UNIVERSITY OF NAIROBI

EFFECTS OF LAND USE CHANGE ON STREAM FLOW, CHANNEL EROSION AND RIVER GEOMORPHOLOGY: A CASE STUDY OF MOTOINE/NGONG RIVER SUB-CATCHMENT, NAIROBI RIVER BASIN, KENYA.

BY
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A Thesis Submitted for the Award of Master of Arts Degree in Geography
(Geomorphology)

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DECLARATION

I declare that this is my original work and has never been presented for examination in any other university.

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LIST OF ABBREVIATIONS

DRSRS: Department of Resource Surveys and Remote Sensing

FAO: Food and Agriculture Organization.

G.O.K: Government of Kenya.

HABITAT: United Nations Centre for Human Settlements.

ISC: Impermeable Surface Cover.

KARI: Kenya Agricultural Research Institute.

KSS: Kenya Soil Survey.

NRBP: Nairobi River Basin Project.

TSS: Total Suspended Solids.

UNEP: United Nations Environment Programme.

UNICEF: United Nations International Children’s Emergency Fund

UNESCO: United Nations Educational, Scientific & Cultural Organization.

WRMA: Water Resources Management Authority.

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ABSTRACT

Urbanization increases impermeable surface cover which causes streamflow variability, the most significant element in geomorphological processes of erosion and sediment transportation. Understanding the interaction among human activities, hydrologic and geomorphic processes, is fundamental in addressing environmental degradation. Motoine/Ngong river sub-catchment has suffered severe spatial land use change in the last three decades due to urban expansion. The study sought to assess effects of land use change on stream flow, channel erosion and channel geomorphology of Motoine/Ngong river sub-catchment. Specific objectives were to determine the land use changes within the sub-catchment from the years 1976 to 2012, to establish the relationship between land use change and stream flow, and assess erosion of gullies and river banks and the geomorphology of the river channel. It was hypothesized that there was no significant relationship between stream flow, gully and river bank erosion and changes in land use from 1976 to 2012 in the Motoine/Ngong River Sub-catchment.

Primary and secondary sources of data were used in the study. Primary data on discharge was obtained from field measurements of cross-sectional area of the channel at the Motoine swamp outlet, Ngong Road Bridge, at the Nairobi dam inlet and at Kangundo Road Bridge. Stream velocity was measured using a current meter by wading. Geomorphology of the river and river bank erosion were obtained by observation and photography. Secondary sources provided information on stream discharge, land use and gully erosion. Analysis of land use change was done from satellite imageries and self-administered structured questionnaires. Data was analyzed using percentages and averages and presented in tables and charts. The study revealed that there has been temporal and spatial change in land use in the sub-catchment. Clearance of forest and grassland vegetation increased bare surfaces resulting to gully erosion at the catchment. Built-up area and road pattern of land use increased from 22.78% in 1976 to 50.98% in 2012. This increased wet weather stream flow resulting to erosion of river banks to produce varied landforms such as river cliffs, river bank cavities, desiccation cracks and river bed outcrop rocks. Sediments produced from the processes of erosion were deposited in the river channel leading to the development of slip-off slopes and sand bars which resulted to the development of a braided channel pattern.

Correlation between built-up area and road and stream flow yielded a value of 0.8. The hypothesis that there is no significant relationship between stream flow and changes in land use between 1976 and 2012 was rejected at a confidence level of 95%, and the research hypothesis was therefore accepted. The study recommends that detention storage and infiltration of rainwater be undertaken to reduce overland and stream flow. There is need for gabions to be constructed to protect highly erodible sections of the river banks.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Urbanization affects the hydrological characteristics of a catchment by reducing infiltration of rainwater into the ground and increasing the volume and speed of surface runoff (Fig. 2.1). The replacement of forest cover with paved surfaces or other land use types increases water yield due to reduction in water losses as a result of compaction of soil (Mansell, 2003). This increases stream discharge, an important element in fluvial processes of erosion and sediment transportation (Christopherson, 2010). The processes of erosion and sediment transport result from an interrelated set of natural, human and hydrologic factors within a river basin. The natural factors responsible for erosion are topography, geology and soils. The hydrologic factors are climate and the amount and distribution of surface water runoff and ground water discharge; while land use is the main human factor (Olaka, 2005). The effect of land use on river flow, and the consequent land degradation, is one of the most important environmental problems of our time.

Population and economic growth often lead to spatial expansion of cities. This expansion may occur at the expense of increased risk of flooding, soil loss, and river bank erosion, changes in river courses, landslides, sediment load deposition and water pollution. These environmental problems are aggravated by land use change from forest to agricultural and other development activities; such as construction of roads and other infrastructural facilities and settlements that result to erosion and large quantities of sediments being carried downstream. For instance, considerable amount of fresh water and sediments are carried down to the Indian Ocean and to the adjacent reefs by the Sabaki River because of agricultural activities in the upland areas having resulted to accelerated soil erosion and tremendous increase in river sediments.

Katwijk et al, (1993) citing Watermeyer, Legge, Piesold and Ulman (1981) report that before 1960 there was an estimated annual sediment discharge of 58,000 tons to the ocean, an indication of occurrence of erosion from the catchment. By 1981 estimates varied between 7.5 and 14.5 million tons per year. According to Ndung'u (2009), suspended sediment concentration at the Sabaki River estuary ranged between 24.3 and 52.7gm per day. Salm (1983) found that the silt of the load of the Sabaki had risen to detrimental levels leading to a decline in the Malindi-Watamu Reef complex. Motoine/Ngong River forms part of the upper catchment of the Athi River basin.

Modifications in river discharge can be caused by climate variability and changes in land use and land cover in the upstream basin, by the construction of large artificial lakes, or by diversion of water for irrigation. Precipitation variability and changes in land use and land cover are the two most significant causes of long-term variation in stream flow in large river basins (Costa et al, 2003). Krhoda (1988) says that clear cutting of forest cover accelerates geomorphic processes leading to high sediment yield, rapid channel degradation and mass wasting.

Many studies on the impact of land use change on stream flow have been done in this country. However few of these studies deal with gully and river bank erosion and channel geomorphology resulting from stream flow variability. Hence the precise magnitude and impact of these land use changes on watersheds and river channel morphology are not well understood. This study examined stream flow, gully and river bank erosion and channel geomorphology of Motoine/Ngong River sub-catchment in relation to land use changes particularly conversion of forest and other vegetation cover to farmland and urbanization/settlement.

1.2 Statement of the Problem

The effect of land use change on river flow and soil loss is one of the most important environmental problems of our time. Food and Agriculture Organization (FAO) (2011) reported that between 1980 and 1990, the world's tropical forests reduced by an average of 15.4 million hectares per year (0.8 percent annual rate of deforestation). The phenomenon of deforestation is happening globally, in diverse types of forests, and for different reasons. According to FAO statistics on Change in Forest Cover, between 1990 and 2010, Kenya lost an average of 12,050 ha or 0.32% per year, a total of 6.5% of her forest cover.

Many parts of Motoine/Ngong river catchment have environmental conditions conducive to occurrence of high wet weather stream flows because of high rate of land use change from forest cover and grassland to farmlands, built up areas and paved surfaces as urbanization occurs at an estimated rate of 7.2% per annum (Olima, 2001). Kithiia (2006), who studied the effects of land use types on the hydrology and water quality of the Upper Athi River basin, found that the change in land use activities results to increased surface runoff which leads to increased discharge in rivers. This has resulted to erosion both at the catchment and river channel, channel migration, flooding of farmlands and residences and siltation of dams. Tibaijuka (2007) reported that the greatest land use change occurred from the year 1976.

Eutrophication of the Nairobi Dam and the consequent water hyacinth infestation is largely a function of land use change and the consequent increased pollution, soil erosion and sedimentation. A study carried out by the United Nations Environmental Programme (UNEP) (2002) on flow rate of Ngong River shows the amount of discharge from within the catchment into the Dam at base flows as being about $0.5m^3/s$. The report indicates that the amount leaving the dam through the spillway as the Ngong River is variable. During dry years, it becomes a mere trickle, but whenever it rains, the river floods. In November 2001, flow from the spillway was measured at $0.2m^3/s$.

A study carried out by Kithiia (2006) shows suspended solids during the peak flows at Embakasi to be 1640 tons/year and total dissolved solids as being 3750 tons/year, and 1360 and 3600 tons/year during low flows respectively. Moore (1979) carried out a study on land use and erosion in the Machakos hills and found that changes in land use practices and their intensity caused extensive surface and gully erosion. Modifications of natural vegetation cover usually lead to changes in rainfall-runoff characteristics of a basin. Changes in land cover and vegetation have an effect on surface and groundwater hydrology and stream flow in sub-basins, and can alter the hydrological cycle (Hu, 2001).

It is necessary to understand stream flow responses to changes in land use/land cover in the basin and its effect on the geomorphology of the river channel. By knowing these responses we can address the questions of how the on-going land use change in Motoine/Ngong river catchment may have influenced the annual and seasonal stream flow and channel morphology. Answers to these and related questions from the study will improve the predictability of hydrological and geomorphological consequences of land use change.

This ability is essential for long-term planning of land use to protect water and soil resources. The Nairobi River, of which Motoine/Ngong is a tributary, is under rehabilitation and restoration by the Nairobi River Basin Programme and signs are clear that there will be clean water for human consumption and for support of the ecosystem. Information on stream flow and erosion is vital at this stage to facilitate decision making on sustainable water utilization and soil and water conservation measures for the rivers under rehabilitation so as to protect the ecosystem. This study examined stream flow, gully and river bank erosion and channel geomorphology of Motoine/Ngong river sub-catchment in relation to land use changes.

1.3 Objectives

1.3.1 Broad Objective of the Study

The broad objective of the study was to ascertain the effects of land use changes on stream flow, channel erosion and river channel geomorphology within Motoine/Ngong River Sub-catchment.

1.3.2 Specific Objectives

i. To determine temporal and spatial land use changes in Motoine/Ngong river sub-catchment from 1976 to 2012.
ii. To establish the effects of land use change on stream flow, gully and river bank erosion.
iii. To assess the geomorphology of Motoine/Ngong River Channel.

1.4 Hypotheses

There were four hypotheses for this study:

1. **H_0:** There is no significant temporal and spatial variation in land use in Motoine/Ngong river sub-catchment from 1976 to 2012.

   H_1: There is significant temporal and spatial variation in land use within Motoine/Ngong river sub-catchment from 1976 to 2012.

2. **H_0:** There is no significant relationship between stream flow and changes in land use from 1976 to 2012 in the Motoine/Ngong River Sub-catchment.

   H_1: There is a significant relationship between stream flow and changes in land use in Motoine/Ngong River Sub-catchment from 1976 to 2012.

3. **H_o:** There has been no significant gully and river bank erosion in the sub-catchment due to land use change.

   H_1: There has been significant gully and river bank erosion in the catchment due to land use change.

4. **H_o:** There are no geomorphic landforms along the Motoine/Ngong River channel.

   H_1: There are geomorphic landforms along the Motoine/Ngong River channel.

1.5 Justification of the Study

Land use change, in particular clearing forests for agriculture, settlement and other infrastructural developments that increase paved surfaces, increases surface runoff and stream flow. These result to high erosion rates, increase in stream transport of sediment load (Christopherson, 2010), river velocity as well as increase in change in channel morphology (Poff and Ward, 1989). This also causes a reduction in water quality, silting of water reservoirs and eutrophication of lakes. The Motoine/Ngong river sub-catchment has suffered severe spatial land use change in the last three decades due to spatial urban expansion.

This urban development has replaced agricultural farmlands and other natural vegetation with paved surfaces and unplanned squatter settlements which are environmentally degrading. Reliable information from studies such as this is required for successful planning of Nairobi's development (Mundia and Aniya, 2006). The information on catchment degradation, resulting from erosion of the catchment and river banks will facilitate planning for soil and water management and conservation programs. These conservation measures will be necessary to reduce the rates of soil loss caused by channel migration as a result of lateral erosion, and for avoidance of landslides, sedimentation and reduced water quality. Information on stream flow will be vital in determining water supply, habitat volume, irrigation and dilution of waste to curb pollution and protect the ecosystem (Herschy, 1995). Stream flow information will provide a scientific foundation for flood planning and management (Leopold, 1968). Konrad (2002) says that data on discharge provides flood managers with information that can guide flood control operations and emergency actions such as evacuations and road closures.

This study was necessitated by shortage of data on gully erosion of the sub-catchment, river bank erosion and channel geomorphology on this urban river. Removal of riparian vegetation coupled with more overland flow getting into the stream from paved surfaces, bare surfaces and built up areas result to erosion of river channels. This increases the risk of damage to homes, aquatic habitats, roads, bridges and other infrastructure. It was therefore necessary to study the extent of land use change and its impact on stream discharge, river bank erosion and river channel morphology. Data from this study will be used in management of the river, to design urban infrastructure such as bridges, culverts, channels, and rain water detention structures.

1.6 Scope and Limitations of the Study

The study focused mainly on the land use changes that have occurred in Motoine/Ngong river sub-catchment from 1976 to 2012 and its effect on erosion of the river banks and gully erosion within the catchment. The study also focused on the geomorphology of the river channel at four sampled points as well as on the effect of land use change on stream flow. The choice of 1976 as the baseline year for the study was occasioned by a report by Tibaijuka (2007) which indicated that greatest land use changes in Nairobi started in 1976. The rationale behind the 40 years period under study from 1976 to 2012 is because some geomorphological processes take a long period of time before their effects are seen. The other forms of erosion namely splash, sheet and rill erosion were out of scope of this study.

Field measurements were taken at four sites along the river course. The questionnaire was administered to farmers in the upper and lower sections of the river within the catchment. This was occasioned by time and financial constraints. Secondly, Motoine/Ngong River is not gauged and therefore available data on discharge was limited to only that on which measurements have been made.

1.7 Definition of Terms

Base flow/low flow: J. R. Miller and M. O. Miller (2007) define it as the portion of stream flow that comes from deep subsurface flow and delayed shallow subsurface flow.

Catchment/Drainage basin: is a part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded water together with all tributary surface streams and impounded water bodies (USGS, 2005).

Channel erosion: refers to the deepening and widening of rills, streams and rivers due to soil loss caused by flowing water as a result of shear (Zaimes and Emanuel, 2003).

Meandering channels/sinuous channels: refers to channels that deviate from straightness such that they curve along their courses. Meandering is related to cohesiveness of channel banks and the abundance and bulk of midstream bars (Christopherson, 2010).

Discharge/Stream flow: Oxford Dictionary of Geography defines discharge as the volume of water that passes a given cross section in the channel during a specified time interval, measured in m^3/s (cumecs).

Geomorphic Processes: refers to the physical and chemical interactions between the earth's surface and the natural forces acting upon it to produce landforms. The nature of the processes and the rate at which they operate is influenced by a change in any of the natural environmental variables that determine these processes such as geology, climate, vegetation, base level and human interference (Collated data).

Land use: refers to the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO/UNEP, 1999).

Land cover: is the physical material at the surface of the earth such as grass, vegetation, bare ground, impervious surfaces and water on which land use occurs (FAO/UNEP, 1999).

River Geomorphology/Morphology: refers to channel patterns and forms that result from the interrelated factors of discharge, water surface slope, water velocity, depth and width of the channel and river bed materials (Matsuda, 2004).

Runoff: is the surface flow of rainwater that is generated when rainfall intensity exceeds the infiltration capacity of the surface materials (J. R. Miller and M. O. Miller, 2007)

Suspended Sediments: refers to the fine particulate material carried by the rivers current and includes both inorganic and organic material (Woodward and Foster, 1997).

1.8 The Study Area

1.8.1 Position and Size of the Study Area

The Motoine/Ngong river basin extends from latitude 1° 17´ N to 1° 18´ N and longitude 36° 40´ E to 36° 55´ E. The source of Motoine/Ngong River is Motoine swamp near Dagoretti forest. The basin may be divided into four sections, the stretch upstream of the Nairobi Dam, the dam itself and the dam outlet, and the stretch from the dam outlet to the confluence with Nairobi River (Kahara, 2002). Kahara reports that the river basin is about 42.3 km long while the total area of the catchment from the source to the confluence with Nairobi River is about 127 km^2 (Fig1.1).

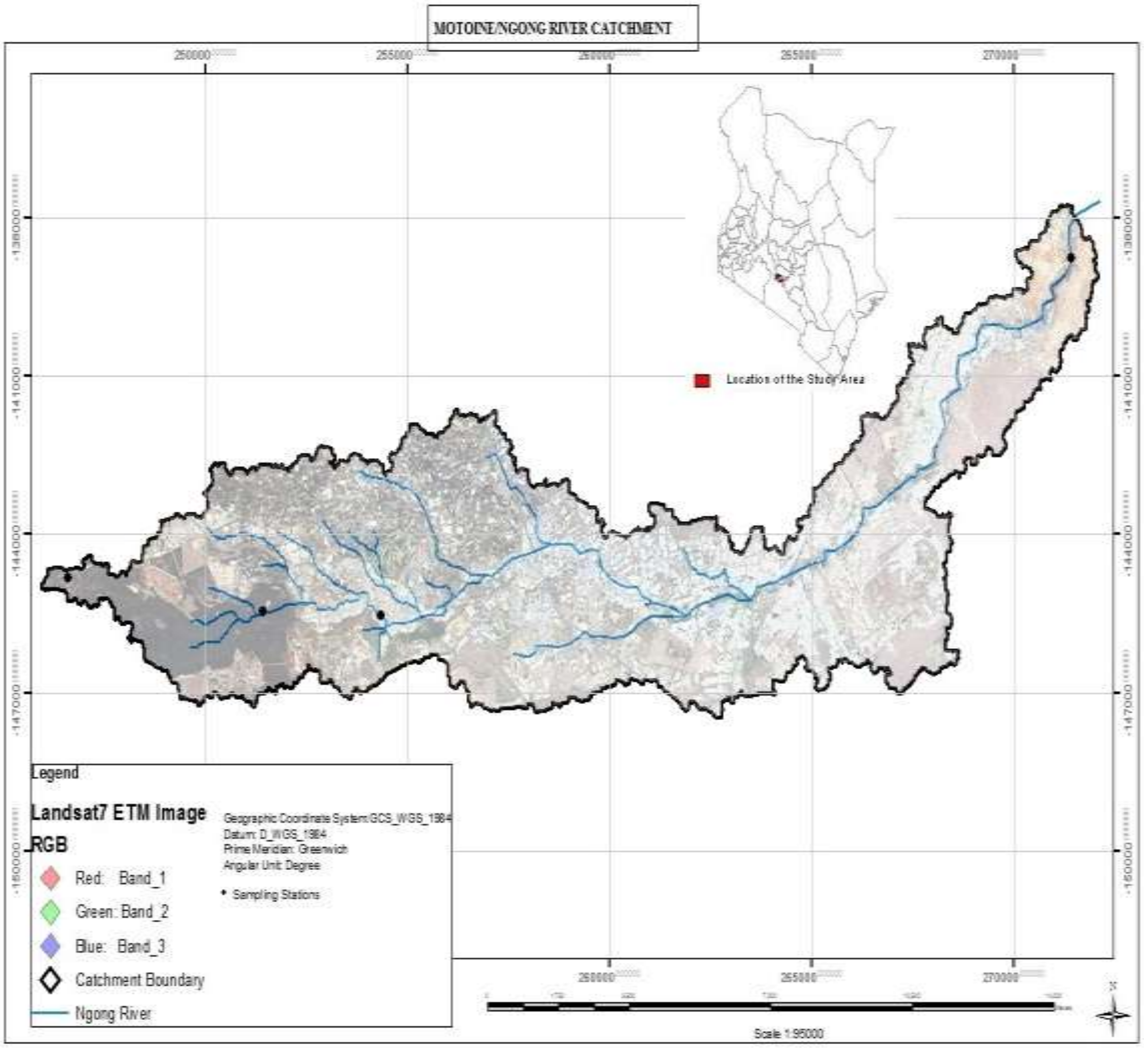

Figure 1.1: The Area of Study

Source: Department of Resource Surveys & Remote Sensing, (2013).

