-water Treatment Works. Separating storm water from sanitary sewer water lines will reduce the occurrence of high water quality parameters concentrations especially during the wet season.

CHAPTER V

5.0: FLOW REGIME IMPACT ON NGONG RIVER WATER QUALITY

5.1 Introduction

Ngong River is a receptacle of waste-water that affects the water quality and quantity. The natural regime of the river has been adversely affected by human interaction through pollution, increase of paved surfaces and the encroachment of river valleys. The key issue for optimizing water quality management is identifying the flow situations when water quality variables become limiting to ecosystem processes (Palmer et al.2005b).

The scale of water abstractions and inflows can be designed to reduce ecological and sanitary problems arising from inappropriate combinations of flow dynamics and physicochemical characteristics of water. Pollutants stem from point as well as non-point sources and affecting river systems differently depending on the location within a catchment (Pringle 2000). Ngong River sections, located in the middle and lower parts of catchments, are subjected to the cumulative effects of human alterations to the flow regime and water quality. During high flows there is a considerable addition of organic and inorganic matter to the water. High flows are also vital for reducing levels of various elements in rivers, by downstream transport, retention, or emission, e.g., denitrification that requires inundation from larger areas (Chang and Carlson, 2005). If high flows are caused by heavy rains, effluents may be collected. In most cases, because of dilution, effects on water quality are insignificant. Periods of low flows lead to increased concentrations of substances that are added in low doses, which will increase and might reach levels toxic to organisms. Most rivers only have a fraction of their natural flow remaining within the channel, and decreasing number of these rivers reach their lakes and oceans.

5.1.1 Objective

- To evaluate the influence of river flow rates on water quality of Ngong River.

5.2 Materials and Methods

Measured flow and water quality data obtained during the study period was used to establish the relationship between water quality parameters and flow rates. Time series data on Dissolved Oxygen, Ammonia and BOD_5 sampled and analysed on a weekly basis for a period of five months (July-December, 2006), were plotted against discharge data measured during this period.

5.3 Results and Discussion

5.3.1 Dissolved Oxygen versus Discharge

Dissolved Oxygen at Kibera station is not affected notably by discharge since it varied during the study period as shown in Figure 5.1. Kibera station is located just after the Motoine forest and the river at this section has minimal human interference thus allowing free flow of water along its natural course and minimal contamination. The same trend is observed at the Nairobi Dam outlet with DO levels varying at different flow rates (Figure 5.2). Water leaving the dam is energised and gathers atmospheric oxygen which increases the amount of oxygen in water flowing within this section. At Mombasa Road station there was a period of increased DO despite constant discharge rates this is because flow at this section has minimal contamination as the river passes well sewered residential areas. DO levels at Outering Road station varied irrespective of constant discharge rates. However, in the wet season DO levels increased with an increase in discharge rates. The same trend was observed at Njiru Bridge. These behaviours are described in Figures 5.1 to 5.5.

Flowing water is more likely to have high dissolved oxygen levels than is stagnant water because of the water movement at the air–water interface as would be the case at all stations. As Ngong River passes through the Industrial Area it becomes heavily polluted due to direct industrial effluent, overflowing manholes and organic wastes from the Mukuru informal settlements, greatly affecting DO levels at Outering Road and Njiru stations. Ngong River maintained a constant flow rate at these two stations but the water quality remains poor, which has lead to these variations. Recommended levels of DO should be above 5mg/l (WHO, 1993).

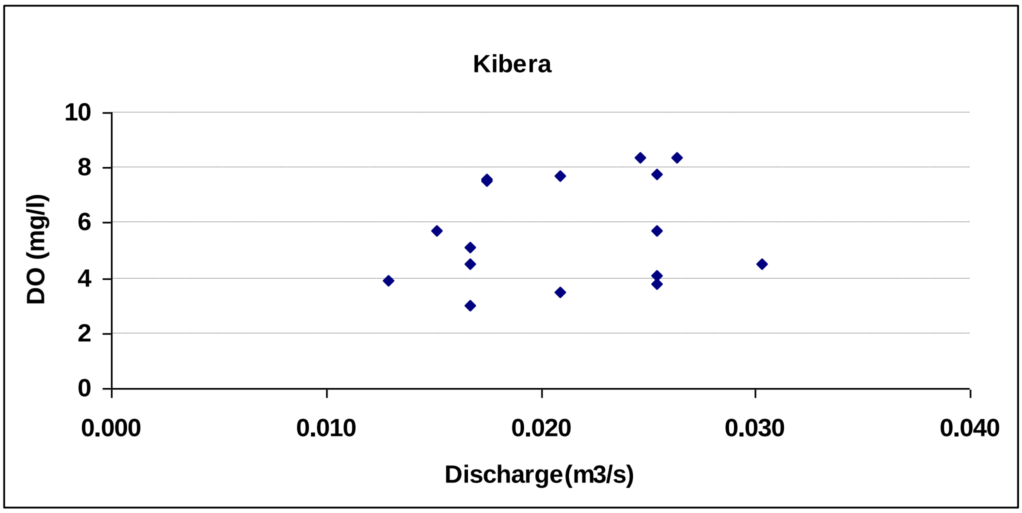


Figure 5.1: Dissolved oxygen trend at Kibera Station

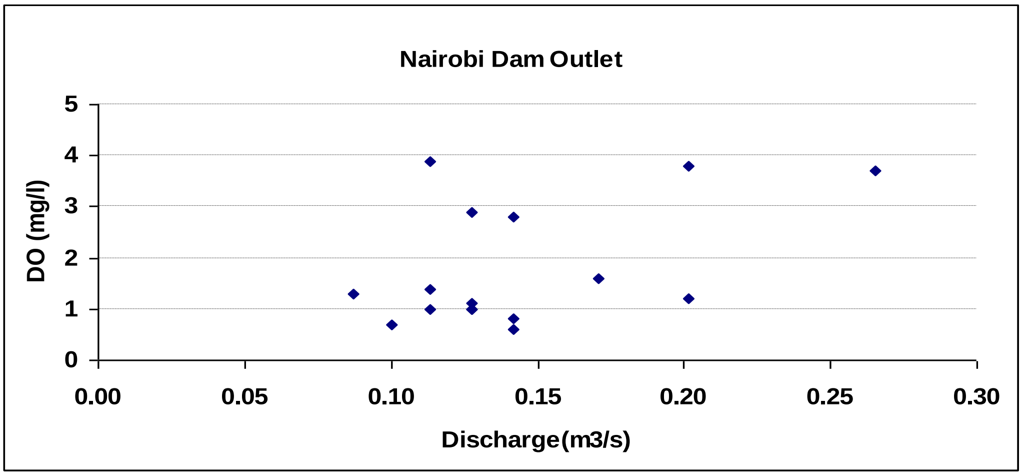


Figure 5.2: Dissolved oxygen trend at Nairobi Dam outlet Station

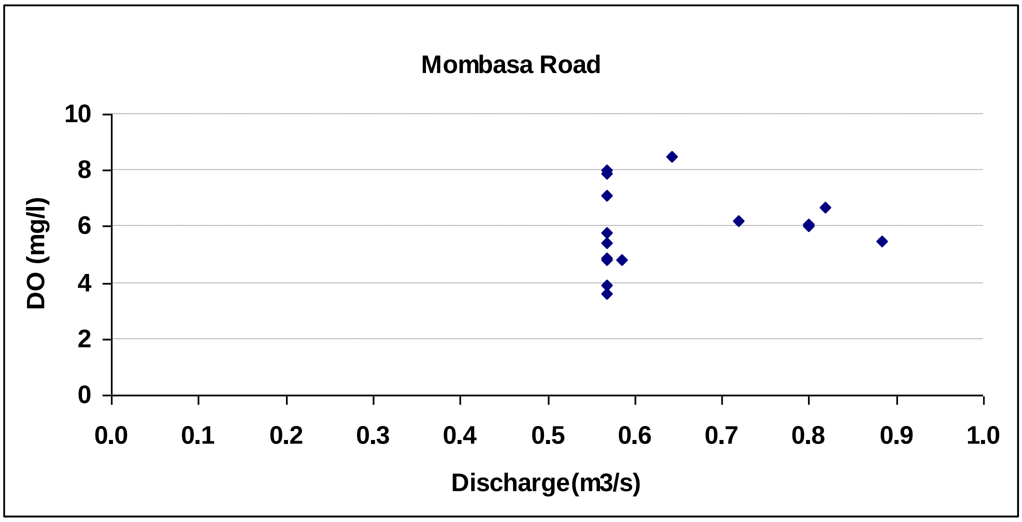


Figure 5.3: Dissolved oxygen trend at Mombasa road Station

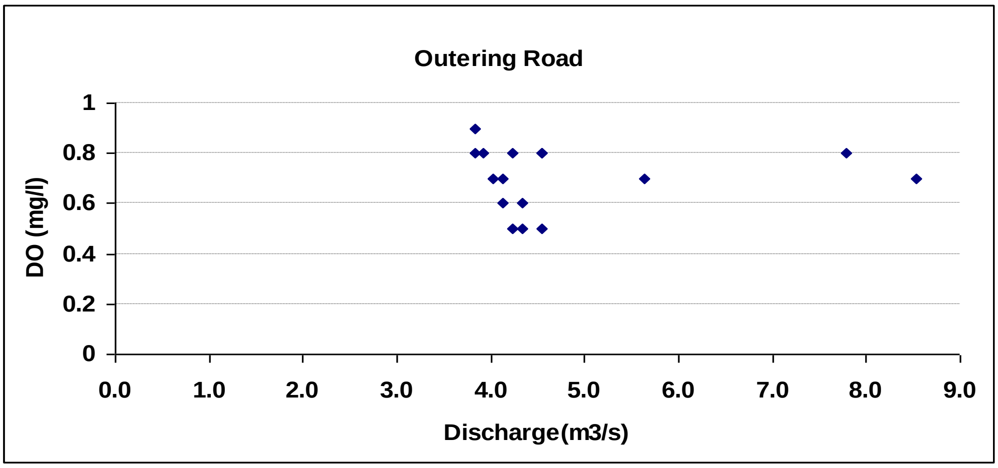


Figure 5.4: Dissolved oxygen trend at Outering Road Station

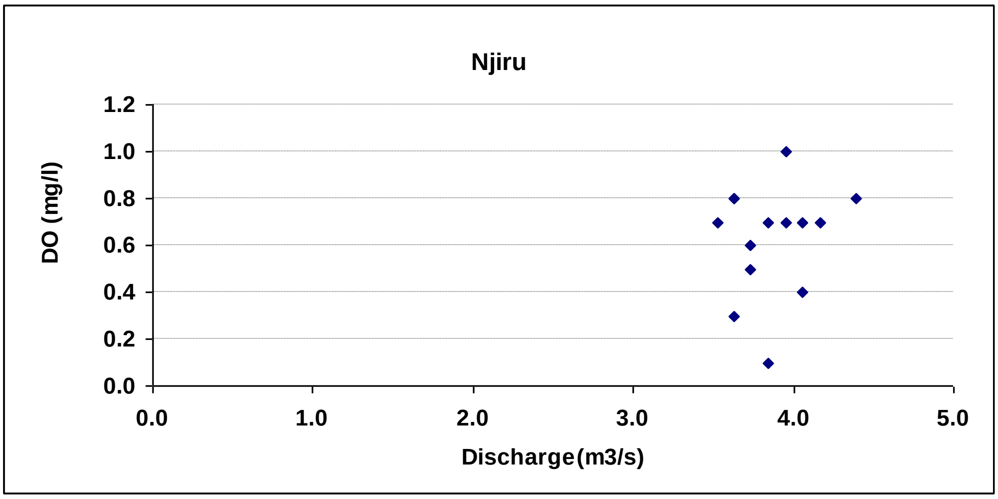


Figure 5.5: Dissolved oxygen trend at Njiru road Station

5.3.2 Ammonia Levels versus Discharge

Kibera station experienced low concentrations of ammonia with no general trend against flow rates as shown in Figure 5.6. However, ammonia levels seemed to reduce as flows increased. Ammonia at this station could be influenced by the runoff from upstream cultivated lands where ammonia based fertilisers are applied. Ammonia levels are still above the maximum contaminant level of 0.5mg/l set by NEMA standards.