1.8.2 Climatic Characteristics

The Motoine/Ngong River basin falls under a wet climatic zone with a mean annual rainfall ranging from 1000 mm to 1200 mm. (United Nations Environment Programme (UNEP), 2003) Long rains come in mid-March to mid-May, and short rains during the months of November and December. The wettest month is April for the long rains, with average monthly rainfall of approximately 223 mm. November records highest rainfall for the short rains at an average of 166 mm. The driest months are August and September. The basin has daily maximum temperatures ranging from 21.4° C in the month of August to 25.6° C in March. Daily evaporation ranges from a minimum of 89 mm in the month of July to a maximum of 191 mm in the month of March (UNEP, 2003).

The highest annual rainfall recorded between 1976 and 2012 was 1687 mm in the year 2007 and 1646 mm in the year 1998. This was during the El Nino phenomenon. The lowest annual rainfall recorded is 482 mm in 1984 and 606 mm in 1983 (Table 1.1).

1.8.3 Hydrological Characteristics

The source of Motoine/Ngong River system is the Motoine swamp. The flow of the river is mainly sub-surface through the Dagoretti Forest for a considerable distance. Runoff is slow due to the undulating nature of its water head. Discharge of the river varies from one point to another along its course (UNEP, 2003). Kahara (2002) says that the presence of clay sandy soils derived from volcanic activities result into good infiltration. Ngong stream rises from just above Jamhuri International Trade Fair grounds at about 1,850 m a.s.l and drains into the Jamhuri Dam (Kahara, 2002). Other five streams namely: Gatwereka, Olympic, Banker, Golf Course and Undugu, flow into the Nairobi Dam through the Kibera slums (Primoz, 2010). Numerous natural springs also contribute significant quantities of water into the dam. Man-made dams namely: Upper and Lower dams, have been constructed along the Motoine valley to detain surface flow (Kahara, 2002).

Table 1.1: Climatic Data for Dagoretti Meteorological Station within the Catchment

Station: Nairobi –Dagoretti			**Altitude:** 1798 m			**Position:**1.30 S, 36.75 E		
Month	Min Temp [°C]	Max Temp [°C]	Humidity [%]	Wind [km/day]	Sun [hours]	Rad [MJ/m²/day]	ETo [mm/day]	Rain [mm]
January	10.5	25.5	70	199	9.1	23	4.54	58.3
February	10.9	26.7	66	190	9.7	24.5	4.97	49.8
March	12.1	26.8	67	190	8.6	23	4.8	92.2
April	13.4	25	74	156	6.8	19.5	3.93	242.3
May	12.1	23.5	77	112	6	17.2	3.31	189.5
June	10	22.5	77	104	5.9	16.4	3.02	38.6
July	9.2	22	78	95	3.9	13.8	2.64	17.6
August	9.1	22.7	74	112	4	14.7	2.91	24
September	9.7	25	70	130	6.2	18.8	3.74	31.2
October	11.3	25.7	68	173	6.8	20	4.2	60.8
November	12.7	24	76	190	6.7	19.5	3.84	149.6
December	11.7	24.4	73	199	7.9	20.8	4.1	107.6
Average	**11.1**	**24.5**	**72**	**154**	**6.8**	**19.3**	**3.83**	**88.46**
Totals								**1061.5**

Source: FAO, CLIMWAT Database

1.8.4 Vegetation Characteristics

The catchment is covered by both natural and planted vegetation. The common plant species are eucalyptus, bamboo, shrubs, Napier grass and vegetables. The Nairobi Dam is heavily covered by water hyacinth. Acacia trees occur around the dams while natural scrub vegetation occurs along Ngong tributary ((UNEP, 2003). The role of trees is to intercept rainfall and influence infiltration rates. Clearing of forests for farming and settlement increases surface runoff and reduces ground water recharge.

1.8.5 Geology of the Catchment

Nairobi area covers part of the eastern flank of the Great Rift Valley. Its geology is dominated by widespread volcanic activity of the Cainozoic age Lavas and other pyroclastics that cover nearly the entire area (Appendix I). These lavas and pyroclastics overlie a foundation of folded and metamorphosed Precambrian rock of Mozambique Belt. Superficial deposits are of Pleistocene and Recent Age (Saggerson, 1991). The rock beneath the Ngong Road and the Dagoretti forests is the Upper Athi Series, which is porous and permeable. This series is composed of sandy sediments, gravel or pebble beds, tuffs and pyroclastic sediments. In Lang'ata area lake deposits occur (Gevaerts, 1964). The Lake bed deposits are characterized by course, gritty volcanic sand (Saggerson, 1991). A section of the Dagoretti-karen area is covered by Nairobi trachytes. From Nairobi West, South C, Industrial Area and Embakasi, the main top formation is the Nairobi Phonolite (UNEP, 2003).

1.8.6 Soil Characteristics of the Catchment

The Motoine/Ngong River flows through part of the Nairobi area covered by deep soils and gravel. At the Lang'ata area alluvial clays and swamp soils occur. Areas underlain by ironstone soils with lithosols, the soils are gravely whose clay content ranges from 60 % to 70%. They are yellowish red to dark yellowish brown in colour, friable, shallow and moderately well drained. Areas underlain by vertisols and vertic gleysols the soil is composed of cracking clay, dark brown to very dark greyish brown, are mottled, firm to very firm, deep to very deep and poorly drained (Kenya Soil Survey (KSS), 2013).

From Nairobi West, South C, Industrial Area and Embakasi, the main top formation is the Nairobi Phonolite. The soils are bouldery and stony with some places having cracking clay, dark grey to black in colour, firm to very firm, very deep and imperfectly drained. In places with calcareous slightly saline, deep and stony subsoil exists (KSS, 2013), (Appendix II). Soil characteristics influence infiltration capacity of rainwater, soil water storage and ground water recharge through percolation into the aquifers which consequently becomes base flow. Infiltration capacity of rainwater depnds on the soil group. Nyangaga (2010) gives four main soil groups based on drainage characteristics: The hydrologic soil group refers to the infiltration potential of the soil after prolonged wetting.

Group A Soils: These have high infiltration at the rate of > 0.76 cm/hr when wet. These soils have low runoff. Soils in this group are Sand, loamy sand or sandy loam.

Group B Soils: These soils have moderate infiltration at a rate of 0.38 to 0.76 cm/hr when wet. They have moderate runoff. Soils in this group are silt loam or loam.

Group C Soils**:** Have low infiltration at a rate of 0.13 to 0.38 cm /hr when wet. They have moderate to low runoff. Soil in this group is sandy clay loam.

Group D Soils: have very low infiltration at a rate of 0 to 0.13 cm/hr when wet. They generate high runoff. Such soils are clay loam, silt clay loam, sandy clay, silt clay, or clay (Table 1.1).

Table 1.2: Basic Infiltration rates for various soils

Soil Type	**Range of Basic Infiltration Rate (mm/hr)**
Sand	>30
Sandy Loam	20 to 30
Loam	10 to 20
Clay Loam	5 to 10
Clay	1 to 5

Source: Nyangaga, (2010)

1.8.7 Topography and Geomorphology

The topography of Motoine/Ngong river basin is of relatively high relief in the West reaching an elevation of 1,950 m a.s.l near the swamp and falling to 1,820 m a.s.l at the Bridge on the main Ngong road. The elevation falls further to 1,525 m a.s.l at the confluence with the Nairobi River (Krhoda, 2002). The catchment is generally gently sloping except along river valleys where slopes range from about 7% to 19% (Ref Appendix III). Motoine River flows into the Nairobi Dam and leaves as Ngong River, passing through Industrial Area before its confluence with Nairobi River near Njiru Shopping Centre.

The catchment is generally a plain. River valleys occur within the catchment. Topographic characteristics influence drainage basin processes; and the character and extent of the channels affect sediment availability and rate of water yield from the drainage basin. Relief and gradient of the stream channel are key controlling factors of velocity of flow and flux (continuous flow and channel change) (Gupta and Chakrapani, 2002). Sediments of Motoine/Ngong River vary from one point to the other along the river's course and between the wet and dry season.

1.8.8 Population

Population has steadily been increasing in the catchment reaching 3.1m in 2009 and is projected to reach 3.8 million in 2015. This growing population is one of the main forces driving the city's environmental challenges (Tibaijuka, 2007). Kibera has the highest population estimated at about 800,000 and a density of about 6,000 pp /km^2 (Ndunda and Mungatana, 2012) (Table 1.3).

Table 1.3: Population of Nairobi (1962-2009)

Year	**Area (hectares)**	**Population**	**% increase in population**	**Density (persons/ha)**
1962	68,945	266,795	124.2	4
1969	68,945	509,286	90.8	7
1979	68,945	827,775	62.5	12
1989	68,945	1,324,570	60.5	19
1999	68,945	2,143,254	61.8	31
2009	68,945	3,138,369	46.4	46

Source: Kithiia and Wambua, (2010), Table 1 and Government of Kenya, (2010).

1.8.9 Human Activities and Land Use

Land use in Nairobi River basin has changed due to the expansion of agriculture and urbanization since the early 1900s (UNEP, 2001). The increase in human population from 0.7 million in 1975 to about 2 million in 1999 has resulted in the reduction of pristine land (HABITAT, 2002). The greatest expansion of urban area was recorded between the years 1976 and 2000 (Tibaijuka, 2007). Various activities such as car washing, small-scale industry and urban farming are undertaken in the area. The Motoine/Ngong river is used in Dagoretti area for irrigation agriculture and several other domestic uses (Krhoda, 2002).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Land use is an important factor influencing stream flow/runoff and erosion. Urbanization with the accompanying loss of plant cover, creation of impermeable surfaces, and routing of storm water runoff directly to streams has significant impact on infiltration. The consequences of urbanization according to Rose and peters (2001) include higher runoff, reduction of lag time between precipitation and runoff and increased peak flows and reduced low flows. Urbanization reduces both evapo-transpiration (Gomitz, 2001) and infiltration capacity (Mansell, 2003) thereby altering the hydrological cycle by reducing infiltration capacity and at the same time increasing surface runoff. This accelerates geomorphological processes of erosion and sediment transportation. Schueler and Holland (2000) illustrate, as shown in figure 2.1, how built up areas associated with urbanization lead to reduced infiltration, thereby increasing surface runoff. This chapter highlights related literature and past studies on land use change and the corresponding effects on channel morphology, watershed hydrology and erosion.

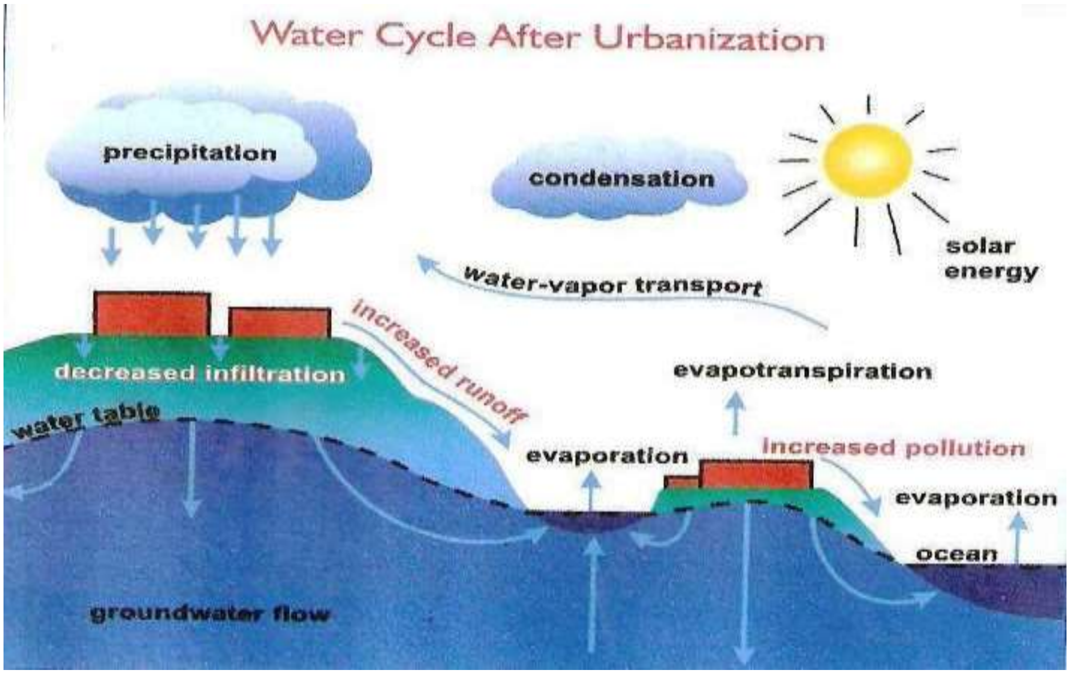

Figure 2.1: Hydrological Cycle of an Urban Watershed

Source: Adopted from Schueler and Holland, (2000).

2.2. Theoretical Framework

Nairobi has experienced steady growth in population over the years. According to a report from HABITAT (2002) human population in Nairobi increased from 0.7 million in 1975 to 2 million in 1999, and reached 3.1million in 2009 (G.O.K, 2010), an annual growth rate of 4.6%. The current rate of urbanization in Kenya is estimated at 7.2% (Olima, 2001), while the Metropolitan is proposed to expand and cover over 3,000km^2 (Omwenga, 2008). Population growth and urbanization have resulted to clearance of forests and other vegetation cover as more land is opened up for settlement, industry, roads and other infrastructural developments.

During such developments construction sites become important sources of sediments that are transported into rivers. This load scours the banks of the river resulting to erosion. During low flow sedimentation occurs. Both erosion and sedimentation lead to development of distinct morphology of a river channel. Urbanization process has led to a reduction in infiltration capacity because of increase of impervious surface cover which increases as homes, shopping malls, roads, playgrounds and pathways replace forest and other vegetation cover. This result to an increase in both overland and stream flow which lead to gully erosion of the sub-catchment and river banks (Fig 2.2: Conceptual Framework).

2.3 Conceptual Framework

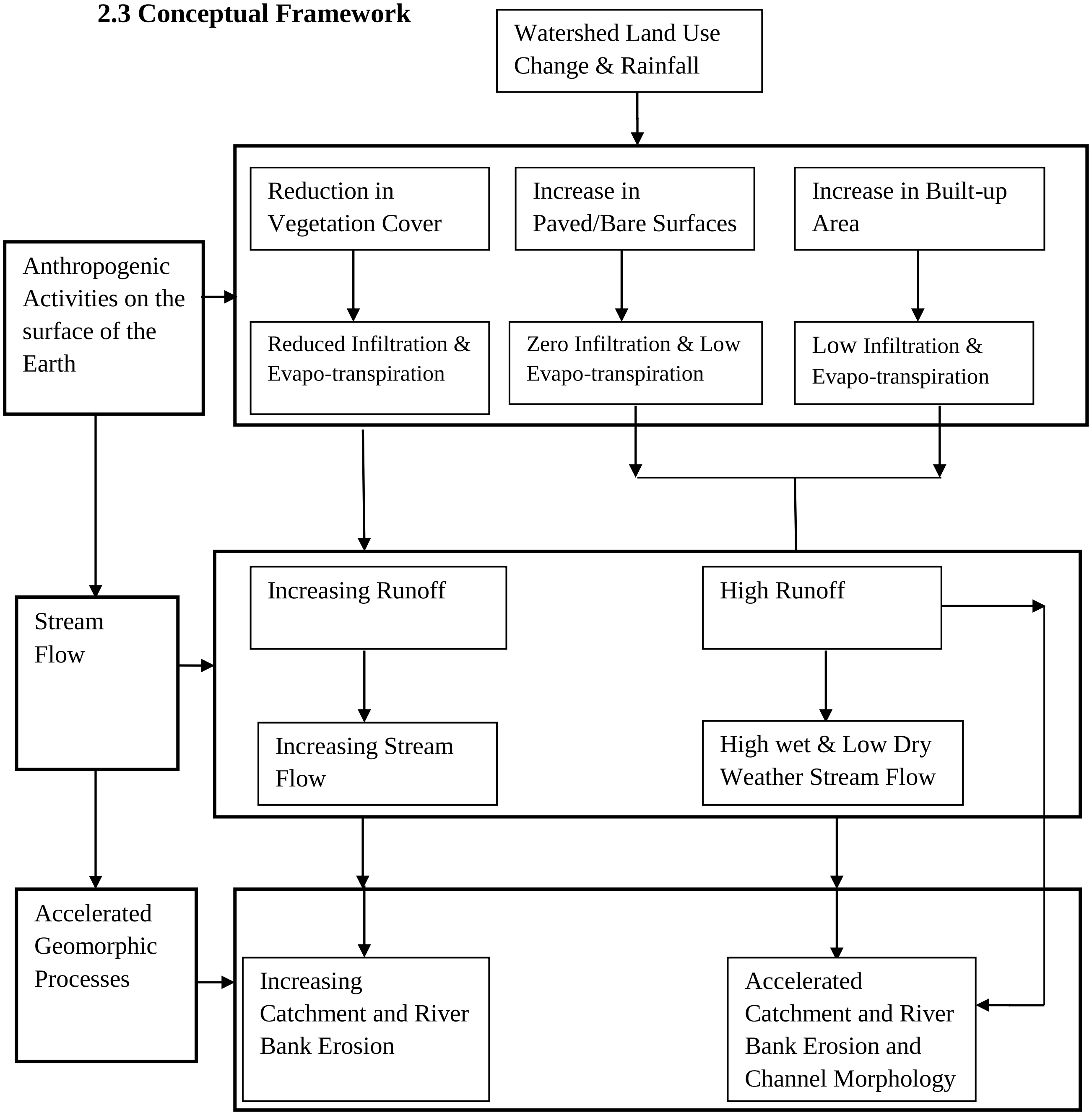

Figure 2.2: Conceptual Framework

Source: Researcher, (2013).

Although much of recent attention on environmental problems has focused on climate change, there is also increasing concern that accelerated soil erosion and land degradation present a major problem for environmental protection and sustainable development (Zapata, 2003). Worldwide changes to forests, farmlands, waterways as well as air are necessitated by the need to provide food, shelter and clothing (Foley, DeFries and Asner, 2005). Coe, Latrubesse, Ferreira and Amsler (2010) say that these changes have altered hydrological and geomorphological states of streams by decreasing evapotranspiration on the land surface and increasing overland flow, river discharge, erosion and sediment fluxes.

2.4 Precipitation and Discharge

Changes in the regimen of flow, whether through land use or other changes, cause adjustments in the stream channel to accommodate the flows. The volume of runoff is governed primarily by precipitation characteristics and basin area, land use/cover, watershed topographic characteristics and characteristics that affect the subsurface base flow (Nyangaga, 2010).

Precipitation is the dominant source of river water. When precipitation occurs some of the rain water gets intercepted by vegetal cover. When the storm is prolonged the interception storage gets filled and the rest of the rain water is passed on to the surface. The water reaching the surface will be infiltrated into the soil or flows as overland flow (J. R. Miller and M. O. Miller, 2007). Friedman and Lee, (2002) in studying intense floods, channel change and riparian forests along ephemeral streams in USA observed that percolating water moves at much lower velocity and reaches the stream slowly, over long periods of time when influences of runoff from a storm are no longer felt within the channel. This groundwater sustains stream flow during dry periods. In urban watersheds much of the rainwater flows as overland flow because of large areas of impermeable surface cover and drains off into designated channels. Typically, accelerated erosion of the catchment and river banks occurs downstream.

Xue and Gavin (2007), in assessing the effect of rainfall intensity on infiltration into partly saturated slopes in China, found that rainfall pattern, rather than the average rainfall intensity during a storm, controls the amount of infiltration and run-off during a given rainfall event. For a given total rainfall, rainfall events which begin at high intensity and end at low intensity generate fewer run-offs than those which start at low intensity and end high.

2.5 Land Use/Cover and Stream Flow

Studies on changes in land use with changes in river discharge generally indicate that deforestation causes an increase in annual mean discharge (Costa, Botta and Cardille, 2003). Interception governs the amount of water that may be lost from the system through evapo-transpiration and protects surface materials from the erosive effects of raindrops. Tall forests have greater evapo-transpiration rates than other vegetation or other land use type, because of greater canopy roughness and deeper root systems which draw on soil moisture.

When they are cut the water pathways are reduced from the watershed and there is a greater total stream flow from the catchment (J. R. Miller and M. O. Miller 2007). Wang and Zhu (2003) also observed that intercepted rainfall by plants evaporated and did not generate runoff, while dried leaves and grass change the soil structure and makes the land rough, so rainfall can seep into the soil. This agrees with a study done by Coe and Ramankutty (2006) in West Africa, which revealed that total deforestation increases simulated runoff ratio from 0.15 to 0.44 and the annual stream flow from 35 to 65%. Complete removal of grassland and savanna results in an increase of simulated stream flow from 33 to 91%.

Costa et al (2003), while considering the effects of large scale changes in land cover on the discharge of Tocantins River, Amazonia, found that anthropogenic changes in vegetation generally result to increased discharge because annual crops and perennial plants have reduced root density and plant leaf area index and hence have lower evapo-transpiration. This is in agreement with Siriwardena, Finlayson and McMahon (2006), who assessed the impact of land use change on catchment hydrology of the Comet River, Australia. The report shows that following the clearance of forests runoff increased to 78%.

Mutie, Home, Gadain, Mati and Gathenya (2006), in evaluating land use change effects on river flow in the Mara river basin Kenya, found that forests, shrubland, savanna, water bodies and grassland had reduced at the expense of increase in agricultural land, tea, open forests and wetlands. Mati, Mutie, Gadain, Home and Mtalo (2008) report that the hydrology of the Mara River has changed and records sharp increases in flood peak flows coupled with increase in soil erosion in the upper catchments, and silt build-up in the downstream flood plains. In previous studies analysis of land use change has not been carried out for Motoine/Ngong River catchment, except Mundia and Aniya (2006) who studied land use change in Nairobi over a 20 year period from 1976 to 2006. The current study filled the gap by assessing land use change in the Motoine/Ngong river sub-catchment from 1976 to 2012.

Baldyga, Miller, Maina and Shivoga (2007), in assessing hydrological response and land cover change in River Njoro watershed, attribute increased downstream flooding to land use change. Kathumo (2011) found the same in river Gucha catchment: that forest cover decreased by 62.94 and 68.49% as agricultural land and residential area increased by 30.36 and 7.53% respectively for the period between 1976-1993 and 1993-2010. Total annual stream flow also increased by 3468.51 and 670.06 cumecs in the same period. Further reports show that base flow reduced by 4.0 and 4.1%, while peak flow increased by 30.4 and 7.36% respectively for the same period.

Giertz, Junge and Diekkruger (2006) report that due to reduced activity of the macro fauna, the infiltration capacity is significantly lower in cultivated soils than in savanna and forests, thus causing higher surface runoff and soil loss in cultivated soils. This study agrees with that of Hurni, Tato and Zeleke (2005) that considered the implications of changes in population, land use and land management on surface runoff for the Upper Nile basin area of Ethiopia. Results indicate that surface runoff rate is influenced by land use and soil degradation. They noted that there is 5-30 times more surface runoff from cultivated or degraded test plots than forested test plots. Deforestation reduces infiltration capacity and increases surface runoff which results to soil erosion and erosion of river banks as channels get widened to accommodate increased flows.

2.6 Urbanization and River Flow

Modification of the land surface during urbanization changes the type and magnitude of runoff processes. Konrad (2002) found that the annual maximum discharge in a stream increases as urban development occurs. He adds that urbanization affects other elements of the drainage system. Water trappers and rainstorm drainages are laid in the urbanized area to convey runoff rapidly to stream channels. In addition Konrad says that natural channels are straight, deepened or smoothed with concrete to make them convey flood waters easily. These result to transmission of the flood wave downstream more quickly and with less storage in the channel. Higher downstream flood peaks result to flooding in nearby streams. Runoff volume also affects low flows because in any series of storms the larger the percentage of direct runoff, the smaller the amount of water available for soil moisture replenishment and for groundwater storage (Booth and Bledsoe, 2011).

Meyer and Wallace (2001) report similar findings from their study on rediscovering small streams: that the major impact of urbanization on basin morphometry is an alteration of drainage density. Natural channel densities decrease dramatically in urban catchments as small streams are filled in, paved over, or placed in culverts. However, artificial channels may actually increase overall drainage densities, leading to greater internal links that contribute to increased flood velocity.

Im, H. Kim, C. Kim and Jang (2007), in assessing the impacts of land use changes on watershed hydrology in Korea found that a 10% increase in urban area increased total runoff by 5.5% and overland flow by 24.8%. According to Mekonnen and Melesse

(2011), areas of rapid through flow and saturated overland flow generation are also erosion hotspots. They found this out in their study on soil erosion and hotspot identification in north western Ethiopia.

Konrad and Booth (2005) studied hydrologic changes in urban streams and reports that the influence of urban development has an effect on base flow. Human use of shallow groundwater or surface water resources can reduce base flow during the dry season. On the other hand using water from a deep aquifer or imported from another basin to irrigate farms during a dry season can actually increase base flows in urban streams. Booth and Bledsoe (2011) conclude that this attribute of stream hydrology, does not comprise a consistent reaction to urbanization.

Paul and Meyer (2008), in their study on streams in urban landscape report that urbanization affects both sediment supply and bank full discharge. High impervious surface cover (ISC) associated with urbanization increases the frequency of bank full floods. As a result, increased flows begin eroding the channel and a general deepening and widening of the channel (channel incision) occurs to accommodate the increased bank full discharge. Urban watersheds with bare/paved surfaces have zero infiltration capacity. This results to high overland and stream flow which causes accelerated gully erosion and erosion of river banks.

2.7 Channel Erosion, Morphology and Sediment Transport

In their book ‘Contaminated Rivers, a Geomorphological-Geochemical Approach to site Assessment and Remediation,’ J. R. Miller and M. O. Miller (2007) have stated that erosion involves two distinct processes: the detachment of particles from the underlying geological materials and the transport of the detached grains down slope. Morgan (2005), in his book ‘Soil Erosion and Conservation’, discusses four major factors responsible for soil erosion: erosivity of rain, erodibility of the soil, topography and land cover.

Often bank erosion occurs in conjunction with bed degradation, local scour and knick point migration. The main factors and forces that cause bank erosion are shear stress, quick variation of water level, seepage flow through the bank soil, structures which deflect flow, bank heightening due to local scour of the river bed and steep bank slope which reduces the stability of the banks (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2010).

Payet and Obura (2004) did an international waters perspective on impacts of human activities in the Eastern African region. They assert that water courses alter naturally as a result of high variability of rainfall among seasons and years, and depletion of water resources is caused by drawing it through boreholes and shallow wells causing perennial streams and rivers to dry up. They associate the changes in physical water supply with increased pollution of water bodies by sedimentation from increased surface erosion and land use changes, with major rivers having perennially high sediment loads.

The results of Vanlooy and Martin (2005), in their study on Channel and vegetation change of the Cimarron River Southwestern Kansas, show that for the entire study reach the channel changed from a wide, braided channel in 1953 to a narrow, meandering one in 2001. In 1953 the mean channel width in the study reach was 151m. They clarify that channel narrowing and expansion of riparian vegetation were more pronounced in some locations than in others. They associate both the channel changes and expansion of riparian vegetation to a decrease in annual peak flows caused by agricultural practices and groundwater withdrawals, which favored in-channel sedimentation and expansion of riparian vegetation.

Foyle and Norton (2007) found that watershed erosion supplied only about 25% of the sediment to the system; in contrast bank erosion and slow bluff retreat supplied almost twice that amount at 41%. A dominant paradigm in fluvial geomorphology holds that streams adjust their channel dimensions (width and depth) in response to long-term changes in sediment supply and bank full discharge (Paul and Meyer, 2008). According to Booth and Bledsoe (2011), gully, stream bank, stream bed and flood-plain scours are examples of channel erosion which depends on energy exerted by forces of concentrated water flow.

Thorne and Furbish, (1995) have identified six factors responsible for decreasing the erosion resistance and mechanical stability of a river bank. Leaching is one of these factors which reduce cohesion of materials. This occurs when minerals are removed by solution in groundwater seeping through the bank. The other factor is trampling by people and animals which destroy the soil fabric therefore weakening the soil. Destruction of riparian vegetation by natural processes and human actions weakens the soil. Desiccation results from intense drying that breaks electro-chemical bonds. Thorne and Furbish say that this loosens soil crumbs on bare and exposed bank surfaces during the dry season. Positive pore water pressure occurs when drainage of water through the bank is restricted to allow the build-up of seepage pressure. Through sinking the efficient power of the bank material they weaken the bank, raising the likelihood of mass failure (Thorne and Furbish, (1995).

Booth and Bledsoe (2011) state that where channels have been straightened and vegetation has been removed from channel banks, stream flow velocities force increase, allowing a river to carry more load. The average sediment load of a channel comprises the average rate at which hill slope sediment is delivered into stream channels and the amount of sediment that is eroded from the bed and banks of the channel itself. Friedman and Lee (2002), in their study on intense flooding, channel change and riparian forests along ephemeral streams in Colorado, found that channel change of those streams was dominated by channel widening, which occurs within hours during infrequent floods and post flood narrowing occurs over decades between floods.

Dragicevic, Zivkovic, Roksandic and Novkovic (2012) conducted a study on land use changes and environmental problems caused by bank erosion of the Kolubara river basin, Serbia and found that the level of landscape degradation and the modification of geomorphologic processes by human activities had been increased. They report that the anthropogenic factor modified existing natural conditions such as bank erosion getting stronger and resulting to soil loss, larger amount of sediment deposition, cutting off of meanders and landscape degradation. Few studies have been done in Kenya that deal with river bank erosion resulting from stream flow variability. This study therefore filled the gap by studying stream flow variability in relation to land use changes; particularly increase in built-up area in the catchment.

Thakur, Laha and Aggarwal (2011), who studied bank erosion hazard of the Ganges River, found that there was a drastic increase in sinuosity and braidedness during the study period from 1955 to 2005. Between 1977 and 2005, 1,670 ha of agricultural land had been lost through erosion. Ahmed and Fawzi (2009) carried out a study on meandering and bank erosion of the river Nile and environmental impact. This study revealed that remarkable meandering of the river’s course occurred with time and space. Heo, Duc, Cho and Choi (2008) did a prediction of meandering channel migration of Sabine River in the USA and observed migration rates of 3.6 m per year between 1996 and 2004.

Kiss, Blanka, Andrasi and Hernesz (2013) studied extreme weather and Rivers of Hungary: Rates of bank retreat and report that mass failure that occurs in high bluffs contributes to bank erosion, and the process of undercutting and removal of the toe material influence bank retreat. He suggests that the most critical condition causing strength reduction include rapid drawdown after a high flow stage, because cohesive materials become more erodible when wet.

Luppi, Rinaldi, Teruggi, Darby and Nardi (2008), in their study on monitoring and numerical modeling of river bank erosion processes of Cecina river, Italy, found that occurrence of fluvial erosion and slide failure depended on seasonal hydrological conditions and initial bank geometry. They suggest that slide failure appears to be closely related to the magnitude of peak River stages particularly during the falling limb and sometimes even before the peak. Fuller (2007) studied river and channel morphology and reports that frequent refreshing of bar surfaces, bar destruction and re-formation removes or minimizes vegetation on bar surfaces. The presence of vegetation indicates a degree of stability.

Gully erosion often indicates an extreme form of land degradation warranting special attention (Gang, Yongqiu, Baoyuan, Yogguang, Zhimin and Zhangtao 2009). In addition Gang et al report that soil loss rates by gully erosion may represent more than half of the total sediment yield caused by water erosion.

Mekonnen and Melesse (2011) studied soil erosion in relation to land use/land cover type in the Northwest Ethiopia highlands and observed the rate of soil erosion to be different for different land use/land cover types. Average soil loss was highest (16 tons/ha/year) in crop land and lowest in eucalyptus plantation (0.14 tons/ha/year). For grazing land, bush land and built up areas soil loss rate was 6.41, 2.28 and 0.34 tons/ha per year respectively. Gang et al (2009) studied the characteristics of gully erosion in Northeastern China and report that the gully head reached more than 10 m, gully area extended 170-400 m^2, net gully eroded volume was 220-320 m^3. Ehiorobo and Izinyon (2012), in their study on soil loss in Benin found that gully erosion removes large volumes of soil from an area. Field measurements show gully areas that ranged from 11,675m^2 to 127,600m^2; depth ranging from 7.768 m to 26.575 m; and width from 22.50 m to 62.785 m. The volume of soil lost varied from 57,901 m^3 at Ikabigbo gully to 385,113 m^3 at Queen Ede gully. In the current study gully parameters measured were depth, width and length to facilitate determination of soil loss.

Waswa, Gachene and Eggers (2002) carried out an assessment of erosion damage in Ndome and Ghazi areas of Taita Taveta, Kenya. Their report indicates that gully erosion was enhanced by degradation of vegetation and destruction of soil structure through inappropriate tillage practices. The gully dimensions measured 8-60 m wide and 1.5–8 m deep. These findings are in line with those of Sirvio, Rebeiro-Hargrave and Pellikka

(2004) on gully erosion studies in Taita hills. The results show that gully erosion occurred as a consequence of past and present human activity. This is in line with the objective of this current study that sought to identify gullies from satellite imageries and study their characteristics. In this research gully parameters that were measured were average depth, average width, and length to facilitate the determination of soil loss from those gullies.

Kithiia and Wambua (2010) did a study on temporal changes of sediment dynamics within the Nairobi River sub-basins between 1998 and 2006. Results indicate an increasing trend in sediment load downstream with Motoine/Ngong River having 237·7 to 310·9 $mg1^{-1}$. Formation of artificial channels in city watersheds increases overall drainage densities and flood velocity as water is conveyed to flow quickly from roads and built up areas. This results to high and concentrated water flows that cause gully erosion of the catchment and eroding of river banks to accommodate increased flows. Many other studies have been carried out on transportation of sediments by rivers. However few deal with channel geomorphology. This current study filled the gap by assessing the geomorphology of Motoine/Ngong River.

This study examined stream flow, gully erosion, river bank erosion and morphology of Motoine/Ngong River and sub-catchment in relation to land use changes particularly conversion of forest and other vegetation cover to farmland and settlement/urbanization.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents the methodology and materials that were used during the study. In particular, the chapter highlights the data sampling techniques, methods for collecting data and its analysis and interpretation. Documented information was the source of secondary data while primary data was sourced directly from sampled points within the catchment. Both quantitative and qualitative approaches were used in this research.

3.2 Land Use Change

This section presents primary and secondary techniques of collecting data and data analysis procedures used to meet the requirements of the first objective of the study that sought to determine the temporal and spatial land use changes in Motoine/Ngong river sub-catchment from 1976 to 2012.

3.2.1 Data Collection

Primary data was collected using structured questionnaires administered by the interviewer to farmers in the catchment (Appendix IV). This enabled the researcher to ensure that the respondents were those that were needed to respond to the questionnaire, so as to improve reliability of the data (Saunders, Lewis and Adrian, 2009). Random sampling technique was used to sample farmers. The targeted population for the study was 864 farmers along the river valley which was obtained from sub-county Agricultural officers in Dagoretti and Njiru. The sample size of 95 used in the study was based on the formula by UNICEF (1995):-

$$n = \frac{t^2 \times p(1-p)}{m^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

n be the necessary study sample, *t* is the confidence level at 95%, *p* is the estimated number of farmers in the catchment and *m* is the margin of error at 5%. Data on forest cover change was obtained by interviewing the forest officer at his office in Ngong Road. Photographs were also taken at various sites to reveal key land use types.

Secondary data from satellite imageries for land use change for 1976, 1984, 1995, 2002 and 2013 were obtained from DRSRS at Kasarani and interpreted to ascertain land use change over the time period. This method was used by Mundia and Aniya (2006) in studying dynamics of land use/cover changes and degradation of Nairobi City. Documented data and forest cover change map were obtained from Kenya Forest Service Headquarters at Karura Forest.

3.2.2 Data Analysis

Land use change pattern from 1976 to 2013 was assessed from satellite imageries. False color composite (band 2-green, 3-red and 4-infrared) was used to process the images for the years 1976, 1984, 1995, 2002 and 2013. Layer stacking of the reflectance was done in ENVI in order to produce a multispectral image. The images were mosaiced and the study area was clipped from the mosaic using the mask tool in ArcGIS. This was then saved in Geodatabase.

Minimum distance supervised classification were done for the land use pattern under five classes namely: bare surfaces, built up area and road, forest, grassland and other vegetation. Vectorization of the classified images was conducted in ArcGIS software. This facilitated the computation of the area for each land cover class for the aforementioned years (Lillesand, Kiefer and Chipman, 2004). The purpose was to determine the temporal and spatial land use changes within the catchment. Qualitative data on land use change was generated from questionnaires using content analysis. The data was cleaned up and evaluated. Interpretation was then carried out. This data was presented in tables and figures. According to Kumar (2005) tables make data to be clear and easily understood.

3.3 Effects on Stream Flow, Gully and River Bank Erosion

This section presents primary and secondary methods of collecting data and data analysis procedures used to meet the requirements of the second objective of the study that sought to establish the effects of land use change on stream flow, gully and river bank erosion.

3.3.1 Data Collection

Primary data on discharge of the river was obtained by taking measurements using velocity-area method. This was done at four representative gauging stations along the river course: at Motoine swamp outlet (37M 0242157 UTM 9857007), Ngong Road Bridge (37M 0271397 UTM 9861770), Nairobi dam inlet (37M 025450 UTM 9854120) and at Kangundo Road Bridge (37M 0271396 UTM 9861765). Measurements were carried out at river stretches that were straight with threads of velocity parallel to each other and with flat streambeds that are not affected by large rocks, weeds or protruding obstructions which form turbulence, and therefore eliminate vertical components of velocity (Herschy, 1995). The watercourse was divided to suitable sub-sections and then measurements were done by wading using a wading rod, with 1m sections graduated in centimeters, a connector cable and an OTT C2 small current meter, manufactured by Hydromet, New Dheli (Plate 3.1). The meter uses water as a calibration medium. Its margin of error is less than 2% (Johnson, 2009). This method was used because it is precise, equipments were accessible and the investigator has control of the gauging procedure.