During this study period, Nairobi Dam Outlet station experienced variations in ammonia levels when flow rates were ranging from 0.10 to 0.15 m^3/s. Mombasa road station had increased ammonia concentrations at a constant flow rate of 0.57m3/s as shown in Figure 5.8. This station had a decrease in concentrations with increase in flow rates which can be attributed to self-cleansing. Wandiga et al, (2005) observed some form of self-cleaning at this station that takes place in the wet season. There was a general increase of Ammonia levels at Outering Road and Njiru station despite a constant river flow rate. This means that Ammonia concentration at these two stations was not influenced by addition of more water but by the fact that all the upstream waters flowing past these stations are already heavily polluted. Figures 5.6 to 5.10 describes the behaviour of ammonia against discharge as observed at each station.

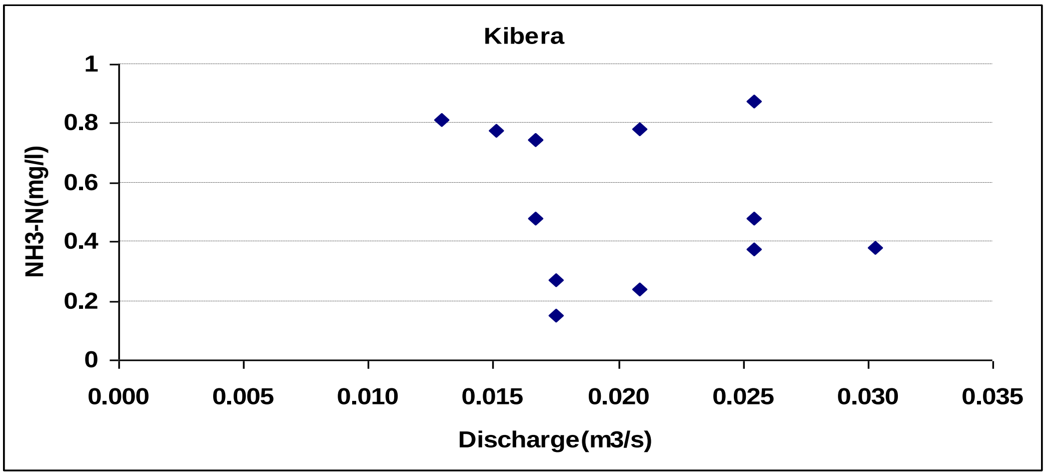


Figure 5.6: Ammonia trend at Kibera Station

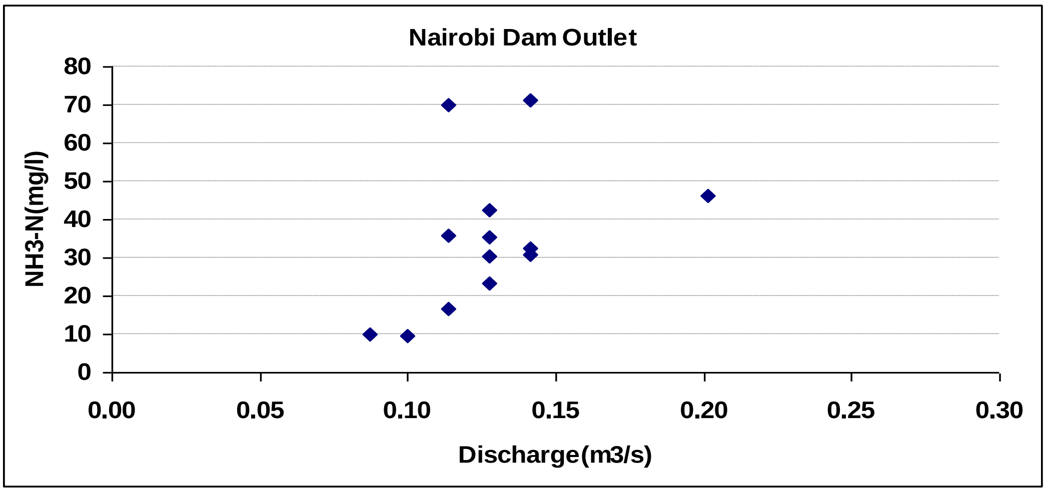


Figure 5.7: Ammonia trend at Nairobi Dam Outlet Station

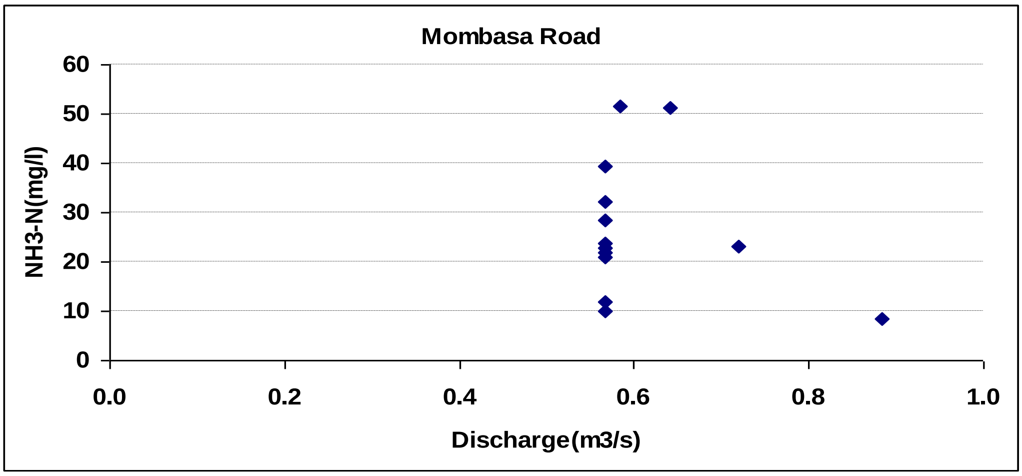


Figure 5.8: Ammonia trend at Mombasa Road Station

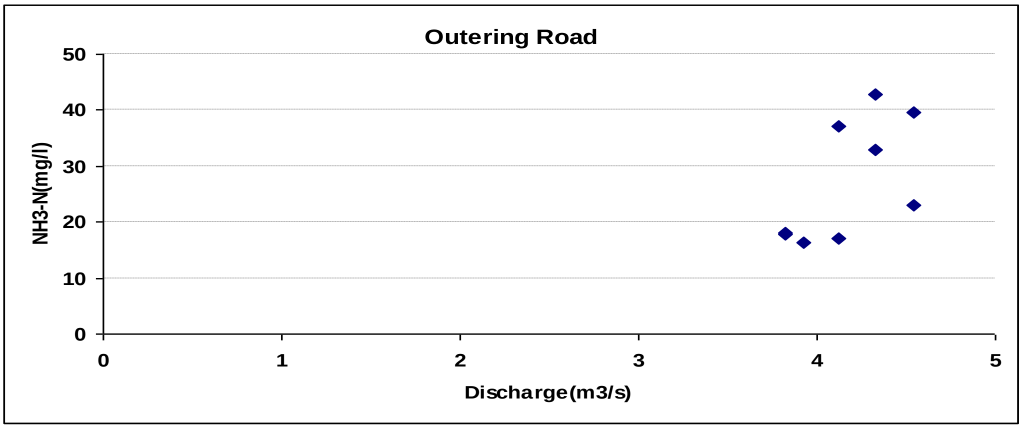


Figure 5.9: Ammonia trend at Outering Road Station

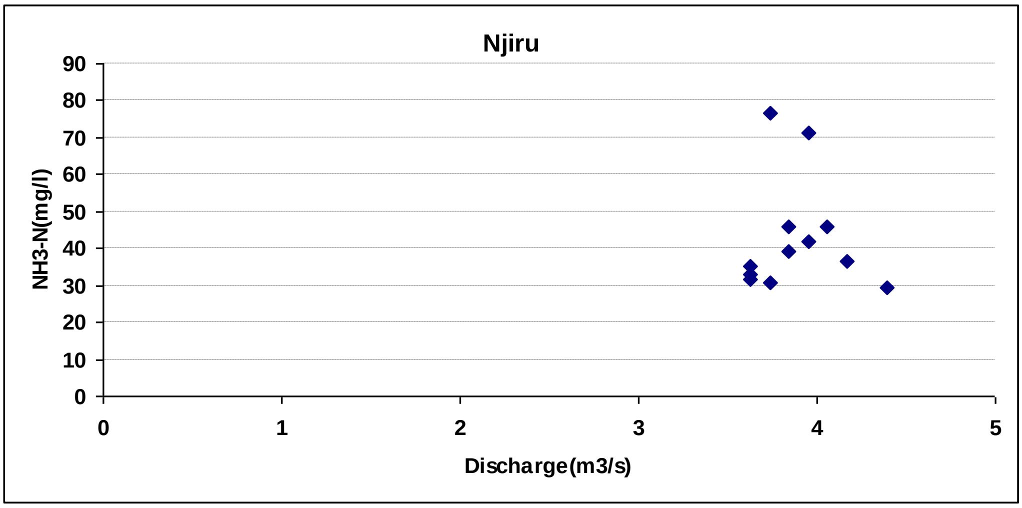


Figure 5.10: Ammonia trend at Njiru road Station

5.3.3 BOD$_5$ Levels versus Discharge

Kibera station showed variations in BOD$_5$ levels. During increased flows the BOD$_5$ levels decreased as shown in Figure 5.11. The upstream waters serving this station may be contaminated as the river passes through farming communities within the Motoine area. Figure 5.12 shows increasing BOD$_5$ levels at the Nairobi Dam outlet consistent with increase in discharge.This shows the high levels of organic wastes that are discharged by the waters leaving the dam due to a long periods of contamination by the Kibera informal settlements. The Mombasa Road station exhibits slight variations in BOD$_5$ contamination with an increase in BOD$_5$ levels during the wet season (Figure 5.13). The station, which is downstream of the Nairobi Dam outlet, is recharged by water from the dam especially in the wet season.