The cross-sectional area for each sub-section of the river was determined from respective widths and water depths using the equation adopted from Hardy, Panja and Mathias (2005):-

$A = w \times d$……….. (2)

Where:

A = Cross-sectional area (m^2), w = width (m), d = depth (m).

The cross-sectional areas were multiplied by respective velocities and these sub-section cross-sectional areas were summed up to obtain the discharge for that particular cross-section of the river using the equation adopted from Hardy et al (2005):-

$Q = AV$……...………………………………………………………………………….. (3)

Where:

Q = discharge (m^3/s), A = Cross-section Area (m^2), V = Mean velocity (m/s).

Plate 3.1:Taking discharge measurements using current Meter by wading at Motoine River, Ngong Road Bridge on 17/12/2013.

Source: Researcher, (2013).

Note: turbidity of water because of sediments from road construction nearby.

River discharge was calculated using the following equation adopted from Kithiia (2006) and modified by researcher (2013) by replacing *k* with *v*:-

$$Qr = \sum_{i=1}^{n} A c_i V_i \quad \text{……………………………………………….…………...…………..} (4)$$

Where:

Qr is the river discharge (m^3/s), Ac_i is the river cross-sectional area (m^2) (i denotes any one measurement in the series of velocity or cross-sectional area), V_i is the sectional flow velocity (m/s) and n is the number of measurements made. This method of measuring discharge was also used by Nyangaga, (2008) in studying effects of environmental degradation on stream flow and turbidity in Itare sub-catchment. Measurement of discharge was done twice for each of the four sampling points: once each during the rainy season and dry season. However measurement for Ngong Road Bridge gauging station was done only during the wet season because there was no flow during the dry season.

Secondary data on discharge was sourced from the Water Resources Management Authority (WRMA) Sub-regional office in Nairobi, Ministry of Environment, Water and Natural Resources. Regional offices in Machakos had similar data with that from the sub-regional office in Nairobi.

Primary data on river bank erosion was obtained by carrying out observations in the field (Appendix V), photography and field measurements. These were carried out at the four gauging stations by noting evidences of erosion at the river banks such as areas swept clean of sediments, washed and exposed plant roots, collapsing banks, undercut banks and cracks on banks of the river.

Secondary data on gully and river bank erosion was obtained from satellite imageries sought from DRSRS. Information on soil characteristics and the soil map of the catchment were sourced from Kenya Soil Survey at Kenya Agricultural Research Institute (KARI). Gullies were identified and their parameters measured from satellite imageries. Width, depth and length of gullies were measured. These enabled the researcher to estimate the volume of soil eroded from the gullies.

The width of the channel at the four sampled points of the river cross-section was measured in the field. The four points were selected close to discharge and sediment load measuring points because human modification to the channel was minimal. Erosion of the river channel was also identified from successive changes in channel cross-section from satellite imageries.

Suspended sediment samples were collected, while ensuring that depth was integrated, at the same point where stream flow measurements were taken so as to relate stream discharge and sediment concentration (Plate 3.2). This was done at river stretches that were straight with threads of velocity parallel to each other and with flat streambeds free from large rocks, weeds or protruding obstructions which create turbulence (Herschy, 1995). There were four representative sampling points along the river course: at the Motoine swamp outlet (37M 0242157 UTM 9857007), Ngong Road Bridge (37M 0271397 UTM 9861770), Nairobi dam inlet (37M 025450 UTM 9854120) and at Kangundo Road Bridge (37M 0271396 UTM 9861765) (Fig 1.1). This method was previously used by Kithiia, (2006) in studying temporal changes of sediment dynamics within Nairobi River sub-basins.

The selection of the sampling points was occasioned by the main land use along the water course. Between the Motoine swamp and Ngong Road Bridge the main land use is farming; the section from the bridge to the Nairobi dam the main land use is forest and grassland cover, and from the dam outlet to Njiru Bridge is urban area with paved surfaces and buildings. Sediment sampling was not possible during the dry season for Ngong Road Bridge sampling point because there was no flow. The sediment samples collected were adequate to show evidence of erosion from the catchment and the river channel.

Plate 3.2: Depth integrated sampling of water of Ngong River 100 m upstream of the Kangundo Road Bridge. Photograph was taken on 17/12/2013.

Direction of flow of the river is from the left towards the right.

Source: Researcher, (2013)

3.3.2 Data Analysis

To find the relationship between land use change and river discharge, mean monthly river flows were computed using the equation adopted from Ward and Trimble (2003):-

$\bar{y} = \sum y_i/n$ ……………………………………………………………………………......... (5)

Where:

$\bar{y}$ = the sample mean, $\sum y_i$= the sum of all measurements (*i* denotes any one measurement in a series) and *n* is the number of measurements made. The purpose was to determine variability in stream flow with changes in land use. The Mean was appropriate for analyzing discharge because data was at ratio scale; it is also precise and more stable than the mode or median. The limitation of the mean is that it is sensitive to extreme scores, (Marczyk, DeMatteo and Festinger, 2005). Qualitative data on stream behavior was generated from questionnaires. The data was cleaned up and evaluated. Interpretation of this data was then done.

Data on rainfall for the catchment was obtained from the Meteorological Department at Dagoretti Corner Meteorological station, station number 9136164. The station is at an altitude of 1798 m above sea level. The data obtained was on monthly and annual rainfall from 1976 to 2012. The data was analyzed using the mean and percentages and presented in tables. The purpose of this was to eliminate the rainfall factor in stream flow variations.

Identification of gullies from aerial photographs was not possible because they were not available for the period under consideration. However satellite images were used for this purpose. Depth, length and width of gullies were measured in GIS. Using these parameters the volume of soil lost from two largest gullies was determined using the equation adopted from Nasri, Feiznia, Jafari and Ahmadi (2009):-

$$V=A\times L \quad \ldots\ldots\ldots\ldots (6)$$

Where:

V= Volume of soil lost (m^3), A= Cross-sectional Area of the gully (m^2),

L= Length of gully (m).

The purpose was to determine the volume of soil lost through gully erosion due to changes in land use. Note that two largest gullies in 1976 were measured. Later years show no gullies because the area had been built up and there was cover of grass and other vegetation.

River bank erosion was determined from successive estimates of channel width. The difference in channel width of one period under consideration to another was calculated. This was done from satellite imageries by digitizing river bank lines and the extent of bank erosion was computed using the measuring tool in Arc map from one river bank to the other at the sample stations from 1976 to 2013 at a ten year interval.

The purpose was to determine the extent of river bank erosion due to changes in land use. In addition to this direct observation was done in the field and photographs were taken to show eroded areas of the river bank and river meanders. This method was used by Vanlooy and Martin (2005) in studying channel and vegetation change on the Cimarron River. Qualitative data on stream bank erosion was generated from questionnaires. The data was cleaned up and evaluated. Interpretation of data on erosion was then carried out.

Sediment concentrations were determined in the laboratory by decantation and drying the solid matter at 105°C. The concentration values were multiplied by the corresponding water discharges to obtain the rate of sediment discharge. Using this value, annual value was computed (Herschy, 1995 and Chow, 1964). Sediment discharge was determined using the equation adopted from Porterfield, (1972):-

$Q_S = Qw \times Cs \times K$…………………………………………………………...……..... (7)

Where:

Qs = Suspended Sediment Discharge (tons/day),

Qw = Water Discharge (m^3/s),

Cs = Mean Concentration of Suspended Sediment (mg/l),

K = a constant based on SI units of measurement of discharge (0.0864)

Parameters that were analyzed in the laboratory were suspended sediment load and total dissolved solids. Suspended sediment load was used to estimate soil loss from river channel and catchment erosion. Qualitative data on water color during the dry and wet seasons was generated from questionnaires. The data was cleaned up and evaluated. Interpretation of this data was then carried out.

3.4 Assessment of Channel Geomorphology

This section presents primary and secondary techniques of collecting data and data analysis procedures used to meet the requirements of the third objective of the study that sought to assess the geomorphology of Motoine/Ngong River Channel.

3.4.1 Data Collection

Direct observation (Appendix V) and photography were used to obtain data on river morphology. These were carried out at four sampled sites by noting features along the river banks and river bed such as meanders, river braids, meander bars and river bluffs. Photographs of these features were taken. The four representative points along the river course were: at Motoine swamp outlet (37M 0242157 UTM 9857007), Ngong Road Bridge (37M 0271397 UTM 9861770), Nairobi dam inlet (37M 025450 UTM 9854120) and at Kangundo Road Bridge (37M 0271396 UTM 9861765). Site inspections of erosion of river banks was also used by Merz (2010) while studying river bank collapsing of Lower River Murray.

3.4.2 Data Analysis

Morphological features at the four sampling points were identified by visual observation in the field. Their location in the channel was noted and photographs were taken and the formation of these features was described. The features that were identified result from both erosion and sedimentation.

3.5 Hypothesis Testing

Pearson's Rank Correlation Coefficient was used to test the hypothesis. According to Helsel and Hirsch (2002), correlation coefficient measures the strength of association (relationship) between two variables. This statistical test was preferred because it takes into account all measurements in any two variables whose correlation is measured. Land use change was correlated with stream flow. A model adopted from Helsel and Hirsch (2002) was used:-

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{\left[n\sum x^2 - (\sum x)^2\right]\left[n\sum y^2 - (\sum y)^2\right]}} \quad \text{...} \quad (8)$$

Where:

r = Pearson's Correlation Coefficient

n = number of observations,

x= Independent Variable (percentage cover of built up area and road from 1976 to 2012),

y= Dependent Variable (monthly flow for Nairobi River for the year 2012).

Correlation values range from -1 to +1. A negative one indicates complete discordance (inverse relationship) between the variables and a positive one indicates complete concordance (variables vary in the same direction). Values from .01 to .30 are considered small and indicate little relationship between the variables being compared. Correlations of .30 to .70 are considered moderate, correlations of .70 to. 90 are considered large and correlations from .90 to 1.00 are considered very large. (Marczyk et al, 2005) Coefficient of determination (r^2) was calculated to find the proportion of variance in stream flow accounted for by change in land use. This was obtained by squaring the correlation coefficient and converting it into a percentage.

The purpose of correlation analysis was to determine the degree and direction of relationship between change in land use and stream flow. Correlation was done on variables considered to have the greatest influence on the other. To test the hypothesis that there is no significant relationship between stream flow and changes in land use between 1976 and 2012; land use (built-up area and Road) was treated as the independent variable and stream flow as the dependent variable. Testing of hypothesis was done at a confidence level of 0.05.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents a discussion of the results of the study in relation to the study objectives. The discussion relates channel geomorphology, gully and river bank erosion and stream flow variability to temporal and spatial changes in land use in the catchment.

4.2 Land Use Change

To meet the requirements of the first objective of the study that sought to determine temporal and spatial land use changes in Motoine/Ngong river sub-catchment from 1976 to 2012, land use change analysis was done from 30 meter resolution satellite images obtained from DRSRS. Aerial photographs were obtained but did not provide required data because the latest available photographs were for 1967 and 1969 and did not adequately cover the catchment. Findings of the study indicate that there has been spatial change in land use over the years. Five land use classes namely: bare ground, built up area and road, grassland, forest and other vegetation showed both increase and decrease in extent of coverage between 1976 and 2012. Built-up area showed a steady increase for the period under study (Table 4.1, Appendix VI).

Table 4.1: Land Use Changes from 1976-2013

Land Use/Cover (%)	**1976**	**1984**	**1995**	**2002**	**2013**
Wetland	0.24	0.24	0.24	0	0
Bare ground	57.48	18.44	3.25	32.54	23.86
Grassland	2.14	7.59	10.84	0.54	1.30
Forest	15.18	6.50	8.68	7.59	8.68
Other vegetation	2.17	35.79	34.70	14.86	15.18
Built up area and road	22.78	31.45	42.30	44.47	50.98
Total in sq. km	92.2	92.2	92.2	92.2	92.2

Source: Researcher, (2013)

Table 4.1 shows a steady increase in built-up area and road pattern of land use from 22.78% in 1976 to 50.98% in 2013, an increase of about 124%. From 1995 to 2002 there was 95% reduction in area under grassland from 10.85% of the catchment to 0.54%. Mundia and Aniya (2006) attributed this change in land use to increasing and rapid economic developments. Increase in built-up area and reduction of grassland and other vegetation has an effect on runoff and erosion. Wang and Zhu (2003) found that areas of rapid through flow and saturated overland flow generation are also erosion hotspots. Coe and Ramankutty (2006) report that complete removal of grassland and savanna result in an increase of simulated stream flow from 33 to 91%.

Grassland pattern of land use registered an increase of about 141% from 0.54% in 2002 to 1.30% in 2013. Information from interviews conducted on some residents indicated that the area of Njiru was formerly a ranch before it was sub-divided and settlements started. Those that moved to the area before the year 2000 reported that the land cover was grass and bush. This explains the marked reduction in grassland and other vegetation between 1995 and 2002. Removal of grassland in an area reduces surface roughness and increases runoff and streamflow which cause erosion at the catchment and river banks. Mutie et al (2006) found that forests, shrub land, savanna, water bodies and grassland had reduced at the Mara river basin. Mati et al (2008) say that the hydrology of the Mara River has changed and records sharp increases in flood peak flows marked with increase in soil erosion in the upper catchments and silt build-up in the downstream flood plains.

Other vegetation pattern of land use reduced by 58%; from 35.79% in 1984 to 15.18% in 2013. Responses from questionnaires indicated that people cleared natural vegetation to grow food crops, rear animals and establish settlements. However in 1976 the catchment had only 2.17% cover of other vegetation land use pattern. Crops are in this class of other vegetation. The crops grown are maize, beans, bananas, arrow roots, sugar cane, sweet potatoes and vegetables like kales, spinach and traditional vegetables. Napier grass was the only fodder crop grown and mainly grown in the area around Njiru. This is because farms are larger, more than 0.25 of an acre. This land is mainly devoted to maize, vegetables like kales and spinach. Only 16.8% of the farmers at Njiru area grew sugarcane. These were the ones with land sizes of more than an acre. The largest farm size found was $3^1/_4$ acres. Grass and bush had completely been phased out in most farms while maize growing was increasing especially at Njiru area of the catchment.

Land owned by individual farmers in Motoine area was small, less than an eighth of an acre. Motoine area was formerly utilized for growing starchy foods like arrow roots and sweet potatoes but currently more land is devoted to growing of leafy vegetables. Apart from sweet potatoes and napier grass, all the other crops grown in the catchment do not provide cover to soil from erosion. Wang and Zhu (2003) observed that long-term cultivation made the soil hardened, destroyed the granular structure and reduced the water holding capacity.

Bare ground pattern of land use showed both increase and decrease over the years. A marked decrease was noted of about 152% from 57.48% in 1976 to 3.25% in 1995. This may be attributed to improved land management and high rainfall recorded in the same period. However, this class increased to reach 32.54% in 2002. This may have been caused by moderate rainfall that was received during this period with the years 1999 and 2000 recording 684 mm and 665 mm respectively (Appendix XII). Bare ground again reduced by 27% from 32.54% in 2002 to reach 23.86% in 2013, while grassland increased simultaneously by 141%. During the period between 1976 and 1995 the area under grasslands experienced a tremendous increase from 2.14% to 10.84%. This was an increase of about 407%, attributable to improved land management. In the period from 1995 to 2002 there was a 95% reduction in area under grassland and increase of 93% of bare ground. Bare ground again reduced by 26.67% from 32.54% in 2002 to 23.86% in 2013. There was high rainfall in 2012 (1475mm). This explains the reduction in bare ground and a simultaneous increase in all the other classes at that time. Mekonnen and Melesse (2011), studied soil erosion in relation to land use/land cover type in the Northwest Ethiopia highlands and observed the rate of soil erosion to be different for different land use/land cover types. They found average soil loss to be highest (16 tons/ha/year) in crop land and lowest in eucalyptus plantation (0.14 tons/ha/year). For grazing land, bush land and built up areas the soil loss rate was 6.41, 2.28 and 0.34 tons/ha/year respectively (Table 4.1, Appendix VI).

The main wetland in the catchment was Nairobi dam which covered 0.24% of the catchment and was only captured in satellite images for 1976, 1984 and 1995. Later years do not show the wetland because it was heavily covered by water hyacinth and fell under other vegetation land use pattern. Photography and direct observation in the field revealed a reduction in the area covered by Nairobi dam because water had been drained away and it currently covers a narrow stretch along the Motoine river channel (Table 4.1).

Satellite imagery (Appendix VI-1976) shows various land use patterns in the sub-catchment in 1976. 0.24% was covered by wetland (Nairobi dam), bare ground covered more than half of the catchment at 57.48%, and grassland covered 2.14% while forest vegetation covered 15.18% of the sub-catchment. Other vegetation covered 2.17% and built-up area and Road covered the remaining 22.78%. Areas of bare ground are erosion hotspots and gully erosion occurred in the catchment in 1976 when much of the sub-catchment was bare.

Land use map (Appendix VI-1984) shows various land use patterns in the sub-catchment in 1984. 0.24% was covered by wetland (Nairobi dam), bare ground reduced drastically to 18.44%, grassland increased to 7.59% while forest cover reduced to 6.50%. Other vegetation and built-up area and Road patterns of land use increased greatly to cover 35.79% and 31.45% respectively.

Satellite imagery (Appendix VI-1995) land use patterns in the sub-catchment in 1995. 0.24% was covered by wetland (Nairobi dam), bare ground reduced further to 3.25% while further increase occurred for grassland to reach 10.84%. Forest cover registered an increase to stand at 8.68% while other vegetation pattern reduced slightly to 34.70%. At the same time built-up area and Road increased further to 42.30%. Increase in built-up area and road result to a reduction in infiltration capacity of rainwater to the ground and increases surface runoff and streamflow that cause erosion along banks of rivers.

Land use map (Appendix VI-2002) shows various land use patterns in the sub-catchment in 2002. The area covered by wetland was covered by other vegetation type of land use because of infestation by water hyacinth. Bare ground increased to 32.54%, grassland reduced to 0.54%, forest reduced again to reach 7.59%. Other vegetation reduced further to 14.84% while built-up area and Road maintained its increase and stood at 44.47%.

Satellite imagery (Appendix VI-2013) shows land use in the sub-catchment in 2013. The area covered by wetland was covered by other vegetation type of land use. Bare ground reduced again to 23.86% while grassland increased slightly to reach 1.30%. Forest cover and other vegetation increased to 8.68% and 15.18% respectively. Built-up area and Road increased further to cover more than half of the sub-catchment at 50.98%. Built-up area was the only land use pattern that recorded a steady increase during the period under study. This built-up area and road form an impermeable surface cover that impedes infiltration and result to low ground water recharge, high surface runoff and stream flow. High stream flow and stream flow variability have caused erosion of the river banks of Motoine/Ngong river as is discussed elsewhere in this document.

The area under forest cover in the sub-catchment reduced by 56% from 15.18% in 1976 to 6.68% in 2013. The main forest cover is the Ngong Road forest which is a gazetted forest. Its gazettement was done in 1932 and covered an area of 2929.6 ha (7239 acres). Through legal notices, (Appendix VII) excisions have been made over the years to provide land for construction of two Education institutions: Lenana School and Kenya Science Campus, Meteorological Department headquarters, Jamhuri International Trade Fair Grounds, the St. Francis A.C.K church, two cemeteries: Lang’ata and War Memorial cemeteries, Nairobi National park and the City Council Depot. The latest excision was done in 2005 of 56 hectares for construction of the southern by-pass interchange. The current forest cover is 1224.4 ha. This present acreage is only 58.2% of the original forest cover. Most of the excisions were made on the northern part of the forest (Table 4.2, Appendix VIII).