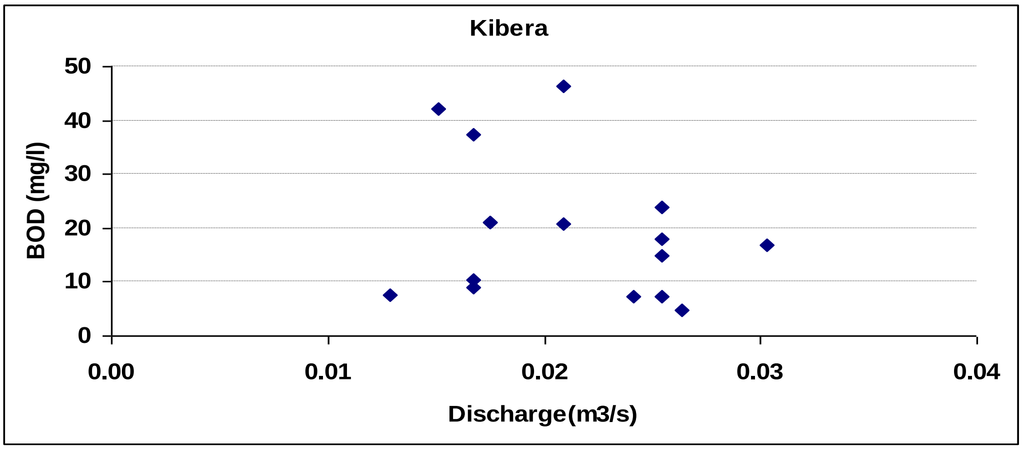


Figure 5.11: BOD$_5$ trends at Kibera station

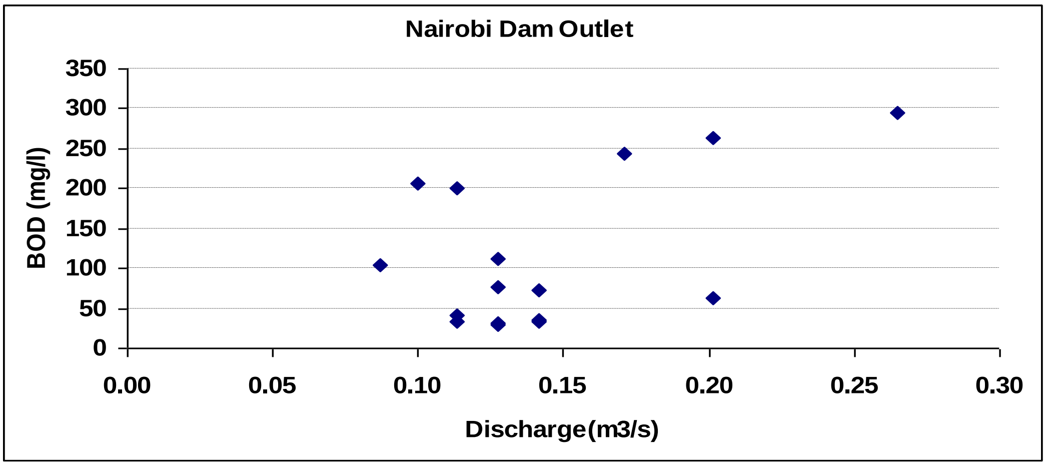


Figure 5.12: BOD$_5$ trends at Nairobi Dam outlet station

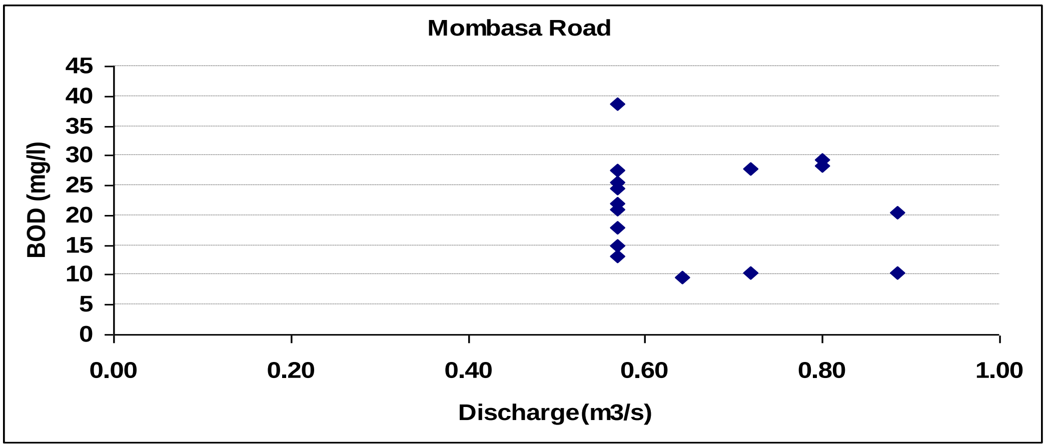


Figure 5.13: BOD$_5$ trends at Mombasa Road station

Outering Road and Njiru stations showed increasing levels of BOD$_5$ contamination with constant flows. At two occasions, BOD$_5$ levels decreased with increase in discharg. See Figures 5.14 and 5.15 below.

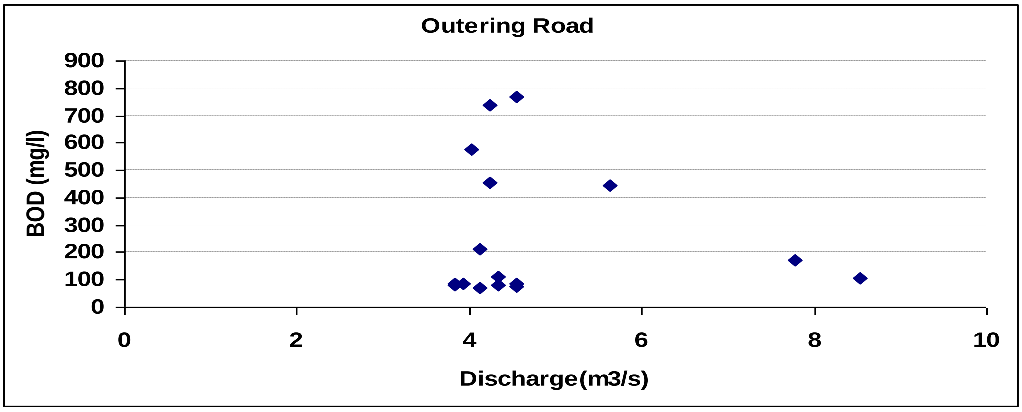


Figure 5.14: BOD$_5$ trends at Outering Road station

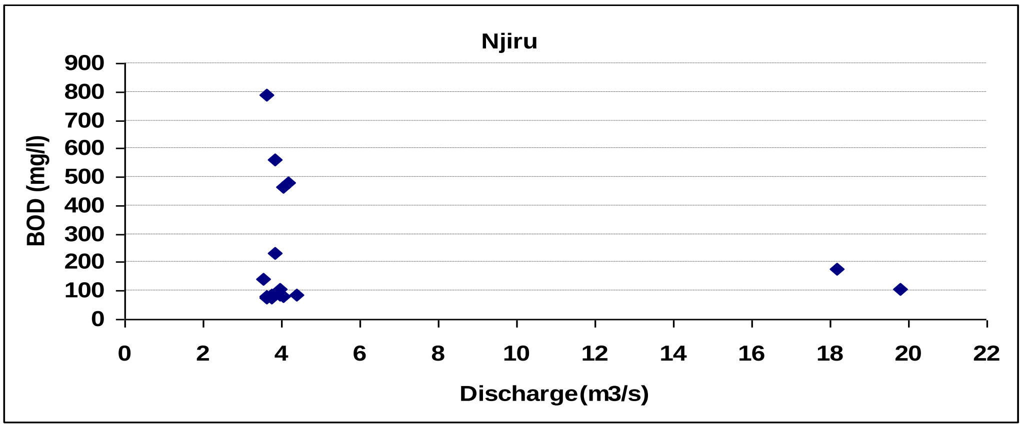


Figure 5.15: BOD$_5$ trends at Njiru station

5.4 Conclusions and Recommendations

Dissolved oxygen, Ammonia and BOD_5 levels are only influenced by variations in discharges at Kibera, Nairobi Dam Outlet and Mombasa road station. At Outering and Njiru stations the three water quality parameters are impacted by the typical contaminated waters flowing past these stations. There was some sought of decrease in BOD_5 levels with higher flows at Outering and Njiru stations though the values are still above environmental guide values. Increase in discharge has a direct effect on water quality as faster movements of water enable rivers to attain self-purification. This is not obvious case with the Ngong River due to pollution sources identified during this study. The river has been termed as an open sewer and it does not receive better water quality as it flows downwards towards its confluence with Nairobi River that would assist it recharge its hydrological potential.

River sections located in the middle and downstream have been subjected to the cumulative effects of upstream human alterations to the flow regime and the water quality. More studies should be done to assess the effect of water flowing at different times during the day and night. Water quality parameters can only be best described if monitored on frequent basis by setting up of automated test kits/equipment along the river to develop an adequate water quality and quantity database. This will inform water resource managers in effective control of pollutant levels within the river. Various controls can be adopted that could balance water quantity and quality and improve environmental conditions, such as reduction of surface run-off, timing of wastewater release, regulation of flows, and development of unpaved areas or reservoirs for water cleaning.

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

In January 2007, the Government of Kenya published its first National Water Resources Management Strategy (2007-2009) guided by the Water Act 2002 which identifies that Kenyans are faced with gross water scarcity (water supplies that are below 1000m3 per person). The publication further identifies the degradation of water resources through the unsustainable use of surface water, pollution and inappropriate land use. The strategy has an overall goal to eradicate poverty by ensuring that Kenyans everywhere have access to safe water for consumption and productive use. It mentions the need to improve the assessment of water resources for more accurate information on the quantity of water produced per year from underground and surface water sources. It also seeks for alternatives to river waste disposal and adopt rules that will ensure deterrence from further pollution such as the Polluter Payer Principle in case of industrial effluent charges. Effluent standards should be developed to take into account the particular assimilative capacities of the receiving water bodies. The untreated sewer waters discharge into the Ngong River through open drains, burst sewer lines and overflowing manholes.

The project findings lead to the following recommendations to be effected as soon as possible if the Ngong river flow and quality are to be improved for the survival and sustenance of a natural eco-system along the river basin:

- Changes in land use through restoration of polluted watersheds with the construction of riparian wetlands which restore water quality but also allow for infiltration to groundwater and sustain hydrological regimes.
- Reduction of rapid surface runoff during rains has been identified as a means of reducing concentration of pollutants during wet seasons. This can be done by provision of storm water drains at shorter intervals along roads and pathways that will reduce the long distance of accumulation of polluted run-off.
- Identification of pollution sources and the collaboration of environmental, society, economy policies to reduce pollution discharge. Cheng et al (2006) made an attempt with modifying releases of pollutants with a discharge program developed by using variation in flow conditions and seasons of polluted rivers to accommodate various waste-water discharge concentrations.

Therefore, integrated approaches like the Integrated Water Resources Management (IWRM) should ensure that participating stakeholders and sectors are aware and committed to maximizing economic and social welfare without compromising the sustainability of vital ecosystems through compliance of existing policies and programs.

Management and research should be directed in understanding the relationship between water quantity, quality and the intended water uses. Use of baseline sampling stations established by the UNEP-NRBP program is an important step towards ensuring co-ordinated efforts and long-term monitoring of river water quality. The communication strategies geared towards educating the public on the implications of inhabiting river valleys should be developed and implemented. Additional studies should be conducted to access the suitability of Ngong River for urban agriculture.