Table 4.2: Ngong Road Forest Excisions

Year	Excision (ha)	Purpose for Excision
1946	1161.45	Royal (Nairobi) National Park
1949	84.17	Duke of York (Lenana) School
1955	50.18	Lang’ata Cemetery
1965	30.76	Kenya Science T.T.C & War Memorial Cemetery
1966	9.40	Meteorological Department Headquarters
1969	17.60	City Council Depot
1971	118.4	Jamhuri ASK showground
1978	3.74	-
1997	82.0	-
1998	53.68	-
2005	56	Southern by-pass interchange

Source: Kenya Forest Service, (2013).

Studies indicate that deforestation causes an increase in the annual mean discharge (Costa et al, 2003). Interception governs the amount of water that may be lost from the system through evapo-transpiration and it protects the surface materials from the erosive effects of raindrop impacts (J. R. Miller and M. O. Miller, 2007). They further report that tall forests have greater evapo-transpiration rates than other vegetation or other land use, because of greater canopy roughness and deeper root systems that draw on soil moisture. When they are cut the water pathways are reduced from the watershed and there is a greater total stream flow from the catchment. In general the greater the amount of canopy lost, the greater the water yield.

Plate 4.1 a: Part of Ngong Road Forest Plate 4.1 b: Site cleared for road construction

Plate 4.1 a was taken on 4/6/2013 and 4.1 b on 25/7/2013

Plate 4.1 c: Road construction underway and site is Plate 4.1d: Road construction
completed source of sediments to the river and forms an impermeable surface cover

Plate 4.1 c was taken on 22/8/2013 Plate 4.1 d was taken on 11/02/2014

Plates 4.1 a to d show a section of Ngong road forest that had been earmarked for construction of the southern by-pass interchange road. The forest cover was cleared to pave way for construction work that left loose soil exposed to agents of erosion. Construction sites are supply sources of sediments to rivers. Road construction was completed with the tarmacking of the surface which is impermeable and impedes infiltration of rainwater and reduces ground water recharge. This results to wet weather high surface runoff and stream flow and reduced dry weather discharge.

4.3 Stream flow, Gully and River Bank Erosion

To meet the requirements of the first part of the second objective of the study that sought to establish the effects of land use change on stream flow, measurement of discharge was done at four gauging stations once during the dry season and once about three weeks following the onset of the rainy season. Stream flow and sediment sampling were carried out at the same point along the course of the river. River bank erosion was observed mainly at the lower section of the river at Njiru, around Kangundo Road Bridge.

4.3.1 Stream flow

Results for the second objective reveal that flow of Motoine/Ngong River is variable between seasons. The dry season flow is low, while wet season flow is high (Table 4.3, Appendix XIII). However rainfall amounts were remarkably low in the month of December 2013 as compared to December 2012. Average flow at Motoine swamp outlet was 0.000899m^3/s or 78m^3/day. However rain season flow was lower as compared to the dry season flow. This may have resulted from low infiltration of the rain water because of dumping of dry waste soil on the swamp. The soil from road construction had been dumped on the swamp earlier and it was spread to cover the whole swamp before the rains started. This may have affected infiltration capacity of the area covered by the swamp considering that rainfall at that time was also low. Motoine swamp forms the source of Motoine River. The water issues from three permanent springs at the margin of Thogoto forest. The river flows across the Karen-Dagoretti market road through a culvert and disappears into nearby farms in what was formerly Dagoretti forest.

There was no flow at the Ngong road bridge gauge station during the dry season despite having flow upstream and downstream of that point (Plate 4.2 a & b*).* This is because of impounding of the Motoine stream by the Upper and Lower dams located in the Ngong Road forest. Payet et al (2004) found that depletion of water resources was caused by drawing it through boreholes and shallow wells causing perennial rivers and streams to dry up. Wet season flow was 889.92 m^3/s or 445 m^3/ day. Flood marks were observed measuring about one meter high on the plants along the river banks. No flood marks were observed outside the banks, an indication that the river does not overflow its banks because of abstraction by the Upper and Lower dams and also because this part of the catchment has the Ngong Road forest cover which has high infiltration capacity.

Average flow at Nairobi dam inlet was 0.0888 m^3/s or 7,672 m^3/ day. There were no flood marks outside the river channel, an indication that the flow is contained within the channel even during the rainy season. This is because the river has cut a deep channel. Average flow at Njiru Bridge was 0.96 m^3/s or 82,944 m^3/day (Table 4.3). The water overflows its banks of about 10.5 m wide to cover a wide area of the valley up to 58.5 m as indicated by flood marks. The height of flash floods reaches 1.4 m outside the river banks as shown by flood marks on tree trunks and banana stems.

Table 4.3: Discharge for Motoine/Ngong River (Drainage Area 3BA) at four Gauging Stations

Station	**Dry Season Discharge (m^3/day) on 5/9/2013**	**Wet Season Discharge (m^3/day) on 17/12/2013**	**Mean Discharge (m^3/day)**
Motoine Swamp Outlet	89	66	78
Ngong Road Bridge	0	890	445
Nairobi Dam Inlet	6,955	8,389	7,672
Njiru Bridge	46,604	119,283	82,944

Source: Researcher, (2013).

Motoine/Ngong river has data limited to only that on which measurements have been made because it does not have gauge stations. For this reason data on discharge for Mbagathi and Nairobi rivers, which are within the same catchment, was interpolated. Discharge for 1970 compared to discharge for 2012, showed that the mean monthly and annual discharge has generally increased over time. Discharge for Nairobi river in the month of April 1970 (Appendix XIV) was 1.720 m^3/s and 8.180 m^3/s for the same month in 2012 (Appendix XVI, Fig 2). This indicates that rain season flow was quite high in 2012 compared to 1970. Total annual rainfall for 1970 was 1,110 mm and 1,475 mm for 2012, an increase of 32.88%. In the months of April recorded rainfall was 469.1 mm for 2012 and 347.3 mm for 1970, an increase of 35%. Discharge for Nairobi River for this same month was 8.18m^3/s for 2012 and 1.72m^3/s for 1970, an increase of 375.58%. In spite of higher rainfall recorded in the months of April 2012 than 1970, stream flow was several times higher in 2012 compared to 1970. This is attributed to increase in impermeable surface cover in the catchment due to increase in built up area and road pattern of land use (plate 4.1 d, Appendix VII*)*.

The same trend was evident for Mbagathi River in the month of September 1970 (Appendix XV) and 2012 (Appendix XVI); an increase in rainfall by 156% and an even higher increase in discharge by 243% (Fig 4.3). Information from the questionnaire indicated that flow filled the channel during the wet season and the water level was very low during the dry season. The trend of flow for Mbagathi river indicates a steady increase in stream flow. This is attributed to land use change and not rainfall because increase in rainfall was not significant as earlier discussed to cause such significant increase in discharge (Fig 4.1, Appendix XVI).

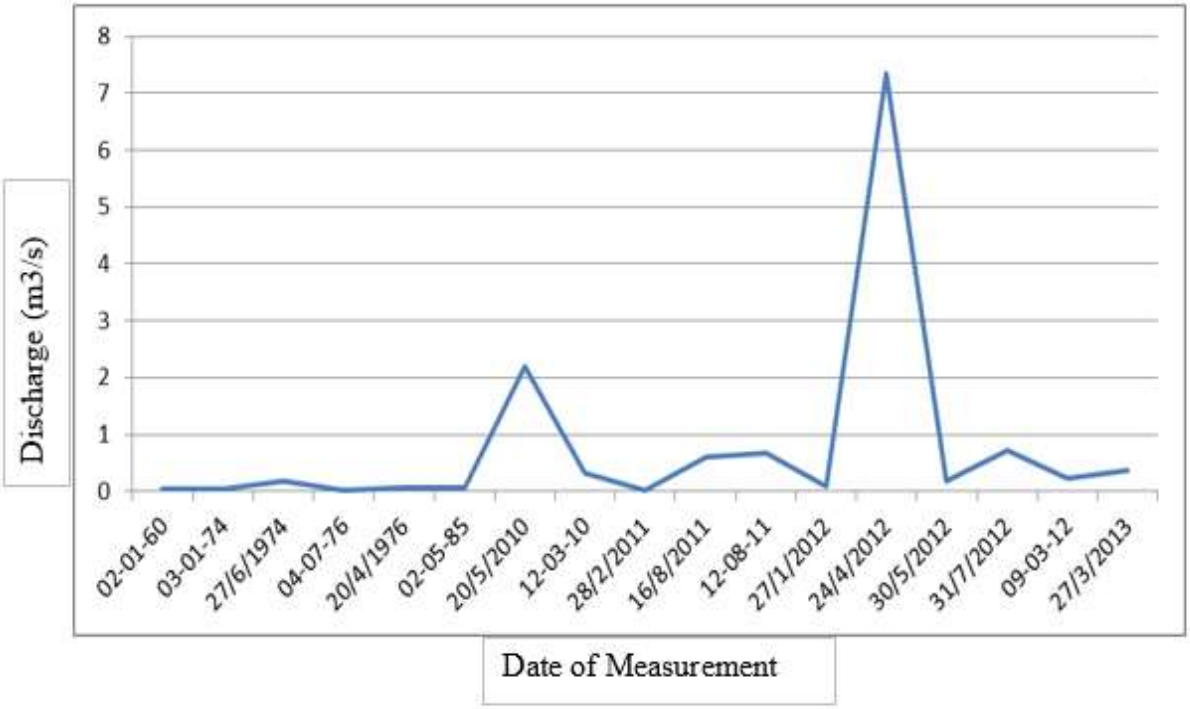

Figure 4.1: Trend of Flow for Mbagathi River (RGS 3AA04) from 1974 to 2012

Source: Researcher, 2013.

In spite of increase in rainfall for those specific months there was a much higher increase in discharge. This situation is brought about by low infiltration rates in the catchment because much of it is built-up and covered by paved surfaces. Built up areas and paved surfaces form impermeable surface cover that reduce infiltration capacity and increase surface runoff and stream flow. Konrad (2002) found that the annual maximum discharge in a stream increases as urban development occurs. Wijesekara, Fariad, Gupta, and Delaney (2013) found similar results in a study in Canada. Hurni et al, (2005) realized that surface runoff rates are influenced by land use and soil degradation.

Correlation between built-up area and stream flow yielded a value of 0.8 (r = 0.8), an indication of a strong positive relationship between increase in built-up area and stream flow. This shows that increase in built-up area and road pattern of land use in the catchment has resulted to an increase in stream flow in Motoine/Ngong river. The hypothesis that there is no significant relationship between stream flow and changes in land use between 1976 and 2012 is therefore rejected at a confidence level of 95%. The alternative hypothesis that there is a significant relationship between stream flow and changes in land use in the Motoine/Ngong river sub-catchment from 1976 to 2012 is therefore accepted. Coefficient of determination (r^2) was 64%. This is the proportion of variance in stream flow for Motoine/Ngong river that is accounted for by increase in built-up area and road pattern of land use in the catchment.

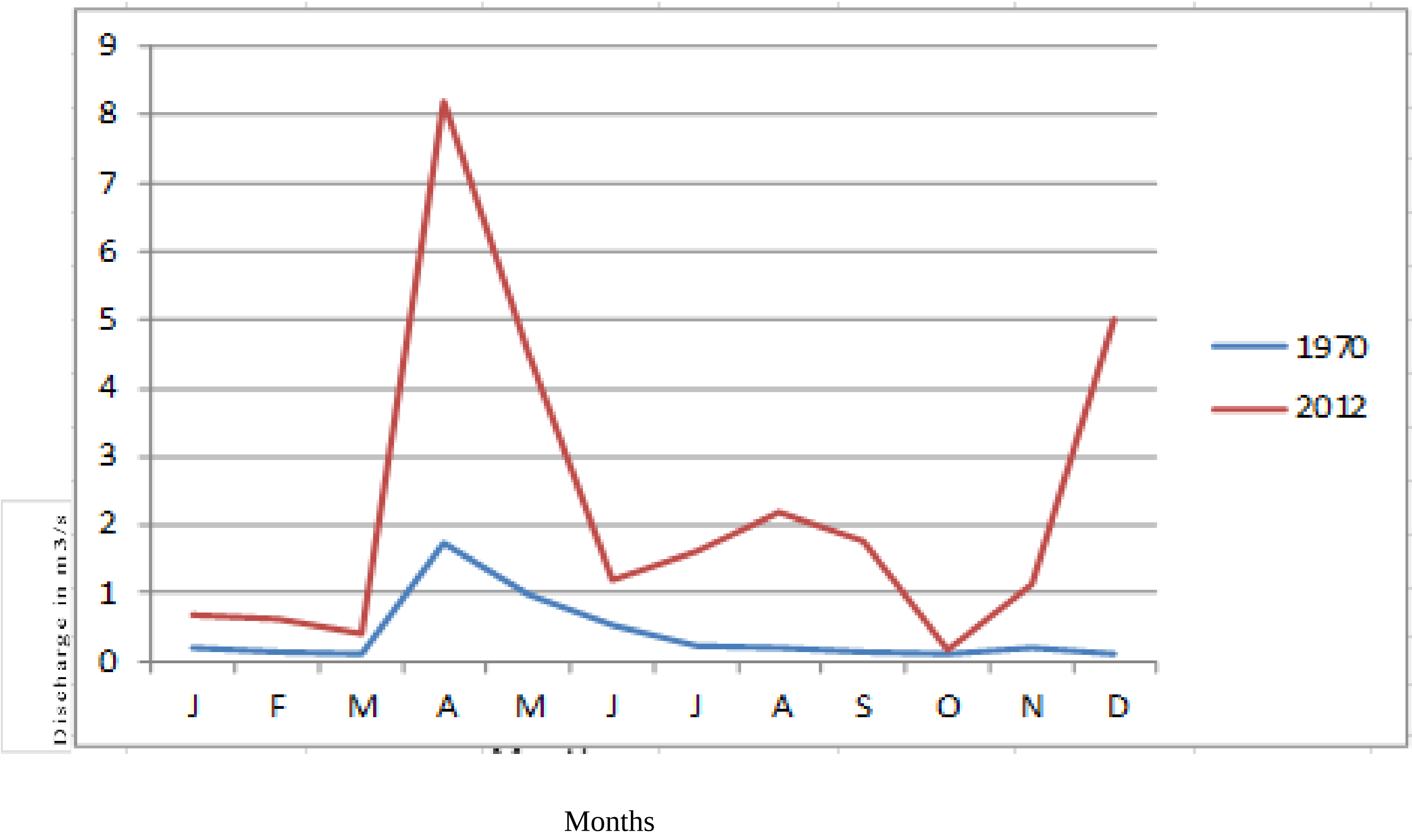

Figure 4.2: Discharge in m3/s for Nairobi River for 1970 and 2012

Source: Researcher, (2013)

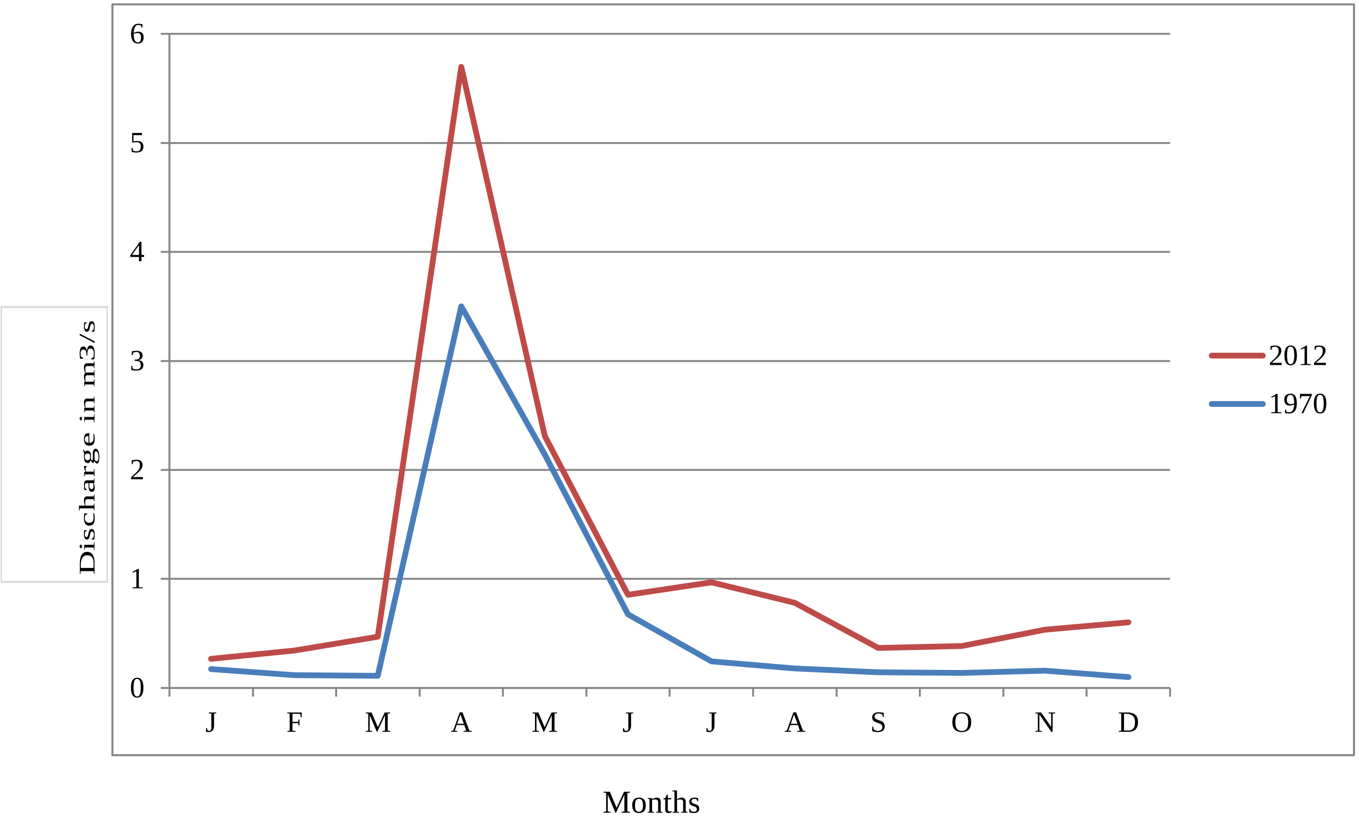

Figure 4. 3: Discharge in m3/s for Mbagathi River for 1970 and 2012

Source: Researcher, (2013)

4.3.2 Gully Erosion.

The second part of the second objective of the study sought to establish the effects of land use change on gully erosion in Motoine/Ngong river sub-catchment. To achieve this gully erosion in the sub-catchment was analyzed from satellite images. Using the satellite image for 1976 the following layers were used to obtain data on gullies; elevation data, slope, aspect, elevation value of the entire area (1795 m a.s.l for Nairobi), flow direction and accumulation. These data sets were then inputted into spatial analyst and raster calculator models in arc map. Results revealed that gully erosion was severe in 1976 because much of the catchment was bare (57%) because of low rainfall received that year, 713 mm and 831 mm in 1975. Barber and Mahler (2010) found that ephemeral gullies observed at the end of an erosion cycle were a manifestation of preceeding weather, basin hydrologic conditions and erosion sensitivity of the basin land cover.