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APPENDIX 1: River Cross-Section Collimation Measurements

Date: 23rd August 2006 Levels taken for: Kibera Station
Surveyor name: Priscilla Kagure

Backsight	Intermediate	Foresight	Collimation	Reduced Level	Distance(m)	Remarks
1.57			1001.57	1000	0	Benchmark no.1
	2.99			998.585	2	Bed level
	3.24			998.33	2.9	Bed level
	3.42			998.15	4.3	Bed level
	3.50			998.07	5.7	Bed level
	3.46			998.11	7.1	Bed level
	3.41			998.16	8.1	Bed level
	3.23			998.34	10	Bed level
	2.86			998.71	12	Bed level
1.6		1.67	1001.5	999.9	16	Change station
		1.84		999.66	18	Benchmark no.1
			error	0.34		

Date: 23th August 2006 Levels taken for: Nairobi Dam Outlet Station
Surveyor name: Priscilla Kagure

Backsight	Intermediate	Foresight	Collimation	Reduced Level	Distance(m)	Remarks
1.05			1001.05	1000	0	Bench mark no.1
	1.5			999.55	1.7	Bed level
	1.85			999.2	3.1	Bed level
	2.5			998.55	3.4	Bed level
	2.785			998.265	3.93	Bed level
	2.785			998.265	4.46	Bed level
	2.955			998.095	4.51	Bed level
	2.956			998.094	4.7	Bed level
	2.955			998.095	4.89	Bed level
	2.8			998.25	4.94	Bed level
	2.75			998.3	6	Bed level
	2.185			998.865	6.3	Bed level
	1.38			999.67	7.7	Bed level
	1.025			1000.025	9.4	Bed level
0.98		1.1	1002.03	1001.05	11.4	Change station
		0.96		1001.07	12.4	Bench mark no.1
			error	1.07		

Date: 23th August 2006 **Levels taken for: Mombasa Road Station**
Surveyor name: Priscilla Kagure

Backsight	Intermediate	Foresight	Collimation	Reduced Level	Distance(m)	Remarks
1.54			1001.54	1000	0	Benchmark no.1
	2.34			999.2	2.7	Bed level
	2.785			998.755	4.15	Bed level
	3.03			998.51	5.77	Bed level
	3.31			998.23	7.39	Bed level
	3.35			998.19	9.32	Bed level
	3.359			998.181	11.25	Bed level
	3.443			998.097	11.35	Bed level
	3.45			998.09	11.86	Bed level
	3.357			998.183	11.96	Bed level
	3.35			998.19	13.88	Bed level
	3.32			998.22	15.81	Bed level
	2.964			998.576	17.43	Bed level
	2.724			998.816	18.95	Bed level
	2.369			999.171	19.95	Bed level
3.59		3.43	1001.7	998.11	21	Change station
		1.69		1000.01	23	Benchmark no.1
			error	0.01		

Date: 24th August 2006 **Levels taken for: Outering Road Station**
Surveyor name: Priscilla Kagure

Backsight	Intermediate	Foresight	Collimation	Reduced Level	Distance(m)	Remarks
1.596			1001.596	1000	0	Benchmark no.1
	1.985			999.611	2	Bed level
	2.705			998.891	2.1	Bed level
	2.775			998.821	3.18	Bed level
	2.89			998.706	4.16	Bed level
	2.918			998.678	5.14	Bed level
	2.91			998.686	6.12	Bed level
	2.759			998.837	7.1	Bed level
	2.015			999.581	7.2	Bed level
		1.417		1000.179	8.7	Benchmark no.1
			error	0.179		

Date: 24th August 2006 Levels taken for: Njiru Road Station Surveyor name: Priscilla Kagure						
Backsight	**Intermediate**	**Foresight**	**Collimation**	**Reduced Level**	**Distance(m)**	**Remarks**
1.54			1001.54	1000	0	Benchmark no.1
	1.785			999.755	1.1	Bed level
	1.77			999.77	2.2	Bed level
	2			999.54	3.3	Bed level
	2.36			999.18	4.4	Bed level
	2.456			999.084	5.5	Bed level
	2.43			999.11	6.6	Bed level
	2.22			999.32	7.7	Bed level
	1.89			999.65	8.8	Bed level
	1.774			999.766	9.9	Bed level
1.174		1.49	1001.224	1000.05	11	Change station
		2.0625		999.1615	13	Benchmark no.1
			error	0.8385		

APPENDIX 2: Water Level Readings

Date	**Time of depth reading**	**Kibera**	**Nairobi Dam**	**Mombasa Rd**	**Outering Road**	**Njiru Bridge**
		Depth reading d,(m)	**Depth reading d,(m)**	**Depth reading d,(m)**	**Depth reading d,(m)**	**Depth reading d,(m)**
2006-07-19	9am	0.045	0.13	0.16	0.755	0.645
2006-07-20	9am	0.056	0.13	0.16	0.675	0.615
2006-07-21	9am	0.05	0.12	0.14	0.695	0.415
2006-07-22	9am	0.045	0.14	0.14	0.725	0.375
2006-07-23	9am	0.055	0.15	0.15	0.715	0.425
2006-07-24	9am	0.045	0.14	0.14	0.685	0.485
2006-07-25	9am	0.045	0.14	0.15	0.635	0.595
2006-07-26	9am	0.05	0.15	0.14	0.665	0.625
2006-07-27	9am	0.05	0.13	0.13	0.675	0.535
2006-07-28	9am	0.05	0.12	0.14	0.625	0.545
2006-07-29	9am	0.05	0.14	0.15	0.625	0.415
2006-07-30	9am	0.045	0.13	0.14	0.635	0.515
2006-07-31	9am	0.045	0.14	0.14	0.635	0.475
2006-08-01	9am	0.045	0.14	0.13	0.625	0.635
2006-08-02	9am	0.045	0.13	0.14	0.635	0.585
2006-08-03	9am	0.044	0.14	0.13	0.625	0.495
2006-08-04	9am	0.055	0.15	0.13	0.595	0.625
2006-08-05	9am	0.056	0.14	0.14	0.615	0.585
2006-08-06	9am	0.055	0.15	0.13	0.675	0.615
2006-08-07	9am	0.045	0.13	0.14	0.685	0.555
2006-08-08	9am	0.05	0.13	0.13	0.655	0.575
2006-08-09	9am	0.045	0.15	0.14	0.635	0.555
2006-08-10	9am	0.04	0.19	0.13	0.625	0.555
2006-08-11	9am	0.045	0.14	0.13	0.655	0.575
2006-08-12	9am	0.04	0.14	0.14	0.655	0.615
2006-08-13	9am	0.035	0.13	0.13	0.635	0.565
2006-08-16	9am	0.035	0.12	0.13	0.625	0.565
2006-08-18	9am	0.035	0.13	0.14	0.705	0.575
2006-08-21	9am	0.035	0.14	0.13	0.675	0.585
2006-08-23	9am	0.035	0.13	0.13	0.695	0.565
2006-08-25	9am	0.035	0.19	0.14	0.715	0.585
2006-08-28	9am	0.045	0.19	0.13	0.705	0.585
2006-08-30	9am	0.04	0.13	0.13	0.695	0.575
2006-09-01	9am	0.035	0.14	0.13	0.695	0.585
2006-09-04	9am	0.035	0.13	0.14	0.675	0.575
2006-09-06	9am	0.035	0.14	0.17	0.675	0.605
2006-09-08	9am	0.04	0.13	0.16	0.775	0.595
2006-09-11	9am	0.035	0.13	0.14	0.725	0.575
2006-09-13	9am	0.03	0.12	0.14	0.675	0.595
2006-09-15	9am	0.032	0.12	0.14	0.635	0.555
2006-09-18	9am	0.04	0.13	0.14	0.665	0.605
2006-09-20	9am	0.045	0.18	0.13	0.655	0.585

2006-09-22	9am	0.043	0.2	0.13	0.645	0.615
2006-09-25	9am	0.04	0.15	0.13	0.635	0.605
2006-09-27	9am	0.033	0.13	0.13	0.645	0.585
2006-10-02	9am	0.04	0.14	0.13	0.655	0.595
2006-10-04	9am	0.036	0.12	0.13	0.665	0.615
2006-10-06	9am	0.033	0.12	0.13	0.685	0.575
2006-10-09	9am	0.031	0.1	0.13	0.715	0.555
2006-10-11	9am	0.036	0.1	0.13	0.695	0.565
2006-10-13	9am	0.035	0.1	0.13	0.685	0.505
2006-10-16	9am	0.035	0.09	0.13	0.655	0.585
2006-10-18	9am	0.04	0.11	0.17	0.665	0.555
2006-10-20	9am	0.035	0.1	0.14	0.785	0.585
2006-10-23	9am	0.033	0.19	0.15	0.785	0.645
2006-10-25	9am	0.045	0.16	0.16	0.795	0.605
2006-10-27	9am	0.035	0.13	0.15	0.775	1.625
2006-10-30	9am	0.032	0.14	0.17	0.825	1.655
2006-11-01	9am	0.031	0.18	0.15	0.975	2.555
2006-11-03	9am	0.045	0.16	0.16	0.945	1.555
2006-11-06	9am	0.045	0.16	0.16	0.965	1.645
2006-11-08	9am	0.046	0.22	0.16	1.035	1.665
2006-11-13	9am	0.052	2.3	1.343	0.985	2.555
2006-11-15	9am	0.045	2.33	1.323	2.735	2.605
2006-11-17	9am	0.152	2.32	1.3421	2.885	2.575
2006-11-20	9am	0.135	2.09	1.3359	2.925	2.495
2006-11-22	9am	0.113	2.04	1.3245	2.785	2.385
2006-11-24	9am	0.102	2.34	1.373	2.585	1.655
2006-11-25	9am	0.101	2.3	1.373	1.695	2.555
2006-11-26	9am	0.3	2.25	1.373	2.741	1.645
2006-11-27	9am	0.3	2.09	1.373	1.025	0.485
2006-11-28	9am	0.279	2.09	1.353	0.665	0.515
2006-11-29	9am	0.251	2.25	1.353	0.625	0.645
2006-11-30	9am	0.3	2.4	1.343	0.775	0.565
2006-12-01	9am	0.299	2.24	1.323	0.705	0.535
2006-12-02	9am	0.3	2.17	1.303	0.725	
2006-12-03	9am	0.3	2.11		0.695	
2006-12-04	9am	0.3	2.17		0.695	
2006-12-05	9am	0.299	0.18			
2006-12-06	9am	0.3	0.16			
2006-12-07	9am	0.286	0.16			

APPENDIX 3: Water Quality Data

Dry season sampling data (River water)

Parameters	UNIT	Kibera				Dam Outlet				Mombasa Road				Outering RoadRoad				Njiru			
		R1	R2	R3	Mean	R1	R2	R3	Mean	R1	R2	R3	Mean	R1	R2	R3	Mean	R1	R2	R3	Mean
pH	**Ph scale**	7.3	7.0	7.4	7.2	6.8	6.7	6.7	6.7	7.4	7.4	7.4	7.4	6.6	6.7	6.6	6.6	7.2	7.2	7.4	7.3
Temp	**°C**	19.8	19.8	19.8	19.8	18.8	18.8	18.7	18.8	27.3	27.3	27.4	27.3	22.7	22.3	21.3	22.1	22.8	22.8	22.8	22.8
EC	**µS/cm**	327.0	332.0	327.0	328.7	703.0	705.0	687.0	698.3	600.0	601.0	585.0	595.3	767.0	727.0	785.0	759.7	854.0	850.0	810.0	838.0
Lead	**mg/l Pb**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cadmium	**mg/l Cd**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkalinity	**mg/l CaCO$_3$**	14.0	12.0	12.0	12.7	32.0	28.0	26.0	28.7	12.0	14.0	18.0	14.7	44.0	36.0	3.2	27.7	26.0	26.0	32.0	28.0
Total Hardness	**mg/l CaCO$_3$**	80.0	78.0	74.0	77.3	170.0	190.0	160.0	173.3	100.0	106.0	118.0	108.0	118.0	110.0	108.0	112.0	102.0	104.0	108.0	104.7
Calcium	**mg/l CaCO$_3$**	23.2	20.0	18.4	20.5	43.2	47.2	40.0	43.5	28.0	30.4	34.0	30.8	40.0	36.0	32.8	36.3	32.0	34.0	36.0	34.0
Magnesium	**mg/l Mg**	5.4	6.8	8.3	6.8	15.1	18.0	15.0	16.0	7.3	7.3	8.3	7.6	4.4	5.0	6.3	5.2	5.4	5.0	4.0	4.8
Nitrates	**mg/l NO$_3$.**	132.0	132.0	132.0	132.0	158.4	158.4	158.4	158.4	176.0	176.0	176.0	176.0	96.8	96.8	96.8	96.8	149.6	149.6	149.6	149.6
B.O.D$_5$	**mg/lO$_2$**	140.0	160.0	180.0	160.0	320.0	290.0	240.0	283.3	340.0	400.0	140.0	293.3	400.0	340.0	380.0	373.3	280.0	240.0	200.0	240.0
DO	**mg/l O$_2$**	6.0	6.1	6.1	6.1	4.5	3.4	4.5	4.1	3.3	3.2	3.2	3.2	2.8	2.4	2.5	2.6	2.3	2.5	2.7	2.5
TSS	**mg/l**	25.0	20.0	16.0	20.3	16.0	22.0	30.0	22.7	65.0	59.0	55.0	59.7	270.0	290.0	270.0	276.7	950.0	990.0	900.0	946.7
TDS	**mg/l**	196.2	199.2	196.2	197.2	421.8	423.0	412.2	419.0	360.0	360.6	351.0	357.2	460.2	436.2	471.0	455.8	512.0	512.0	486.0	503.3
Chloride	**mg/l CI**	50.0	48.0	46.0	48.0	70.0	80.0	90.0	80.0	50.0	56.0	60.0	55.3	60.0	65.0	67.0	64.0	109.0	113.0	117.0	113.0
Bicarbonates	**mg/lCa CO$_3$**	80.0	12.0	12.0	34.7	32.0	28.0	26.0	28.7	12.0	14.0	18.0	14.7	44.0	36.0	32.0	37.3	26.0	26.0	32.0	28.0
Sodium	**mg/l Na**	35.0	27.5	28.8	30.4	35.0	60.0	85.0	60.0	32.5	46.3	53.8	44.2	55.0	50.0	62.5	55.8	37.5	40.0	50.0	42.5
Potassium	**mg/l K**	8.0	7.6	7.0	7.5	24.0	30.0	30.0	28.0	20.0	25.0	30.0	25.0	22.0	27.0	32.0	27.0	20.0	22.0	27.0	23.0

Wet season sampling data (River water)

Parameters	Unit	Kibera				Dam Outlet				Mombasa Road				Outering Road				Njiru			
		R1	R2	R3	Mean	R1	R2	R3	Mean	R1	R2	R3	Mean	R1	R2	R3	Mean	R1	R2	R3	Mean
pH	pH scale	6.63	6.63	6.83	6.70	6.76	6.82	6.68	6.75	7.71	7.72	7.76	7.73	6.68	6.9	6.9	6.83	7.63	7.53	7.52	7.56
Temp	°C	20.3	20.3	20.3	20.30	21.4	21.3	21.4	21.37	22.5	22.2	22.4	22.37	26.7	26.8	26.8	26.77	27.5	27.2	27.4	27.37
EC	µS/cm	200	216	223	213.00	490	489	499	492.67	472	472	470	471.33	831	825	828	828.00	788	787	787	787.33
Lead	mg/l Pb	0.41	0.4	0.4	0.40	0.39	0.39	0.39	0.39	0.43	0.44	0.44	0.44	0.45	0.46	0.46	0.46	0.41	0.41	0.41	0.41
Cadmium	mg/l Cd	0.06	0.06	0.06	0.06	0.1	0.1	0.11	0.10	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Alkalinity	mg/l $CaCO_3$	344	346	350	346.67	390	390	394	391.33	220	222	222	221.33	322	324	330	325.33	328	328	328	328.00
Total Hardness	mg/l $CaCO_3$	48	50	54	50.67	88	96	114	99.33	84	88	100	90.67	90	116	120	108.67	122	118	118	119.33
Calcium	mg/l $CaCO_3$	20	20	21	20.33	32	34	36	34.00	28	28	30	28.67	9	9	9	9.00	29	30	30	29.67
Magnesium	mg/l Mg	NIL	NIL	1	1.00	2	3	6	3.67	4	5	6	5.00	17	23	24	21.33	12	11	10	11.00
Nitrates	mg/l NO_3.	140	140	132	137.33	97	97	88	94.00	53	49	49	50.33	49	49	49	49.00	74	79	79	77.33
B.O.D_5	mg/lO_2	50	40	50	46.67	250	250	260	253.33	180	180	200	186.67	460	460	470	463.33	160	160	170	163.33
DO	mg/l O_2	6.55	6.82	6.65	6.67	3.8	3.9	1.9	3.20	6.2	6.4	7.1	6.57	1.6	1.6	1.6	1.60	1.5	1.6	1.7	1.60
TSS	mg/l	146	146	146	146.00	210	210	210	210.00	20	22	23	21.67	125	120	120	121.67	190	190	195	191.67
TDS	mg/l	138	139	139	138.67	292	291	294	292.33	274	279	288	280.33	483	485	486	484.67	488	488	488	488.00
Chloride	mg/l CI	22	22	23	22.33	55	55	55	55.00	102	104	105	103.67	60	60	61	60.33	72	74	74	73.33
Bicarbonates	mg/l$CaCO_3$	344	346	250	313.33	390	390	394	391.33	220	222	22	154.67	322	324	330	325.33	328	328	328	328.00
Sodium	mg/l Na	19	20	20	19.67	33	33	38	34.67	28	30	30	29.33	55	55	60	56.67	73	75	75	74.33
Potassium	mg/l K	6	6	6	6.00	16	16	17	16.33	14	30	14	19.33	11	12	12	11.67	15	18	18	17.00

Dry season sampling data (Sewer water)

Parameter	**UNIT**	**Kibera**				**Enterprise Road**				**Outering Road**				**Imara Daima**			
		R1	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**
pH	**pH scale**	7.36	7.56	7.47	7.46	6.54	6.37	6.54	6.48	7.07	7.09	7	7.05	6.8	6.98	6.95	6.91
Temp	**^{o}C**	21.3	21.2	21.3	21.27	24.1	23.7	24.5	24.10	25.1	24.9	26.1	25.37	24.6	23.4	23.2	23.73
EC	**µS/cm**	790	790	790	790.00	694	708	705	702.33	547	545	537	543.00	861	821	887	856.33
Lead	**mg/l Pb**	0.39	0.39	0.39	0.39	0.44	0.44	0.45	0.44	0.41	0.41	0.42	0.41	0.44	0.44	0.44	0.44
Cadmium	**mg/l Cd**	0.07	0.08	0.08	0.08	0.12	0.12	0.13	0.12	0.11	0.11	0.12	0.11	0.11	0.11	0.12	0.11
Alkalinity	**mg/l $CaCO_3$**	280	280	290	283.33	240	250	250	246.67	210	210	220	213.33	380	370	370	373.33
Total Hardness	**mg/l $CaCO_3$**	116	118	118	117.33	64	70	70	68.00	74	72	80	75.33	120	120	122	120.67
Calcium	**mg/l $CaCO_3$**	35	36	36	35.67	28	28	28	28.00	26	27	27	26.67	30	30	30	30.00
Magnesium	**mg/l Mg**	7	7	7	7.00	NIL	NIL	NIL	-	2	1	3	2.00	11	11	11	11.00
Nitrates	**mg/l NO_3.**	97	88	88	91.00	97	98	94	96.33	88	93	93	91.33	55	53	53	53.67
B.O.D$_5$	**mg/lO_2**	470	450	470	463.33	400	400	490	430.00	100	100	110	103.33	140	140	140	140.00
DO	**mg/l O_2**	2.37	3.72	2.64	2.91	2.3	2	2.4	2.23	2.2	2.1	2.1	2.13	1.6	1.6	1.6	1.60
TSS	**mg/l**	66	66	70	67.33	110	110	110	110.00	100	102	104	102.00	120	120	120	120.00
TDS	**mg/l**	483	483	486	484.00	456	457	459	457.33	330	330	331	330.33	517	517	519	517.67
Chloride	**mg/l CI**	70	71	71	70.67	50	51	51	50.67	66	67	67	66.67	60	60	61	60.33
Bicarbonates	**mg/l$CaCO_3$**	280	280	290	283.33	240	250	250	246.67	210	210	220	213.33	380	370	370	373.33
Sodium	**mg/l Na**	60	50	50	53.33	60	60	65	61.67	40	40	50	43.33	50	50	50	50.00
Potassium	**mg/l K**	22	22	24	22.67	14	14	15	14.33	10	10	10	10.00	12	12	13	12.33

Wet season sampling data (Sewer water)

		Kibera				Enterprise Road				Outering RoadRoad				Imara Daima			
Parameter	**UNIT**	**R1**	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**
pH	**pH scale**	6.97	6.89	7.03	6.96	5.85	5.97	5.95	5.92	7.64	8.23	6.86	7.58	6.63	6.72	6.65	6.67
Temp	**°C**	20.40	19.90	20.00	20.10	20.20	20.20	20.30	20.23	22.30	22.50	22.40	22.40	23.90	23.00	23.90	23.60
EC	**µS/cm**	1259.00	1226.00	1252.00	1245.67	3260.00	4740.00	4650.00	4216.67	1250.00	1330.00	472.00	1017.33	577.00	430.00	604.00	537.00
Lead	**mg/l Pb**	0.06	0.07	0.07	0.07	0.64	0.64	0.64	0.64	0.19	0.18	0.19	0.19	0.12	0.12	0.12	0.12
Cadmium	**mg/l Cd**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.02
Alkalinity	**mg/l $CaCO_3$**	44.00	48.00	50.00	47.33	20.00	20.00	30.00	23.33	30.00	24.00	20.00	24.67	38.00	28.00	24.00	30.00
Total Hardness	**mg/l $CaCO_3$**	216.00	304.00	350.00	290.00	60.00	64.00	70.00	64.67	78.00	66.00	62.00	68.67	54.00	58.00	60.00	57.33
Calcium	**mg/l $CaCO_3$**	56.00	65.00	68.00	63.00	18.40	21.00	24.00	21.13	28.00	24.00	22.00	24.67	15.20	17.30	18.40	16.97
Magnesium	**mg/l Mg**	18.50	35.00	44.00	32.50	3.40	3.00	2.40	2.93	2.00	1.50	2.00	1.83	4.00	3.90	3.40	3.77
Nitrates	**mg/l NO_3.**	149.60	149.60	149.60	149.60	93.30	93.30	93.30	93.30	114.40	114.40	114.40	114.40	102.10	102.10	102.10	102.10
B.O.D_5	**mg/lO_2**	300.00	280.00	260.00	280.00	480.00	500.00	520.00	500.00	140.00	260.00	240.00	213.33	360.00	360.00	260.00	326.67
DO	**mg/l O_2**	2.50	2.90	2.80	2.73	4.80	5.00	4.90	4.90	2.80	2.60	2.80	2.73	3.60	3.60	3.90	3.70
TSS	**mg/l**	320.00	390.00	420.00	376.67	750.00	790.00	820.00	786.67	335.00	295.00	255.00	295.00	590.00	690.00	710.00	663.33
TDS	**mg/l**	755.40	735.60	751.20	747.40	1956.00	2844.00	2850.00	2550.00	750.00	798.00	282.20	610.07	346.20	258.00	362.00	322.07
Chloride	**mg/l CI**	127.00	140.00	150.00	139.00	1624.00	1649.00	1649.00	1640.67	59.00	52.00	49.00	53.33	45.00	40.00	35.00	40.00
Bicarbonates	**mg/l$CaCO_3$**	44.00	48.00	50.00	47.33	20.00	20.00	30.00	23.33	30.00	4.00	20.00	18.00	38.00	28.00	24.00	30.00
Sodium	**mg/l Na**	80.00	85.00	100.00	88.33	350.00	370.00	428.00	382.67	51.30	35.00	32.50	39.60	62.50	67.50	65.00	65.00
Potassium	**mg/l K**	54.00	64.00	75.00	64.33	32.00	28.00	35.00	31.67	17.00	14.00	12.00	14.33	25.00	20.00	18.00	21.00