Later years show no evidence of gully erosion because the area had been built-up. Mekonnen and Melesse (2011) found erosion in built up areas to be low at 0.34 tons/ha/year compared to other land use patterns. Gullies in the study area ranged from 1 m to 2 m deep. Two largest gullies were measured and their parameters are shown on (Table 4.4 and Appendix X).

Table 4.4: Estimated Gully Parameters

No.	Depth (m)	Width (m)	Length (m)	X coordinates	Y coordinates
1	2	75	558	9854664.8	265997
2	2	95	386	9853334.5	262547.2

Source: Researcher, (2013).

Using the equation described in section 3.3.2, the volume of soil lost from the largest gully in 1976 was 83,700 m^3 and soil loss from the smaller gully was 73,340 m^3. Rowntree (1991) found gullies in Baringo measuring up to 151 m long. Boardman (2003) found that ephemeral gullies contribute significant proportions of soil loss to total erosion. Barber and Mahler (2010) estimated areal rates of erosion from agricultural regions in the Pacific Northwest, USA to be between 33.6 tons/km^2 and 88.4m ton/km^2.

4.3.3 River Bank Erosion

To meet the requirements of the third part of the second objective of the study that sought to establish the effects of land use change on river bank erosion, analysis was carried out from satellite images, photographs and direct observation in the field. River bank erosion is a natural geomorphic process which occurs in all channels as they adjust their size and shape to convey the discharge and sediment supplied from the catchment. Accelerated river bank erosion is often associated with land use change. According to Watson and Basher, (2006) river bank erosion processes are classified into two, those dominated by gravitational failure (mass movement and individual grain failures) and those where hydraulic–induced failure mechanism (fluvial erosion) dominates. The two process groups are often linked and both were observed along the Motoine/Ngong river channel particularly at and around Kangundo Road Bridge. Hydraulic-induced mechanism such as bank undercutting causes a gravitationally-induced failure such as cantilever failure (collapse of overhanging block of sediment) (Watson and Basher, 2006). These processes or mecahanisms of instability, operate on the bank either simultaneously or sequentially (Thorne and Furbish, 1995).

Photography and direct observation in the field revealed that collapse of overhanging blocks of undercut river banks occurred along the Motoine/Ngong river channel near kangundo road bridge (Plate 4.2 c & d). The occurrence of these processes is determined by many factors according to Thorne and Furbish (1995). Key of which are discharge, characteristics of bank material and local soil moisture condition.

To determine river bank erosion due to changes in land use, the difference in channel width of one period under consideration to another was calculated. This was done from 50 cm spatial resolution worldview satellite images for 1976, 1984, 1995, 2002 and 2013. Results indicate an apparent narrowing of the channel during dry months as sedimentation occurs and vegetation colonizes the sediments (Plate 4.2 a & b). Small plants and grass grew at the river bed and banks. The roots of these plants were shallow so they are washed away by flash floods. Generally there seems to be no significant channel widening as shown by the measurements taken from satellite imageries (Table 4.5 and Appendix XVII). It seems much of the channel erosion is caused by flash floods following heavy rainfall events as indicated by flood marks, although the wet season flow during the study period was unusually low.

Channel narrowing and widening seems greater at Motoine swamp outlet and Kangundo Road Bridge than the other two points (Appendix XVII). These two points occur at areas of very gentle gradient and wide shallow valleys over which get eroded by flood waters as they overflow the banks. This is more so at Kangundo Road Bridge. Ngong Road Bridge and the dam inlet have deep valleys within which flood waters are contained. Their channel cross-sections show little variation from 1976 to 2013 (Appendix XVII).

Table 4.5: Estimated Channel width (m) at four Points between 1976 and 2013

Point Name	**Years/Months**				
	1976 Jan	**1984 Dec**	**1995 Jan**	**2002 Feb**	**2013 May**
Motoine Swamp Outlet	4.50	1.84	3.45	1.24	2.20
Ngong Road Bridge	1.78	2.31	2.01	2.4	2.21
Nairobi Dam Inlet	4.82	4.09	3.98	3.79	4.65
Kangundo Road Bridge	9.84	8.68	10.84	9.24	10.56

Source: Researcher, 2013.

Plate 4.2 a: River bed drying up

Plate 4.2 b: Dry river bed

Source: Researcher, (2013)

Plate 4.2 a was taken on 25/7/2013 and 4.2 b on 5/9/2013 at Ngong Road Bridge

Plate 4.2 a: River bed drying up and vegetation growing at the river banks. Photograph was taken at the onset of the dry season.

Plate 4.2 b: Dry river bed and vegetation growing at the river bed and banks, causing the apparent narrowing of the channel during the dry season. Photograph was taken during the dry season. The dry river bed is evidence of human activities (abstraction) on stream flow and flow variability.

Ngong Road Bridge was the only point along the Motoine/Ngong river that had a dry valley during the dry season. The channel at this sampling point appeared to be narrow during the dry season because of vegetation that had grown to cover the river banks completely (as seen at the background of photograph 4.2 b) and parts of the river bed. This was the same scenario at other sampling points along the river as observed during field study. This was also indicated by measurements of channel width from satellite images.

Measurements taken of channel width did not show any significant widening of the river channel from 1976 to 2012. However, river bank erosion was evident particularly at the lower section of the river at Njiru near Kangundo Road Bridge. Information from questionnaires, direct visual observation in the field and photography revealed that river bank erosion occurred mainly during the rainy season. The water was also turbid during this period of the year because of supply of sediments by surface runoff (Plate 3.1). Erosion of the banks at the Motoine/Ngong river is described below.

Erosion processes of river banks occur as a result of direct removal of bank materials by the shearing action of flow. This is aided by mass wasting of banks under the influence of gravity. It was observed that mass wasting resulted to the delivery of sediments to the channel (Plate 4.2 c & d). Mass wasting occurred as a result of undercutting of the river banks (Plate 4.2 c). Once they were undercut the overhanging upper parts of the river bank seemed quite unstable. These overhanging upper parts eventually collapse into the river. This apparently widens the river channel. Kiss et al (2013) found that mass failure that occurred in high bluffs contributed to bank erosion of rivers in Hungary, and the process of undercutting and removal of the toe material influenced bank retreat.

The section of the river shown in Plate 4.2 c is approximately 6.5 m wide and was about 12 m downstream of the section shown in Plate 4.2 d which is relatively straight and measured 4.9 m wide. The section shown in Plate 4.2 c was on a meander and had loose soil on its banks, making it conducive for undercutting and collapse of the banks to take place. Such materials from collapsed banks can be seen in Plate 4.2 c and d, while other blocks were seen hanging precariously at the middle of the river banks. Nasermoaddeli and Pasche (1998) found that undercutting of the river banks, avalanche of the submerged zone of the river bank and failure of the overhang were dominant processes on non-cohesive river banks.

It was noted that mass wasting occurred along sections where the bank material was composed of erodible soil as well as having high cliffs and therefore had low resistance. Prolonged rainfall events cause strength reduction and increase in unit weight of the materials causing them to collapse. Gray and Sotir (1996) say that failure occurs when the erosion of the bank and the bed adjacent to the bank have increased the bank height and steepness (slope), to a point where it reaches a condition of limiting stability.

Plate 4.2 c: Land slide of high river cliffs (17/12/13)

Plate 4.2 d: Collapsing of banks (5/9/13)

Plate 4.2 c shows erosion of an outer river bank by land slide process at Njiru (50 m) upstream of the Kangundo Road Bridge. The photograph was taken during the wet season. It shows erosion by land slide process on high river cliff with loose soil which is erodible.

Plate 4.2 d shows erosion of an outer bank of the river by land slide process at a relatively straight section at Njiru (100 m) upstream of the Kangundo Road bridge. It also shows napier grass slanting towards the stream bearing flood marks on it. This forms an overhanging bank which easily collapses into the river when there is additional weight to the material from rainwater.The collapse of banks supplies sediments to the river.

Flow characteristics of the river varied across its cross-section; the greatest velocities were near the surface at the center, corresponding with the deepest part of the stream channel. Velocities decrease closer to the banks and bed of the channel because of the frictional drag on the water flow. However in a curving stream, the maximum velocity line migrates from side to side along the channel, deflected by the curves. The outer portion of the meander curve was subjected to erosion by hydraulic action and abrasion. This formed a deep and steep bank, an undercut bank. This resulted to development of a river cliff. The inner portion of a meander receives sediment fill and had formed a point-bar deposit, which had developed into a slip-off slope (Plate 4.3 a and b).

Undercutting was noted both on the concave (outer) banks of the river and the convex (inner) banks of the river as evidenced by occurrence of cavities at both river banks (Plate 4.2 e & f). The cavities occurred at the middle and lower parts of the banks which imply that removal of toe material occurred during medium and low stage periods due to excessive pore pressure and overburden. As earlier discussed flow of Motoine/Ngong river varies between seasons and flash floods rise and fall rapidly after a rainfall event. Thorne (1998) found that pore pressure along the river banks caused small to medium sized blocks of fine grained cohesive material to fall out leaving a cavity. The fine cohesive materials allow the buildup of positive pore water pressure and strong seepage within its structure. The roof of the cavity may collapse resulting to river bank retreat.

Plate 4.2 e: Undercutting of outer bank

Plate 4.2 f: Undercutting of inner bank/pop out failure results to cavities

Plate 4.2 e was taken on 17/12/2013 and 4.2 f on 5/9/2013

Plate 4.2 e & f show undercutting of the river banks near Kangundo Road Bridge. Plate 4.2 e was taken during the rainy season and the site is at an outer bank near the river bed. Plate 4.2 f was taken during the dry season and it shows undercutting midway at the inner bank. This undercutting and the consequent collapse of the overhanging banks result to bank retreat and soil loss.

Slab failure was also observed along a section of the river bank near Kangundo Road Bridge. Slab failures are sliding and forward toppling of a deep seated mass into a channel (Plate 4.2 h). Slab failure that was observed and photographed was on a steep, low height, fine-grained bank. Watson and Basher, (2006) says that slab failures tend to occur during low flow conditions. They result from the combination of scour at the bank toe, high pore-water pressure in the bank material and the development of tension cracks at the top of the bank. Under these conditions the stability of the bank depends on the strength of the bank material. An accumulation of failed loose blocks were observed and they seemed to offer temporary protection to the lower section of the river bank (Plate 4.2 h).

Some sections of the river banks had deep and gaping tension cracks (Plate 4.2 g). Other sections where the cracks had progressed lost resistance and had collapsed into the channel (Plate 4.2 h). This results from weathering through desiccation which occurs in rocks with high clay content. During the wet season the clay soils absorb moisture and expand. During dry weather the soil loses moisture and contracts. It is during contraction that cracks develop in the soil and subsequently collapse into the river. This steepens and erodes river banks.



Plate 4.2 g: unstable outer bank showing cracks   Plate 4.2 h: collapsed outer bank

Source: Researcher, (2013)

Photographs were taken 10m downstream of Kangundo Road Bridge on 17/12/2013.

The cracks were on the outer bank of the river, were about 2 m deep and seemed quite unstable. Collapse of these unstable blocks results to erosion of banks of the river, exposes a new surface to erosion, causes soil loss and supplies sediments to the river.

Some points of the river banks portrayed basal cleanout as they had been freshly swept clear of loose soil particles (Plate 4.2 i and j). Direct observation and photography in the field revealed that flash floods had removed loose soil particles and uprooted vegetation that had colonised the river banks. This removal of supportive and protective material, either vegetation or sediments, at the base resulted to bank instability. It was noted that the removal of collapsed bank material left the lower river bank material exposed to a continuous cycle of undercutting, collapse and removal, and the subsequent process of river bank retreat. This removal of sediments and vegetation resulted to apparent widening of the river channel during the rainy season mainly at the outer banks. Sedimentation at the inner banks was observed forming point bars.

Friedman and Lee, (2002) found that channel change of streams in Colorado was dominated by channel widening, which occurred within hours during infrequent floods and post flood narrowing occurred over decades between floods. They explain that narrowing occurs where moisture accelerates the density and growth rates of vegetation on the former bed. Vanlooy and Martin (2005) also found that the channel of Cimarron River changed from a wide, braided channel in 1953 to a narrow, meandering one in 2001. They associate both the channel changes and expansion of riparian vegetation to in-channel sedimentation.

Plate 4.2 i: Basal Cleanout of the inner bank. Plate 4.2 j: Basal Cleanout of the outer bank

Source: Researcher, (2013)

Photographs were taken near Kangundo Road Bridge on 28/12/2012.

There were two days of high rainfall, before the day the photographs were taken, that had removed all loose soil particles from the river banks and uprooted much of the vegetation along the river bed and banks.

4.3.4 Sediment Discharge

Sediment discharge of Motoine/Ngong river increases downstream and between seasons. The total suspended solids discharged through the river at Kangundo Road Bridge were

260.058 tons/year. Suspended solids are materials suspended in the water column. This includes silt, sand and organic matter, the source of which is erosion of soils from the catchment, river beds and river banks. Information from the questionnaire indicated that the upstream side of Motoine river had clear water during the dry season. Wet season flow of the Motoine river was turbid because of sediments (Plate 3.1). The river flow from the Jamhuri Park was very clear but got highly polluted at Kibera slums (Table 4.4, Appendix XVIII). Dry season flow at Njiru was black, described by respondents as sewage like (Plate 4.3 b). The increase in sediments downstream was because of supply of sediments from construction sites, erosion from farms by surface runoff and erosion of river banks by powerful flash floods. Much of the land that was under construction in the catchment was formerly covered by forest. This agrees with the results of Payet and Obura (2004): that increased pollution of water bodies by sedimentation results from increased surface erosion and land use changes, with major rivers having perennially high sediment loads.

Total suspended solids varied from one sampling point to the other along the Motoine/Ngong river. Table 4.6 shows that TSS was lowest at the Motoine swamp outlet and Ngong Road Bridge because much of this part of the catchment is covered by forest with low rates of erosion. TSS was highest at the Nairobi dam inlet because of heavy pollution from Kibera slums. Heavy rainfall, fast moving water and low resistance of river bank materials cause erosion of banks at Njiru area resulting to high levels of TSS at this point. Table 4.6 provides summary information for seasonal TSS and corresponding discharge of Motoine/Ngong river at four sampling points.

Land use is the major factor influencing changes to total suspended solids or turbidity in rivers. Available data on sediment discharge for Nairobi river (Appendix XX) indicates an increasing trend in sediment load of Nairobi river long before rapid developments started in Nairobi. Development of the Motoine/Ngong river watershed has resulted to an increase in disturbed areas like construction sites (Plate 4.1 c), a decrease in vegetal cover, and an increase in paved surfaces as well as the rate of surface runoff. These resulted to an increase in both erosion and ready supply of sediments to rivers. This is particularly the case for Motoine swamp outlet and Ngong Road Bridge which recorded higher sediment discharge during the rainy season than the dry season (Table 4.6, Appendix XIX). Kangundo Road Bridge recorded lower sediment discharge than the dam inlet upstream because sedimentation occurs in the dam where Motoine drains into and leaves as Ngong river. Dilution of pollutants from Kibera slums may have led to lower sediment discharge at the dam inlet sampling point during the rainy season. Payet and Obura (2004) found that increased pollution of water bodies by sedimentation from increased surface erosion and land use led to high sediment loads in rivers. High concentrations of TSS cause increased sedimentation and siltation in rivers, which can ruins habitats for aquatic life. Suspended particles also provide attachment places for other pollutants like metals and bacteria.

Table 4.6: Average Sediment Discharge of Motoine/Ngong River (Drainage Area 3BA)

	Dry Season 5th Sep, 2013			**Wet Season 17th Dec, 2013**			
Point Name	**Channel Cross-Section (m)**	**Discharge (m^3/s)**	**TSS (mg./l)**	**Channel Cross-Section (m)**	**Discharge (m^3/s)**	**TSS (mg./l)**	**Mean Suspended Sediment Load (tons/year)**
Motoine Swamp Outlet	0.3	0.00103	6	0.5	0.000768	40	0.0563
Ngong Road Bridge	5.1	0	0	2.4	0.0103	60	0.420
Nairobi Dam Inlet	1.4	0.0805	800	1.6	0.0971	140	11.359
Kangundo Road Bridge	5.0	0.5394	140	10.5	1.3806	60	260.058

Source: Researcher, (2013).

4.4 Geomorphology of the River Channel

To meet the requirements of the third objective that sought to assess the geomorphology of the Motoine/Ngong River Channel, results reveal that the geomorphology of the river channel varied from the upper section at Motoine to the lower one around Kangundo Road Bridge. Stream geomorphology records the balance of erosional and depositional processes induced by geology, alignment and energy of flow at differing flow stages. The Motoine river has three springs that form its source. The channel is small and narrow and crosses a seasonal swamp. The channel has no distinct valley because much of the area around it is a plain and stream flow and velocity are low. According to Saggerson (1991) the rock formation here is the Upper Athi Series, which is composed of sandy sediments, gravel or pebble beds, tuffs and pyroclastic sediments, and is porous and permeable (Appendix I).

The Motoine river at Ngong Road Bridge has a well cut out valley and its channel meanders along its course. This section is covered by Nairobi trachytes (Gevaerts, 1964). At the Nairobi dam inlet the Motoine river has developed a deep and steep meandering channel with outcrop rocks on its bed. This section is covered by lake deposits that are characterized by course, gritty volcanic sand. Ngong rivet at the Kangundo Road Bridge has developed a wider valley and a deep channel with meanders and braids, and the main top formation is the Nairobi phonolite (Saggerson, 1991). Most of the landforms discussed below were found at the lower section of the river at Njiru near Kangundo Road Bridge. Topographically the area has steep slopes ranging between 10 and 19 percent (Appendix III). The gradient of the channel is 1.456°. Soil types in this area are the vertisols and vertic gleysols (Appendix II). The soil is composed of cracking clay, dark brown to very dark greyish brown. Vegetation type is mainly the planted type classified under other vegetation land use pattern. The observed land forms along Motoine /Ngong river channel are discussed in greater detail as follows;

4.4.1 Undercut banks and Desiccation Cracks

The Motoine/Ngong river showed undercutting at its banks, desiccation cracks and collapsing of river banks (cantilever failure). These result to development of river cliffs. Most of these river cliffs were observed at sections of the channel with high bank height (Plate 4.2 e). Undercutting is the direct removal of bank material at or below the water level by the physical action of flowing water and the sediment it carries. The erosive power of a river increases with increasing flow until the fluid-derived shear stresses exceed the cohesive strength of the bank material. Watson and Basher, (2006) found that undercutting occurs as a result of redirection and acceleration of flow around obstructions such as debris and vegetation within the channel. It is common on the outside of meander bends where velocity flow and shear stress is higher. Much of the undercutting was evident along sections of the river banks with vertisol soils.

This soil was composed of cracking clay commonly called the black cotton soil (Plate 4.2 g). Other points along the river bank had dark brown to very dark greyish brown soils that are highly erodible (Plate 4.2 c). The slopes around this section of the river with highly erodible soil were steep ranging between 10 and 19 percent. This section at Njiru was mainly covered by other vegetation type of land use basically characterized by napier grass, maize crop, bananas and kales and very little cover by natural grass was observed. Such vegetation does not provide cover to the banks from erosion.