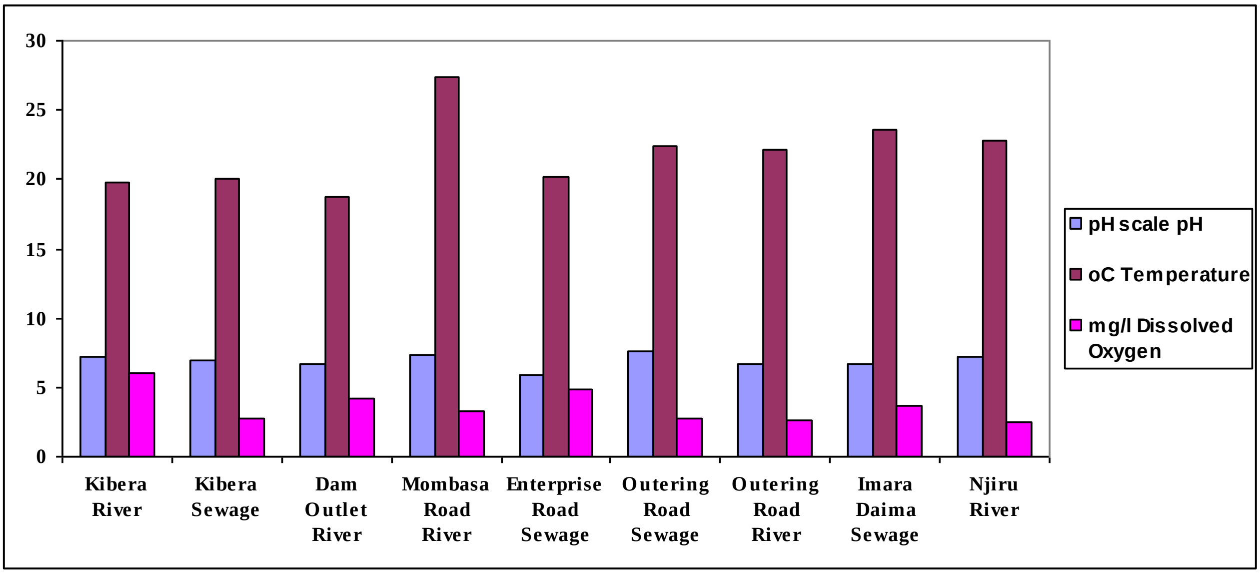
	Ammonia(mg/l)	**Dissolved Oxygen(mg/l)**	**BOD55(mg/l)**

Date	Kibera	Dam Outlet	Mombasa Rd	Outering	Njiru	Kibera	Dam Outlet	Mombasa Rd.	Outering	Njiru	Kibera	Dam Outlet	Mombasa Rd	Outering	Njiru
8/16/2006	1.52	28.38	26.43	10.20	53.57	5.70	2.80	6.20	0.80	1.00	7.19	35.82	10.45	85.07	86.57
8/23/2006	1.12	32.48	23.24	16.24	41.81	3.80	0.80	4.90	0.90	0.80	23.88	32.83	17.90	82.09	83.58
8/30/2006	0.37	20.91	28.37	17.73	29.31	4.50	2.90	4.80	0.70	0.50	16.76	29.34	13.17	73.13	76.12
9/6/2006	0.00	25.39	23.71	17.17	30.52	3.00	1.00	5.40	0.50	0.30	10.45	31.14	38.81	74.63	76.12
9/13/2006	4.48	25.76	11.01	17.73	5.23	5.10	1.40	5.80	0.80	0.80	37.31	32.84	20.96	83.58	82.09
9/20/2006	0.75	0.56	0.93	1.12	2.99	3.50	1.00	3.90	0.80	0.60	46.27	76.12	24.55	86.57	85.07
9/27/2006	1.12	2.43	2.24	2.99	156.61	4.50	0.60	4.80	0.50	0.40	8.95	73.13	10.45	82.09	80.60
10/5/2006	0.75	24.06	51.52	39.57	45.73	3.90	1.00	8.50	0.60	0.70	7.46	41.32	9.60	110.45	107.46
10/11/2006	1.12	70.19	51.14	42.93	111.07	4.10	1.20	8.00	0.60	0.10	15.00	562.50	15.00	210.00	232.50
10/18/2006	0.37	46.11	39.39	32.85	45.92	5.70	1.10	7.90	0.70	0.70	42.00	112.50	85.50	576.92	562.50
10/25/2006	1.12	23.25	22.77	17.17	19.25	7.50	3.90	7.10	0.50	0.70	21.20	201.00	222.00	457.00	480.00
11/1/2006	0.63	21.59	19.97	30.90	34.39	6.67	2.02	6.12	0.70	0.66	17.97	157.43	52.58	283.80	290.93
11/8/2006	0.55	20.97	19.38	32.78	32.64	7.60	1.30	3.60	0.80	0.80	21.00	103.50	97.50	768.04	791.04
11/15/2006	0.47	20.35	18.79	34.66	30.90	7.70	0.70	5.50	0.80	0.70	20.80	207.00	40.50	139.50	142.50
11/22/2006	0.07	16.50	12.00	36.54	6.41	7.80	1.60	6.10	0.70	0.70	18.00	150.00	28.20	442.50	465.00
11/29/2006	0.15	10.17	10.07	38.42	1.50	8.40	3.80	6.70	0.80	0.80	7.35	102.00	37.80	174.00	177.00
12/6/2006	0.24	9.42	8.42	40.30	25.66	8.40	3.70	6.00	0.70	0.70	4.80	198.00	19.20	107.01	105.00

Time Series Data for Weekly River Water Sampling

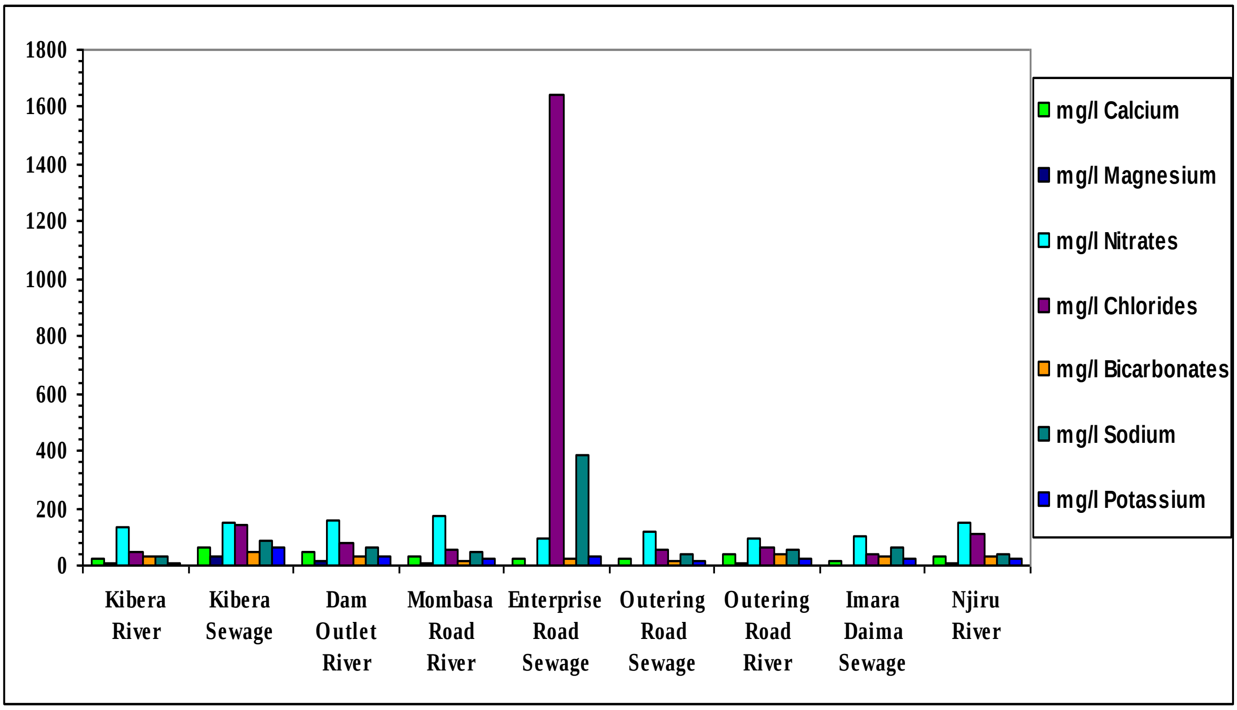
APPENDIX 4: Dry Season Concentrations Graphs