Slab failures were also observed at some points along the channel around Kangundo Road Bridge These were characterized by cracks that formed at some distance back from the river bank (Plate 4.2 g). Tension cracks developed from desiccation and tension. These cracks often develop due to stress release. Tension reduces the bank stability. In low river banks (less than 3m) tension cracks may occupy a significant portion of the bank height (Thorne, 1998). At Njiru area the cracks covered the whole bank height. Simons and Li (1982) found that crack development allowed surface flows to drain into the bank, increasing seepage forces and subsequently reducing stability, causing blocks of affected bank material to slide downward and outward into the channel as a mass failure.

Desiccation and bank material collapse was noted in sections of the river bank with clayey material. According to Merz (2010); desiccation cracks play a role in the erosion of banks of high clay content. The factors which were noted and considered significant in decreasing resistance of the Motoine/Ngong river banks to erosion were rapid drawdown of water levels after a rainfall event, consistent lowering of the water levels during the dry season, existence of erodible river banks (Plate 4.2 c) and desiccation of sections of the river banks (Plate 4.2 g*)*. Desiccation occurred during dry periods resulting to development of tension cracks some of which had collapsed (Plate 4.2 h).

4.4.2 River Bank Cavities

River bank cavities develop as a result of pop out failure which was observed at about 100 m upstream of Kangundo Road Bridge. Medium sized blocks had been forced out near the base of the river bank leaving an alcove-shaped cavity at the bank face. Thorne, (1998) records the same in his book ‘Stream Reconnaissance Handbook’. The cavities at Ngong river were on a steep inner bank with fine-grained cohesive bank materials. Cohesive materials allow for the build-up of positive pore water pressure and or strong seepage within its structure. Kiss et al (2013) report that the most critical condition causing strength reduction is rapid drawdown after a high flow stage, because cohesive materials become more erodible when wet (Plate 4.2 f). Thorne, (1998) reports that fallout of blocks from river banks occurred due to excessive pore–water pressure and overburden.

4.4.3 River Cliffs, Slip-off Slopes and Meanders

River Cliffs, Slip-off Slopes and Meanders form in rivers with sinuous channels. A river cliff is a steep slope on the outside of a meander often marked by an undercut bank. A slip-off slope is a gentle slope on the inside of a meander marked by a point bar in the river. These features were observed around the Kangundo Road Bridge sampling point.

Kiss et al (2013) says that meander bends result from stochastic fluctuations of the direction of flow due to the random presence of direction-changing obstacles in the river path. Obstacles, bars or irregularities at the river bed cause riffles and pools (turbulent flow). These lower the channel efficiency (hydraulic radius) of water flow for the area, causing the water to flow more inefficiently over such irregularities. Water finds a way around the areas of higher frictional contact. It was observed that as the water flowed around such areas, it created variations in flow, and so it developed a side to side motion.

Between the shallow riffle areas are deeper areas (pools) that get eroded, mainly during periods of high discharge. During such times water swings around one side of a riffle leading to undercutting of the opposite bank (Fig 4.4 a and b). When the slight meandering course is established, combined processes of erosion and deposition occur. It was observed that the outer bend with deeper waters had a higher flow velocity because it was free from frictional drag. According to Christopherson, (2010) this higher velocity erodes the bank by hydraulic action and abrasion at or near the toe of the bank resulting to the development of river cliffs. Along river cliffs around Kangundo road bridge undercutting, bank failure and bank retreat or widening of the channel were evident (Plate 4.2, c, d & e).

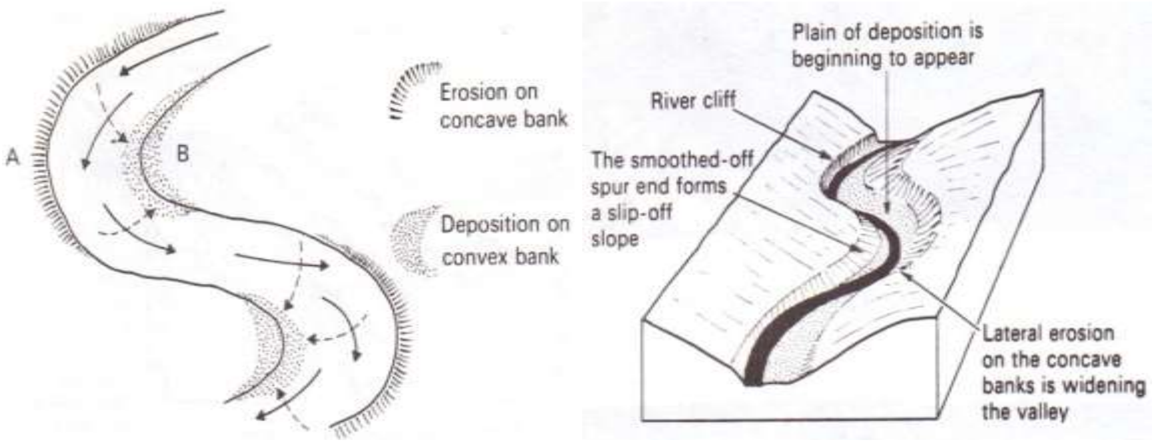

Figure 4.4 a and b: Erosion and Deposition at River Meanders

Source: Bunett, (1987)

On the opposite side a shallow profile with lower hydraulic efficiency (flow velocity) was observed. According to Christopherson, (2010) this low velocity at the inner bank causes sedimentation resulting to the development of a point-bar or slip-off slope. (Fig.4.5) The river current swung around the bend at the surface and back to the opposite side as sub-surface flow described as corkscrew shaped flow (Plate 4.2 a and b). Bunnet (1987) says that the cross-current along the floor of the channel, which is part of the secondary flow, sweeps dense eroded material towards the inside of the bend. This flow allows eroded materials from the outer bank to be deposited on the inner bank to form a point bar (Plate 4.2 a at the foreground and 4.2 b at the left middle ground).

The greater the curvature of the bend, the faster the flow, and the stronger is the cross-current and the sweeping (Christopherson, 2010 and Collated data). Meanders, slip-off slopes and river cliffs were observed at Ngong Road Bridge, at the Nairobi dam inlet and at Njiru (Plate 4.3 a - d). At the dam inlet outcrops of rock were observed at the river bed. These were remnants of the former cover of the river bed when the overlying bed materials were eroded. Vertical erosion removed a less resistant former cover of the river bed to leave the resistant rocks at the bed to form bed outcrop rocks. These rocks provide stability to the river beds and banks.

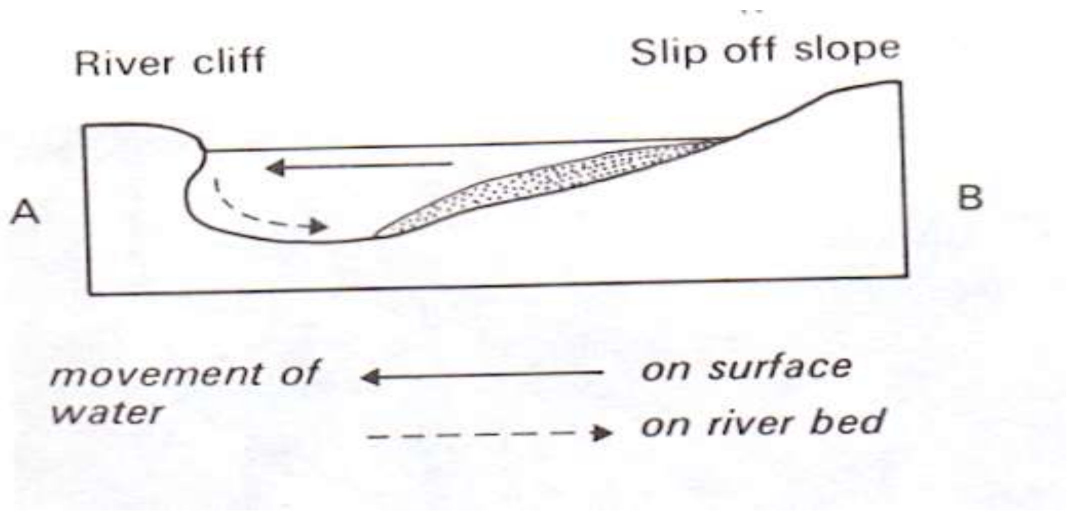

Figure 4.5: Cross-section of a River Meander

Source: Bunett, (1987)

Plate 4.3 a **Plate 4.3 b**

Plate 4.3: a & b: Channel meanders, slip-off slopes and river cliffs at Njiru 100 m upstream kangundo Road Bridge. Photographs taken on 5/9/2013

Plate 4.3 c

Plate 4.3 c: Channel meanders, slip-off slopes, river cliffs and outcrop rocks near dam inlet.

Plate 4.3 d

Plate 4.3 d: Channel meanders, slip-off slopes and river cliffs at Ngong Road Bridge.

Photographs were taken on 17/12/2013

Plate 4.3 a to d show channel meanders at four sampled points along the river's course. This meandering results from alternating erosion and sedimentation at the outer and inner banks of rivers respectively.

4.4.4 Channel Braids

A braided river is one that, over some part of its course, flows in two or more channels around alluvial islands. Climate exerts a great influence on bar morphology particularly size and material composition. Motoine/Ngong river bar, downstream the Kangundo road bridge was larger during the dry season than during the rainy season. The bar disappeared at high flow stages and reformed as discharge fell, so that at bankfull stage the river acts as a single channel and only adopts a characteristic braided pattern on the falling stage. This is shown by the level at which the bar occurred in relation to the level of observed flood marks, an indication that it gets submerged by flash floods *(*Plate 4.3 e and f*)*.

Church and Jones (1982) say that at such higher flow stages the largest volumes of sediment are transported and the channels are scoured. The bar is reduced in height or in some cases completely eroded. However, during the falling stage maximum deposition occurs as discharge and flow competence are reduced. The channel bed aggrades, the high stage bed forms are modified and a new bar forms or enlarges as sediment is deposited. The bar emerges and as discharge falls the bar dissects the low stage flow to form a braided channel. Apart from reducing discharge, the other factor that has contributed to the development of the bar at Ngong river is the presence of the Kangundo road bridge because flow under the bridge was constricted. As the flow left the area of constriction the water spread out, got shallower and friction with the bed and banks increased. This resulted to a reduction in its competence resulting to sedimentation. The Ngong river channel splits into two and flows for a distance of about 20 meters before rejoining downstream to form a single stream. This distance was much less during the rainy season.

Motoine/Ngong river has variable flow as earlier discussed, and its banks are composed of erodible material. Its channel pattern is controlled by water and sediment supply. According to Church and Jones (1982), rivers with high discharge variability have a greater probability of braiding due to rapid fluctuations in discharge that typically produce high sediment supply and width to depth ratios. The extreme discharges lead to bank erosion and irregular, episodic bed load movement, which are important to braided channel formation. Banks of readily erodible materials are key sources of sediments as well as channel widening, which is a key component of braided channels. The Ngong river channel is wide immediately downstream of the bridge and tends to narrow farther downstream.

Direct observation and photography in the field revealed that the bars that form the braided channel at the Motoine/Ngong river have no vegetation. This implies that there is frequent refreshing of bar surfaces, bar destruction and re-formation. This means there is increased erosion and flood frequency and magnitude. Presence of vegetation indicates a degree of stability. The bar size and material composition also vary between the rainy and dry season. During the dry season the bar was larger and composed of finer materials (Plate 4.3 e). During the rainy season the fine materials that formed the bar had been eroded by flash waters, leaving behind boulders. Some of the boulders may have been deposited by flash floods because of their high competence. At the same time of high flow no sedimentation of fine sediments occurs because the river’s competence is high (Plate 4.3 f).

Plate 4.3 e: Dry season Channel Braids

Plate 4.3 f: Wet Season Channel Braids

Source: Researcher, (2013).

Plate 4.3 e was taken on 5/9/2013 and shows a river braid during the dry season. The bar was much bigger because of the low flow and was composed of fine materials.

Plate 4.3 f was taken on 17/12/2013 and shows a river braid during the wet season. The bar is smaller because of high flow and is composed of course materials. Photographs were taken at about 2-20 m downstream of Kangundo Road Bridge.

CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of the research findings, conclusions and recommendations made towards enhancing conservation and effective management of water catchment areas. The conclusions are drawn from the research findings and discussions. Areas for further research have also been proposed for the purpose of exploring environmental problems facing water catchments so that they can be addressed appropriately.

5.2 Summary

The findings of the study indicate that there has been spatial change in land use over the years in Motoine/Ngong river sub-catchment. Five land use classes were identified within the catchment, namely: bare ground, built up area and road, grassland, forest and other vegetation. Built-up area and Road pattern increased from 22.78% in 1976 to 50.98% in 2013, an increase of 124%. This forms the main pattern of land use covering more than half of the catchment. However, other vegetation pattern of land use registered an increase from of 600% from 2.17% in 1976 to 15.18% in 2013. Bare ground registered the greatest reduction of 58% from 57.48% in 1976 to 23.86 in 2013. Other patterns that reduced were forest by 43% and grassland by 39%. Increase in built-up area and road and other vegetation increased stream flow and erosion in the sub-catchment due to increase in impermeable surface cover.

The main forest cover is the Ngong Road forest which was gazetted 1932, and covered an area of 2929.6 ha at that time. Excisions were made for road construction, development of schools, churches, public cemeteries and other social facilities. The current cover is 1224.4 ha. The latest excision was done for 56 ha for the construction of the southern by-pass interchange. Reduction in cover of forest and grassland increased ISC in the sub-catchment which reduced infiltration and increased stream flow and erosion within the catchment and river banks.

The flow of Motoine/Ngong River is variable between seasons and from 1976 to 2012. The dry season flow is low; recording zero at the Ngong Road Bridge sampling point, while wet season flow was as high as 82,944 m^3/day at Kangundo Road Bridge. Average flow at Motoine swamp outlet was 78 m^3/day. However rain season flow was lower as compared to the dry season flow because of dumping of waste soil on the swamp. The water issues from permanent springs at the Thogoto forest. Ngong Road Bridge had no flow during the dry season because of impounding of the Motoine stream by the Upper and Lower dams located in the Ngong Road forest. Wet season flow does not overflow the banks of the Motoine river. Average flow of Ngong river at Njiru Bridge was 82,944 m^3/day. The water overflows its banks of about 10.5 m wide to cover a wide area of the valley up to 58.5 m as indicated by flood marks. The height of floods reaches 1.4 m as shown by flood marks on tree trunks and banana stems.

Gully erosion was severe in 1976 because much of the catchment was bare (57%) and low rainfall received that year, 713mm and the previous years. Gullies ranged from 1m to 2 m deep. The volume of soil lost from two gullies whose parameters were measured was 83,700 m^3 and 73,340 m^3. The river channel apparently narrows during dry months as sedimentation occurs and vegetation colonizes the sediments. These are washed away by flash floods. Measurements of the river channel showed no channel widening. However river bank erosion was evident particularly during the rainy season. This was indicated by the presence of turbid flow in the channel, undercutting of the outer banks of rivers, cavities at the middle and lower parts of the river banks, tension cracks, slab failure and basal cleanout.

Sediment discharge of the Motoine/Ngong River increases downstream. The total suspended solids discharged through the river were approximately 260.058 tons/year near Kangundo Road Bridge at Njiru. The sources of the suspended solids in the river are erosion of soils from the catchment and river banks. The upstream side of Motoine river has clear water during the dry season. Wet season flow of the Motoine river is turbid because of sediments. River flow from the Jamhuri Park was very clear but got highly polluted at Kibera. Water was black at Njiru during the dry season. The TSS was lowest at the Motoine swamp outlet and Ngong Road Bridge because much of this part of the catchment was covered by forest with low rates of erosion. TSS was highest at the Nairobi dam inlet because of heavy pollution from Kibera slums.

The geomorphology of the Motoine/Ngong river varies along its course from the source at Thogoto springs to its confluence with Nairobi river. Upstream from the source no significant landforms were observed. At the Ngong road bridge meanders started developing with low cliffs and slip-off slopes. Sedimentation also occurred from the river banks due to reduction in flow competence during the dry season. At the swamp inlet river bed outcrop rocks, meanders, slip-off slopes and cliffs were observed. Around the Kangundo road bridge both erosional and depositional land forms were observed. These were undercut banks and high river cliffs, tension cracks and slab failures, collapse of river banks, river bank cavities, meandering channel, relatively wide slip-off slopes and gravel-bed channel braids. The bars that formed along the river course had no vegetation on them, an indication that the channel is highly unstable.

5.3 Conclusions

The findings of the study indicate that there has been spatial change in land use over the years in the sub-catchment. This change was characterized by both increase and decrease over the years in the area of coverage of forest, grassland, bare ground and other vegetation land use patterns. Overall each of these patterns' coverage was lower in 2012 than in 1976, and together they cover 49.02% of the catchment. Built up area and road was the only pattern that recorded a steady increase from 1976 to 2012, and currently covers the remaining 50.98% of the catchment. This has increased the impervious surface cover in the catchment, which reduces infiltration capacity of the catchment while increasing surface runoff and stream flow leading to changes in the geomorphology of the river channel.

This study has shown that river bank erosion occurs along the Motoine/Ngong river channel. This is attributable more to increasing river discharge and discharge variability between seasons, associated with increasing impervious surface cover in the catchment, reduction in forest cover and grassland vegetation and the presence of erodible soils along the river banks than to the geology of the catchment. Erosion and flow variability have resulted to a sinuous channel morphology characterized by river cliffs, river bank cavities, collapsing overhanging banks, tension cracks, slip-off slopes and a braided river channel.

5.4 Recommendations

5.4.1 Recommendations to Policy Makers

a). Detention storage and infiltration of rainwater be undertaken to reduce rainwater surface run off and stream and sediment discharge and thereby increase sub-surface flow. This can be done through cover cropping, terracing of farms and rain water harvesting. There is need for construction companies to develop measures of controlling flow of sediments from construction sites while construction is underway.

b). There is need for heightened conservation measures for the remaining part of the Ngong Road Forest because it is under threat from the high demand for land for settlement and other urban developments.

c). Gabions be built along sections of the river whose banks are highly erodible so as to protect them from flash floods and undercutting during low stage flows. Planting trees seem to overload the banks and results to mass failure.

5.4.2 Recommendations for Further Research

To provide an in-depth understanding of the catchment, the following areas are recommended for further research:

a) To determine the rate of channel change and lateral shift of the Motoine/Ngong river channel.

b) Detailed study on the apparent increase and decrease of channel width between seasons.

c) Modeling of Motoine river channel from the Motoine swamp outlet, swamp near Nyumbani children’s home, along Dagoretti-Karen road and Lower dam in Ngong Road forest.