Onsite tested parameters levels

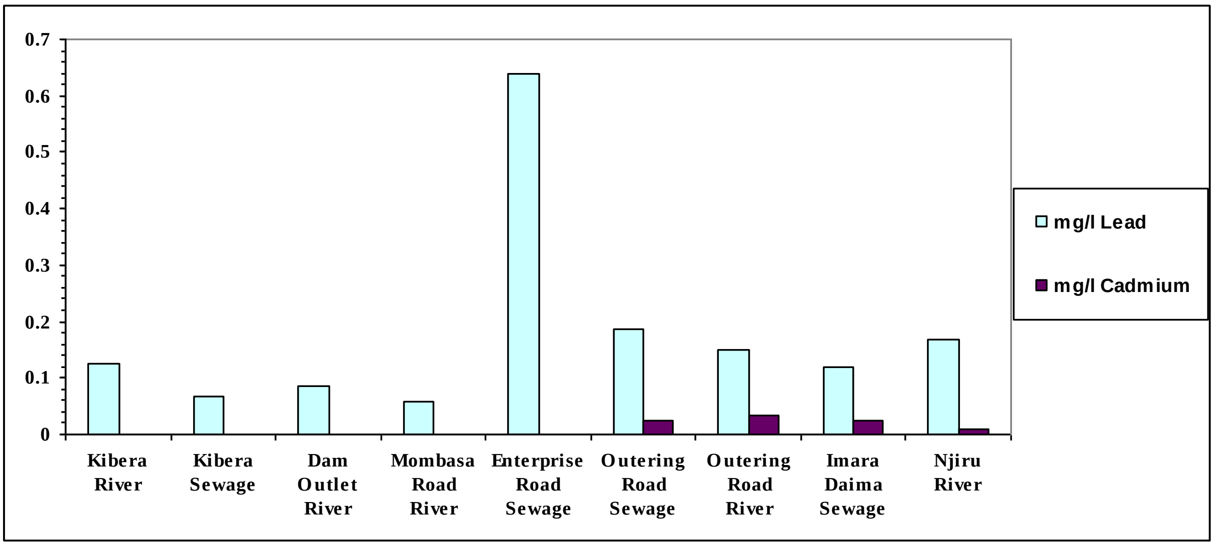


Chemical parameter concentrations

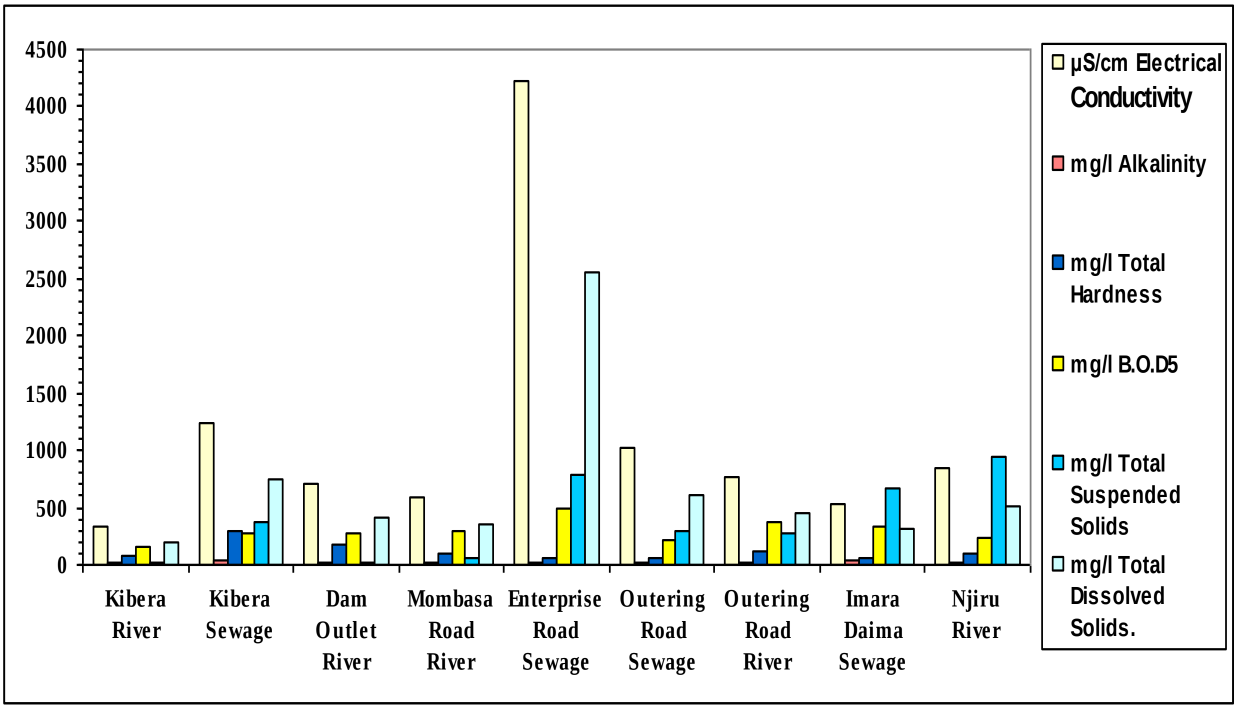
Fuii



Heavy metal concentrations

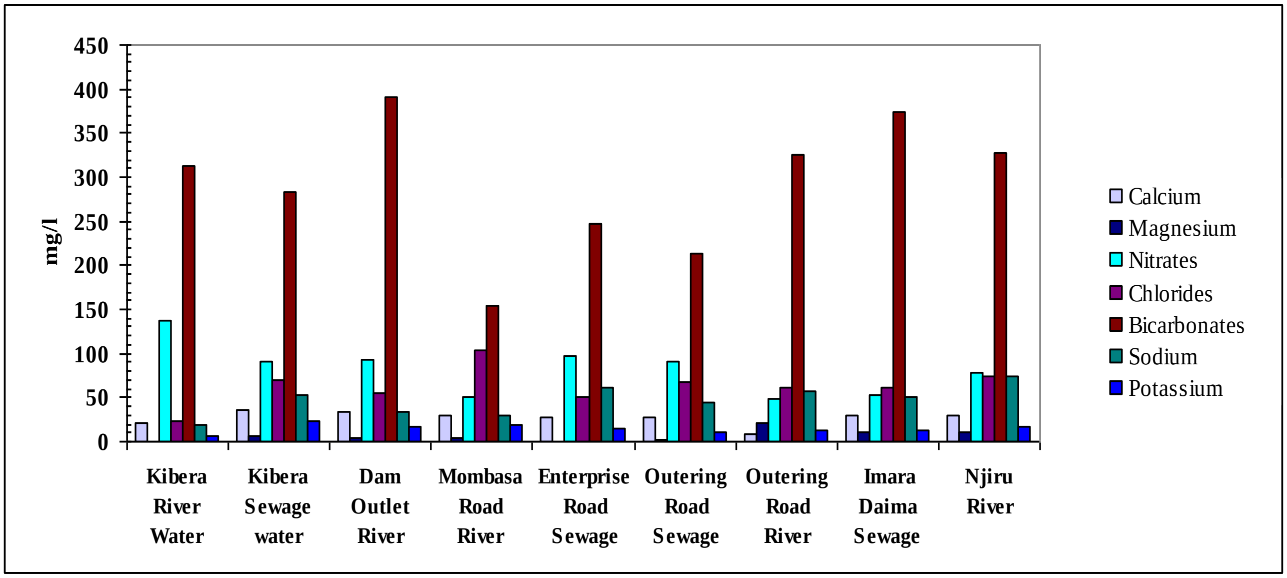


Physico-chemical parameter levels

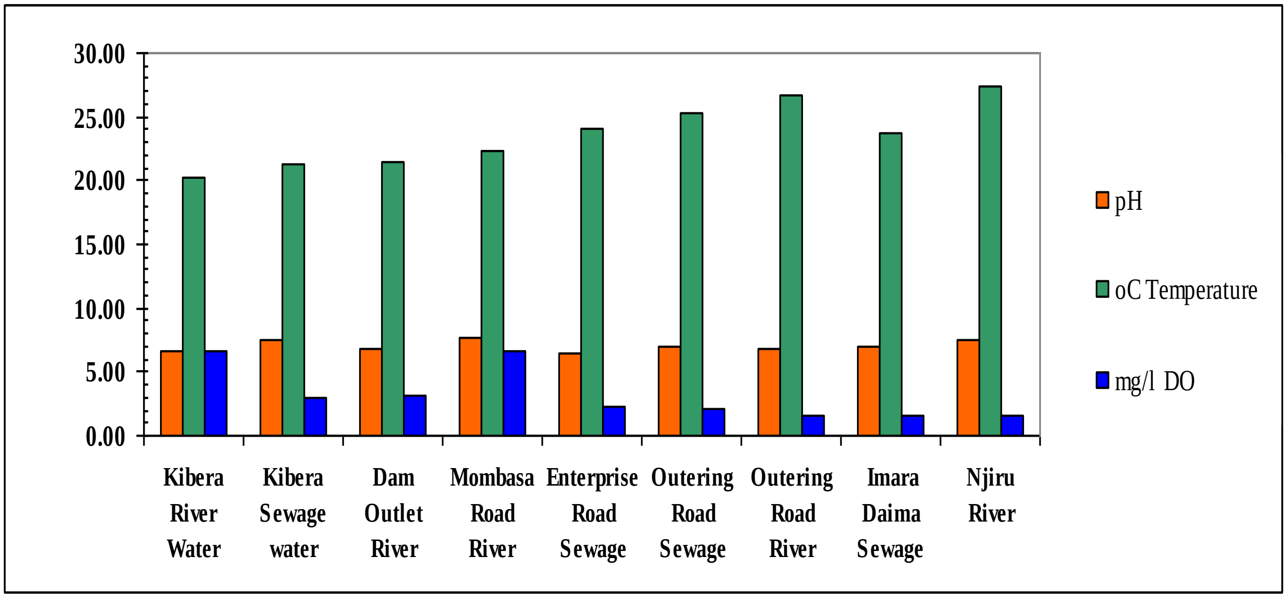


APPENDIX 5: Wet Season Concentrations Graphs

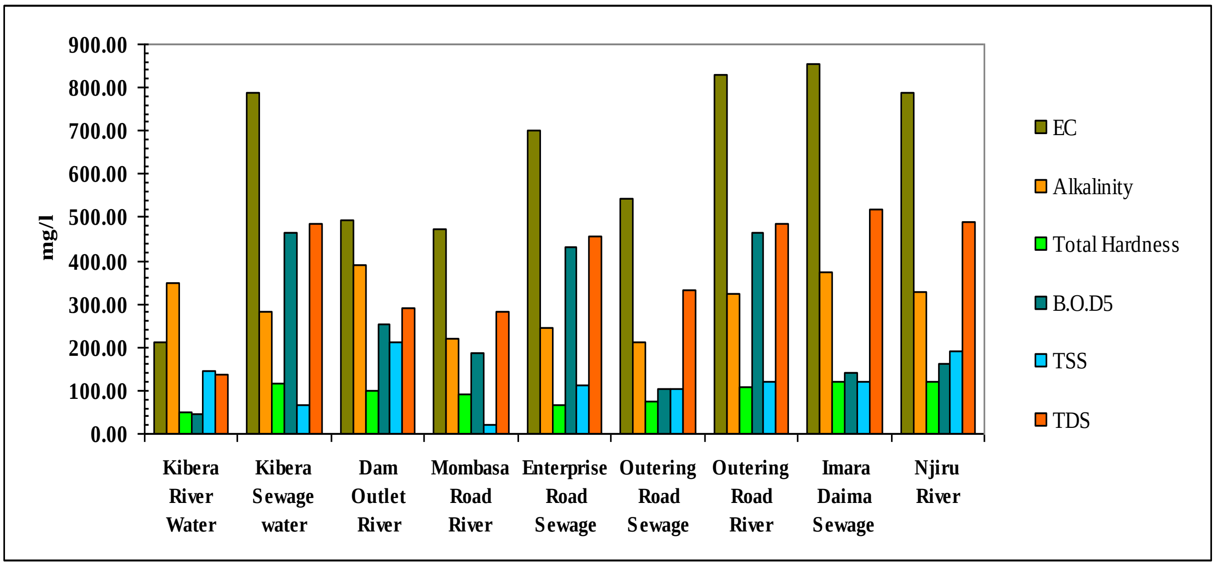
Chemical parameter levels



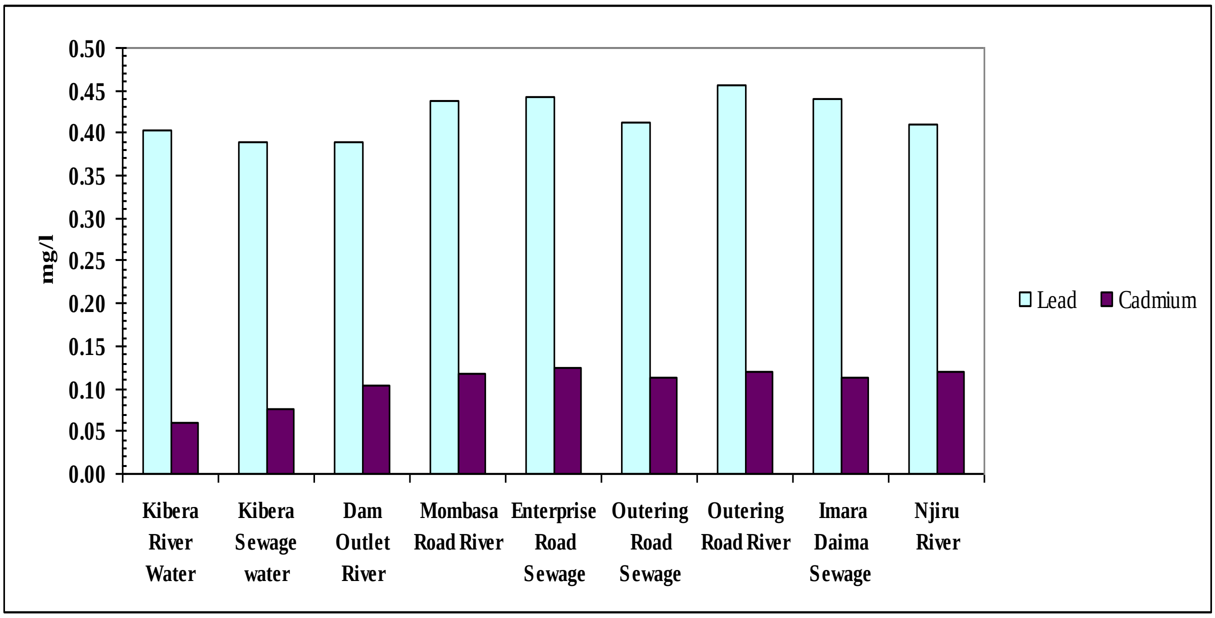
Onsite tested parameter levels



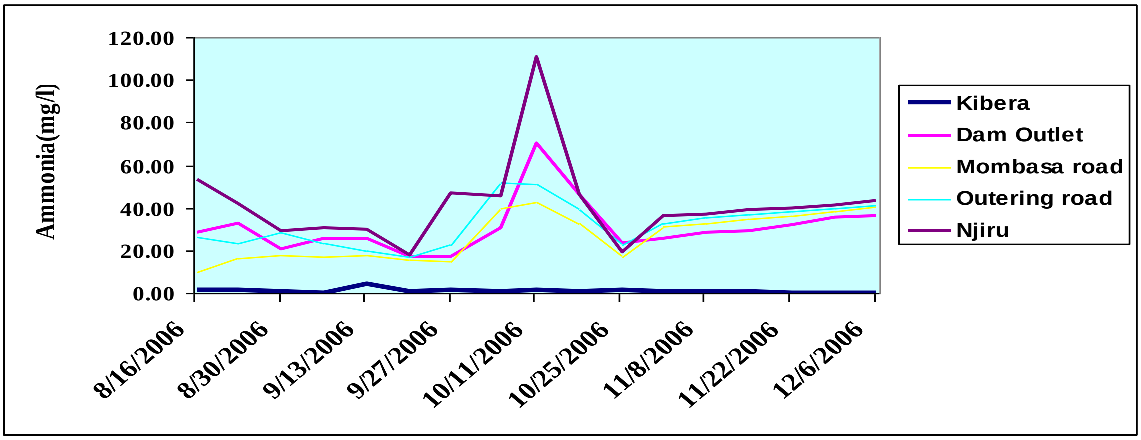
Physico-chemical parameter levels

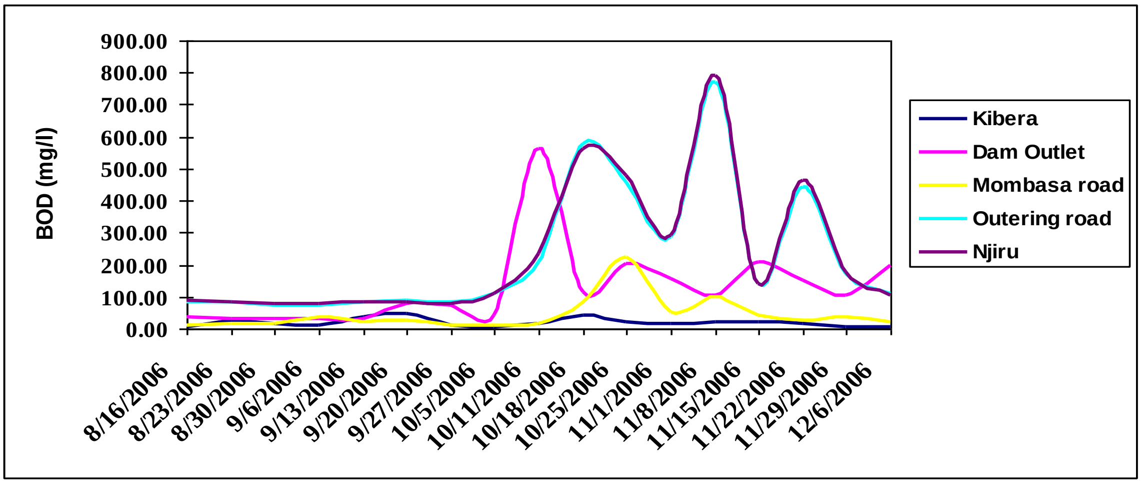


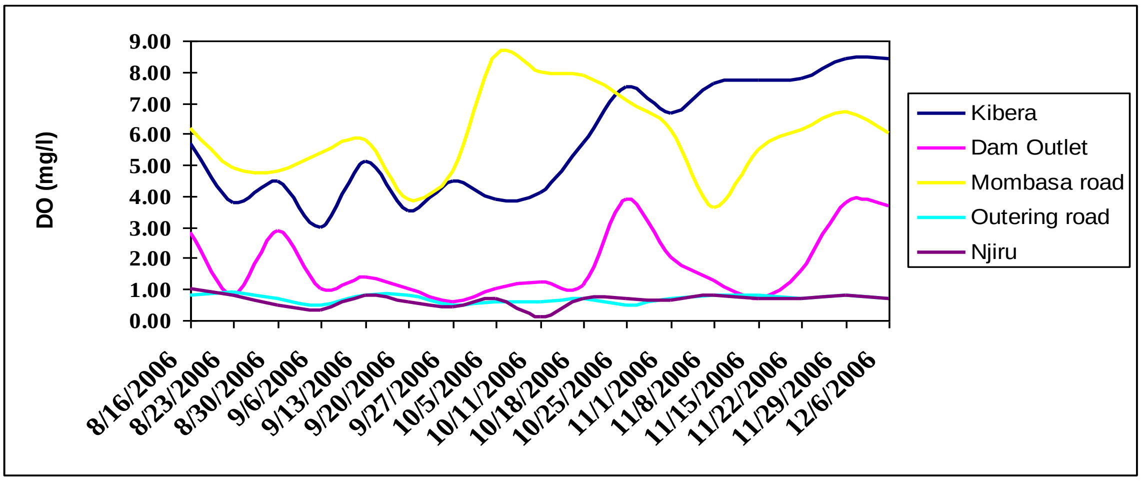
Heavy metal parameter levels



APPENDIX 6: Time Series Graphs







APPENDIX 7: Guide Values for Estimating Manning's n

Table 1: Base Values of Manning's *n*

Bed Material	**Median Size of bed material (in millimeters)**	**Straight Uniform Channel1**	**Smooth Channel2**
Sand3	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--
	.6	.023	--
	.8	.025	--
	1.0	.026	--
Stable channels			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020
Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--
[Modified from Aldridge & Garret, 1973 Table 1) -- No data 1Benson & Dalrymple --No data 2 For indicated material; Chow(1959) 3 Only For Upper regime flow where grain roughness is predominant			

Table 2: Adjustment values for factors that affect the roughness of a channel [modified from Aldridge and Garrett, 1973, Table 2]

Degree of Irregularity (*n*1)

Channel Conditions	***n* Value Adjustment1**	**Example**
Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
Minor	0.001-0.005	Compares to carefully degraded channels in good condition but having slightly eroded or scoured side slopes.
Moderate	0.006-0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes
Severe	0.011-0.020	

Variation in channel cross section (*n* 2)

Channel Conditions	***n* Value Adjustment1**	**Example**
Gradual	0.000	Size and shape of channel cross sections change gradually.
Alternating occasionally	0.001-0.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
Alternating frequently	0.010-0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.

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Effect of obstruction (n 3)

Channel Conditions	***n* Value Adjustment1**	**Example**
Negligible	0.000-0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.005-0.015	Obstructions occupy less than 15 percent of the cross-sectional area, and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.

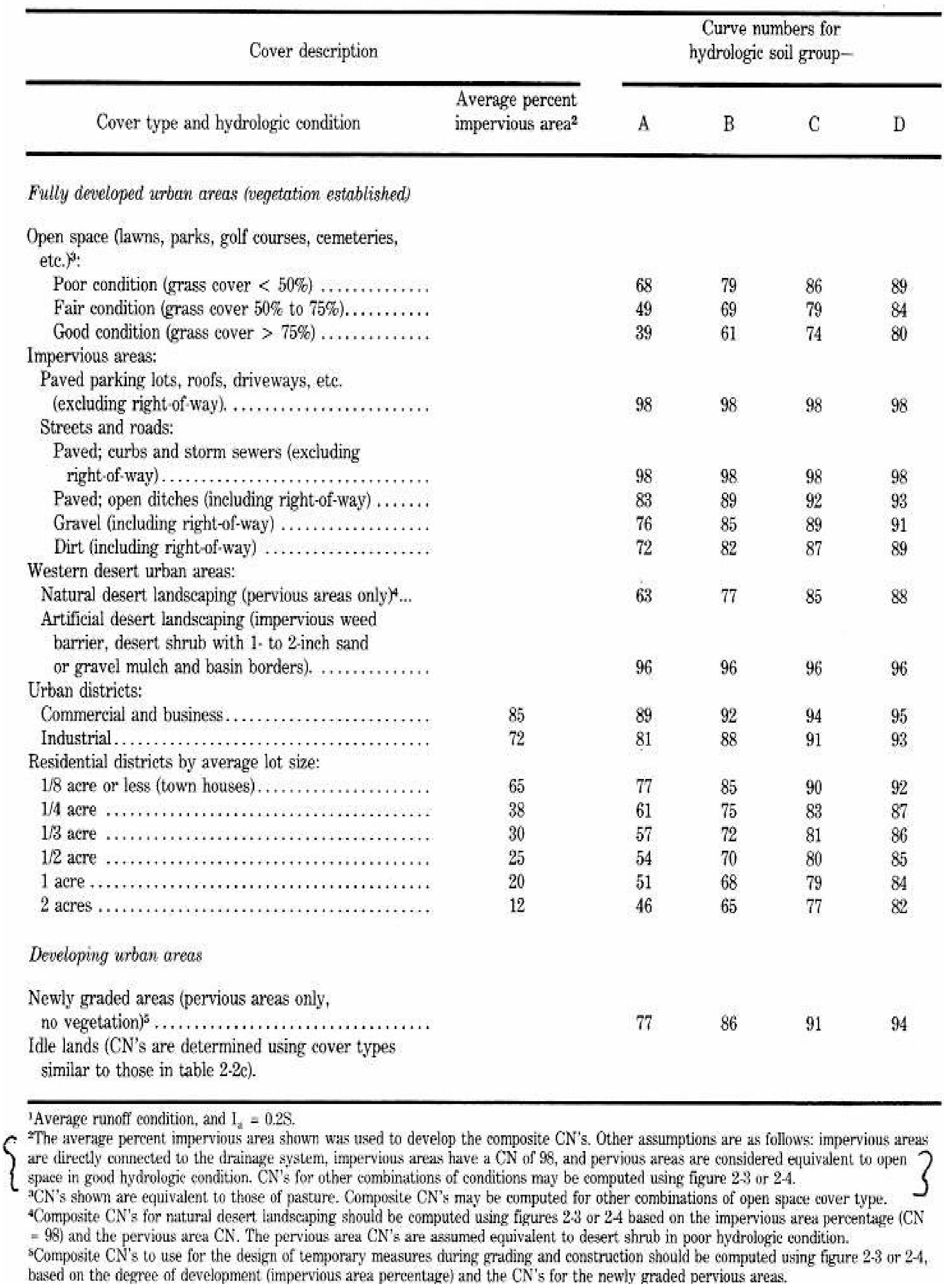
Degree of Meandering (m)

Channel Conditions	***n* Value Adjustment1**	**Example**
Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2.
Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5.
Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

1 Adjustments for degree of irregularity, variation in cross section, effect of obstructions, and vegetation are added to the base *n* value (Table 1) before multiplying by the adjustment for meander.

2 Adjustment values apply to flow confined in channel and do not apply where downvalley flow crosses meanders.

APPENDIX 8: Runoff Curve numbers for Urban Areas



Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

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[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.