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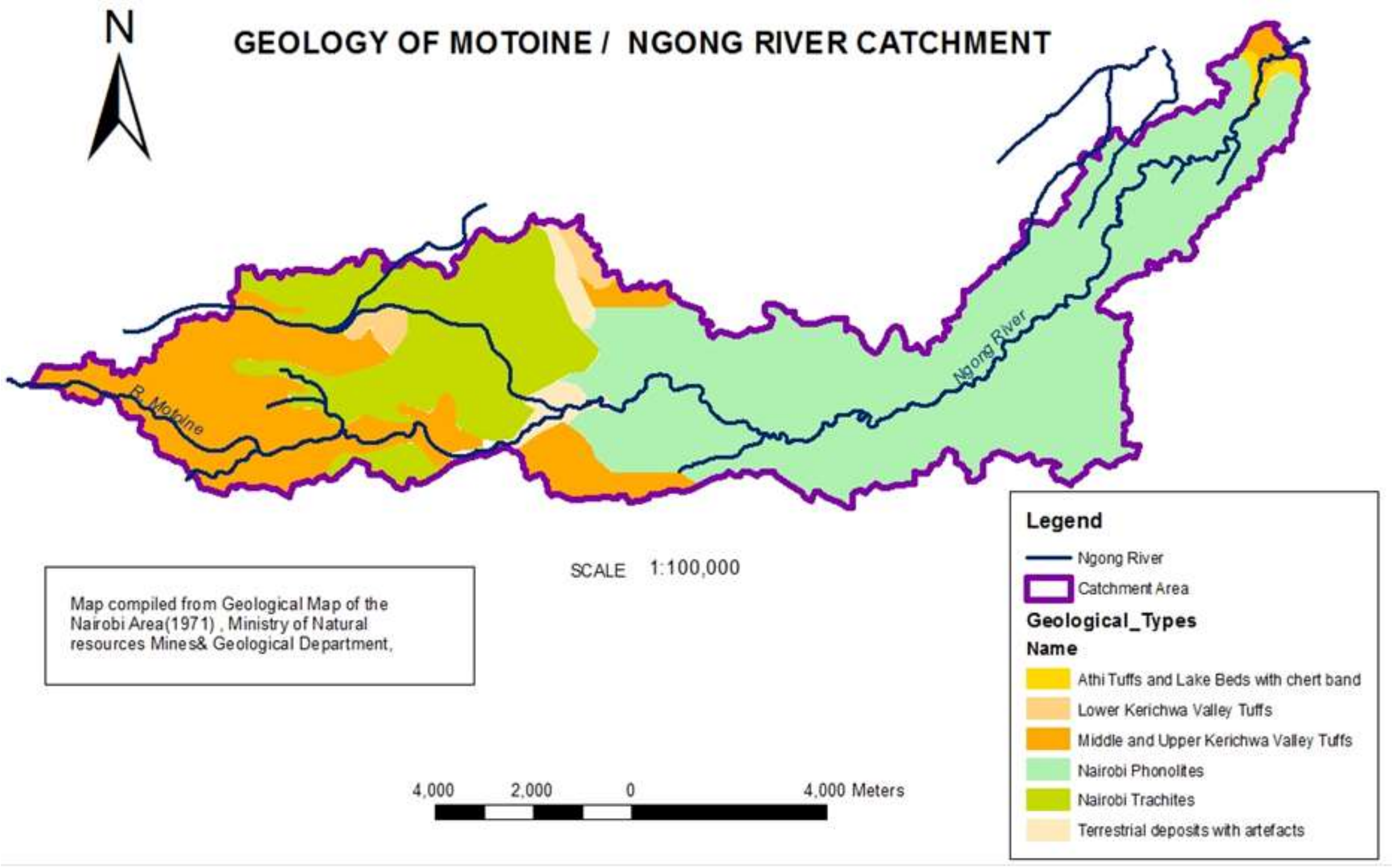
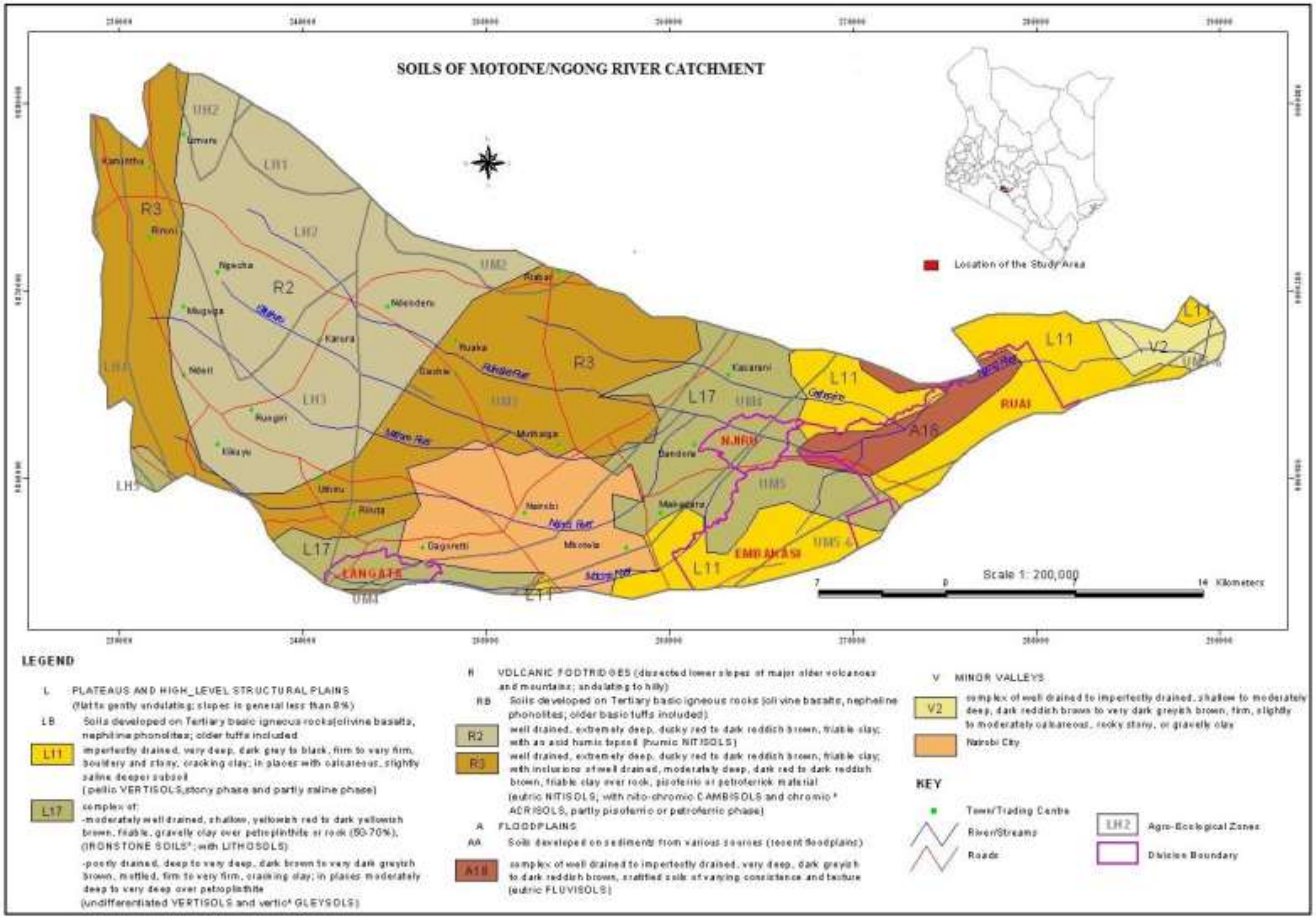
APPENDIX I: GEOLOGY OF THE STUDY AREA



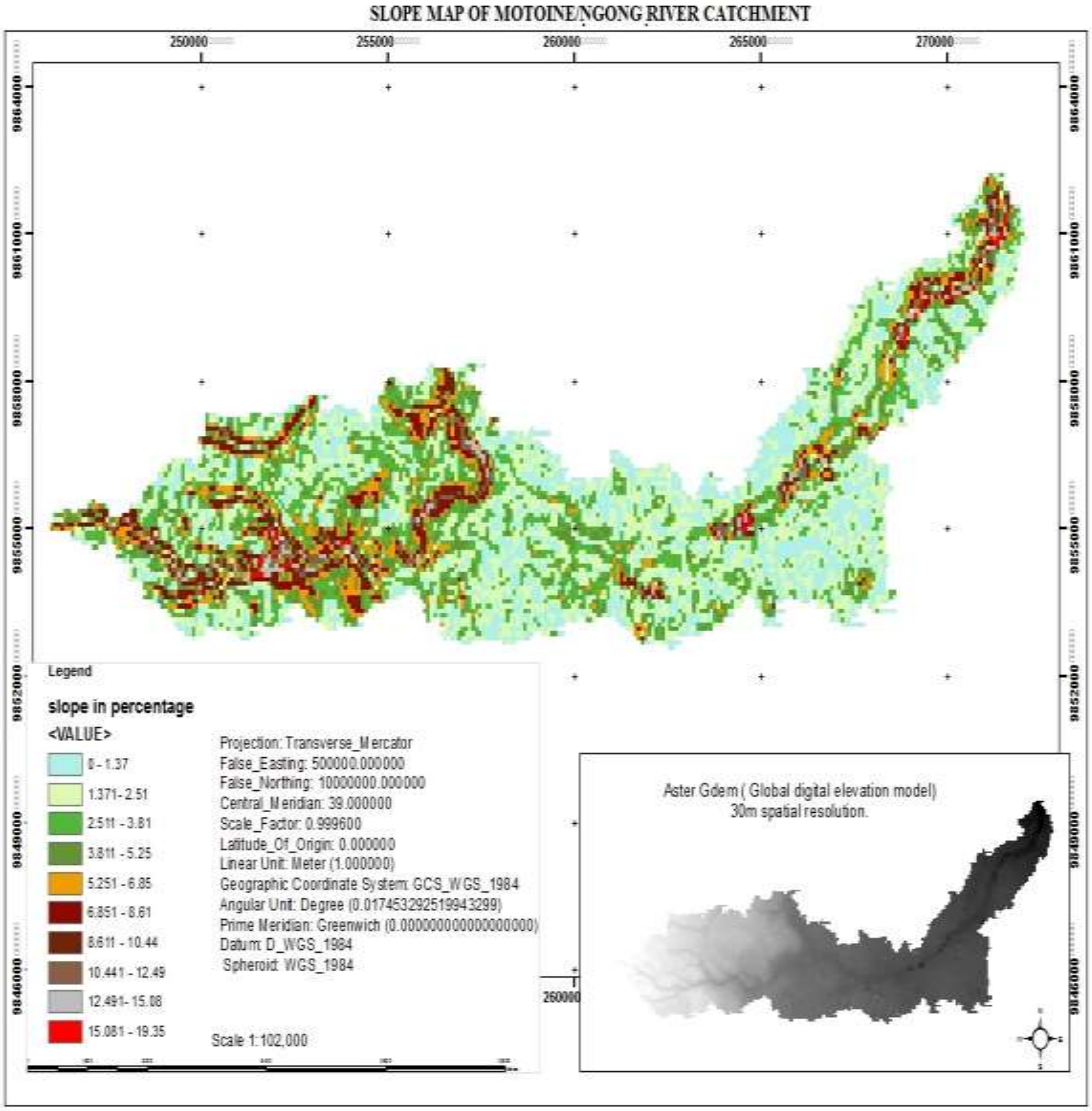
Source: Geology Department, UON, (2014)

APPENDIX II: SOILS OF THE MOTOINE/NGONG RIVER CATCHMENT



Source: Kenya Soil Survey, (2013)

APPENDIX III: SLOPE MAP (PERCENTAGE) OF MOTOINE/NGONG RIVER CATCHMENT.



Source: Department of Resource Surveys & Remote Sensing, (2013)

Note: A 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger.

APPENDIX IV: QUESTIONNAIRE

Alice K. Monene
Department of Geography and Environmental Studies
University of Nairobi
P.O. Box 30197
Nairobi.

10th July, 2013.

Dear Respondent

I am a postgraduate student of the University of Nairobi currently undertaking a Master of Arts Degree in Geography in the Department of Geography and Environmental Studies. My research topic is “Effects of Land Use Change on Stream Flow and Channel Erosion, and River Geomorphology: A case study of Motoine/Ngong River Catchment”. I kindly request you to respond to this questionnaire. Your responses will be held in confidence and used for academic purposes only.

Thank you in advance.

Questionnaire No………………………
Sampling Station………………………

PART A: Personal Details

Gender of Respondent:

Male ☐ Female ☐

Age:

Below 24 ☐ 25-34 ☐ 35- 44 ☐

45-54 ☐ 55-64 ☐ Above 65 ☐

Marital Status:

Married ☐ Widow/Widower ☐

Single ☐ Others ☐

Education Level:

Tertiary ☐ Secondary ☐

Primary ☐ None ☐

PART B: Socio-Economic and Land Use Data

1. Which year did you start farming in this area? ....
2. Do you own land? Yes ☐ No ☐
3. If yes, how big is it?

   Less than 0.5 hectare ☐ 0.5 ha ☐

   1 hectare ☐ More than 1 hectare ☐

4. How far is your farm from the river?

   Next to the river bank ☐ 100-200m ☐ 200-300m ☐

   300-400m ☐ Other ☐

5. How have you currently utilized your land?

   ....

   ....

   ....

   ....

6. Is this the same way you have utilized your farm even in the past years?

Yes ☐ No ☐

7. If the answer is no, what changes have you made as pertains to land use?
a) What cover/ land use has been phased out completely...........................
………………………………………………………………………………..
b) Give the land use whose acreage has been reduced over the years
………………………………………………………………………………
c) Give the land use whose acreage has increased over the years
………………………………………………………………………………
8. What is the portion of land that you have devoted to each one of the land uses mentioned above?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………………………………………………………
9. What was the land use/cover when you acquired the land/started farming on this land?
…………………………………………………………………………………………………
…………………………………………………………………………………………

PART B: Stream Flow and Erosion

1. Has the fertility of soils on your farm increased, reduced or has remained the same since you acquired the land/moved to this place?
………………………………………………………………………………
2. If it has decreased, what could be the reason(s)?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………...
....
3. Have there been any of the following incidences at the river bank/ in your farm/area?

Soil erosion ☐ Land sliding ☐ Caving in of land ☐

4. If yes, when did it/ does it occur?

………………………………………………………………………………………

5. What is the color of water:

a) During the wet season? ....

b) During the dry season? ....

6. What is the level of the water in the river during;

a) The rainy season?...

b) The dry season?...

7. Is this the same level the river used to get in the past years;

a) During the dry season? Yes ☐ No ☐

b) During the wet season? Yes ☐ No ☐

8. If no, What used to be the water level:

(a) During the dry season?………………………….............................

……………………………………………………………………………

(b) During the wet season?..

…………………………………………………………………………..

9. Has the river channel changed in any of the following ways since you came to this place?

Widening ☐ Narrowing ☐ Shifting ☐

Thank you for Responding to this Questionnaire.

APPENDIX V: OBSERVATION SCHEDULE

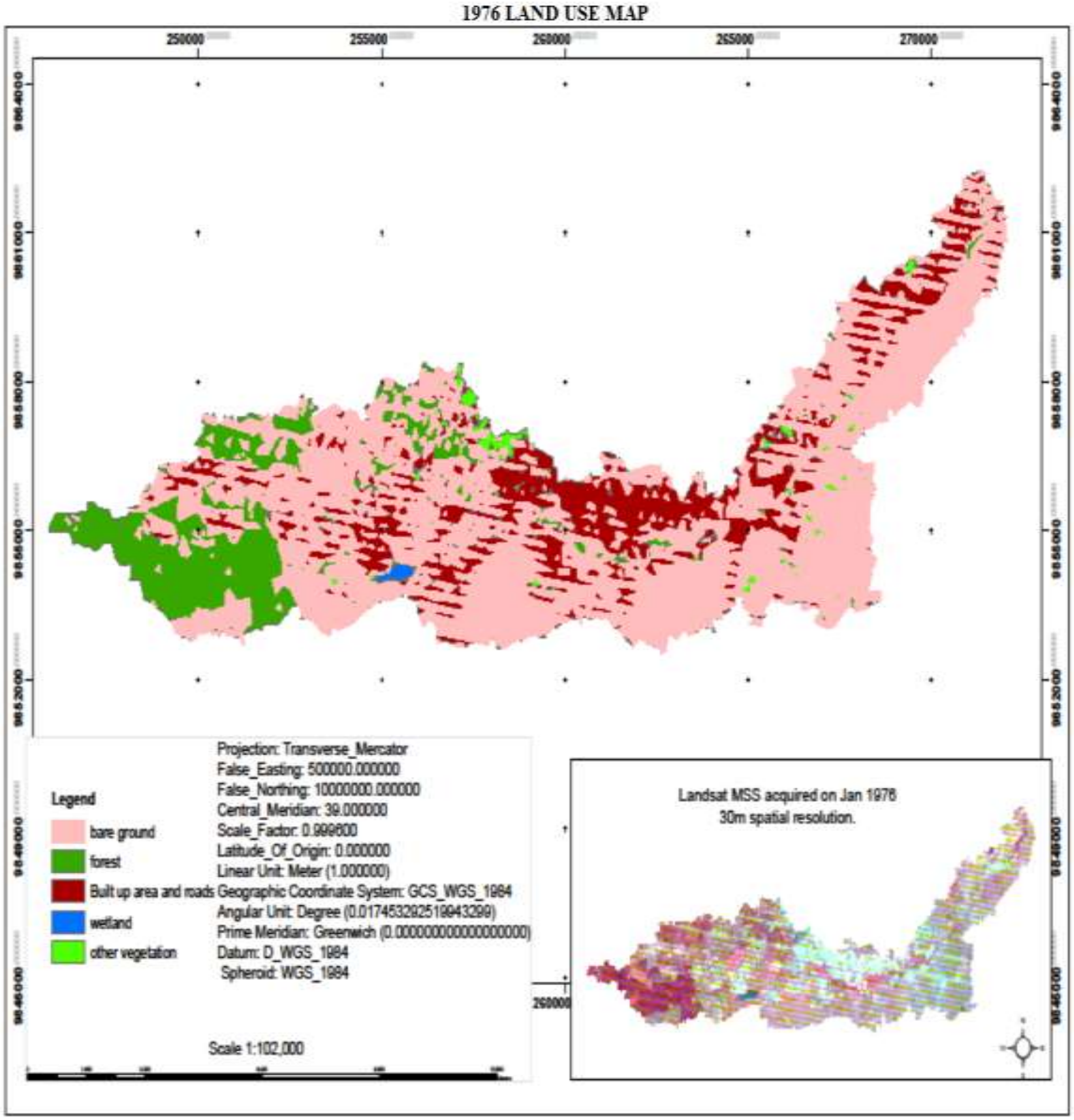
Date	Where observed	What to observe	Observation Comments
Sep 5th& Dec 17th, 2013.	At Motoine swamp outlet	-Land use	-Grass cover -Dumping of soil waste from construction sites
		-water level in the river	-river at the source with low flow
		-Flood marks	-No flood marks were observed
		-Channel widening	- channel is quite small wide about one foot, no evidence of channel widening
		-Channel shifting	-No clear evidence of channel shifting
		-Colour of the water	-Water is clear
		-Gully erosion	-No evidence of gully erosion
		-Other evidences of erosion	-No evidence of erosion

Sep 5th& Dec 17th, 2013.	Ngong Road Bridge	-Land use	-Forest cover -Bare loose soil
		-water level in the river	- dry river bed
		-Flood marks	- flood marks were observed
		-Channel widening	- channel is 5.1m wide, -there is evidence of channel widening
		-Channel meandering	-There is evidence of channel meandering
		-Colour of the water	-No water
		-Gully erosion	-No evidence of gully erosion
		-Other evidences of erosion	- accumulation of sediments at the bed

Sep 5th& Dec 17th, 2013.	Nairobi Dam inlet	-Land use	-Grass cover -Small vegetable plots -settlement
		-water level in the river	-river has low flow
		-Flood marks	-No flood marks were observed
		-Channel widening	- channel is 1.4m wide, -no evidence of channel widening
		-Channel meandering	-No clear evidence of channel meandering
		-Colour of the water	-Water is black in colour
		-Gully erosion	-No evidence of gully erosion
		-Other evidences of erosion	-sediments trapped by grass at the catchment

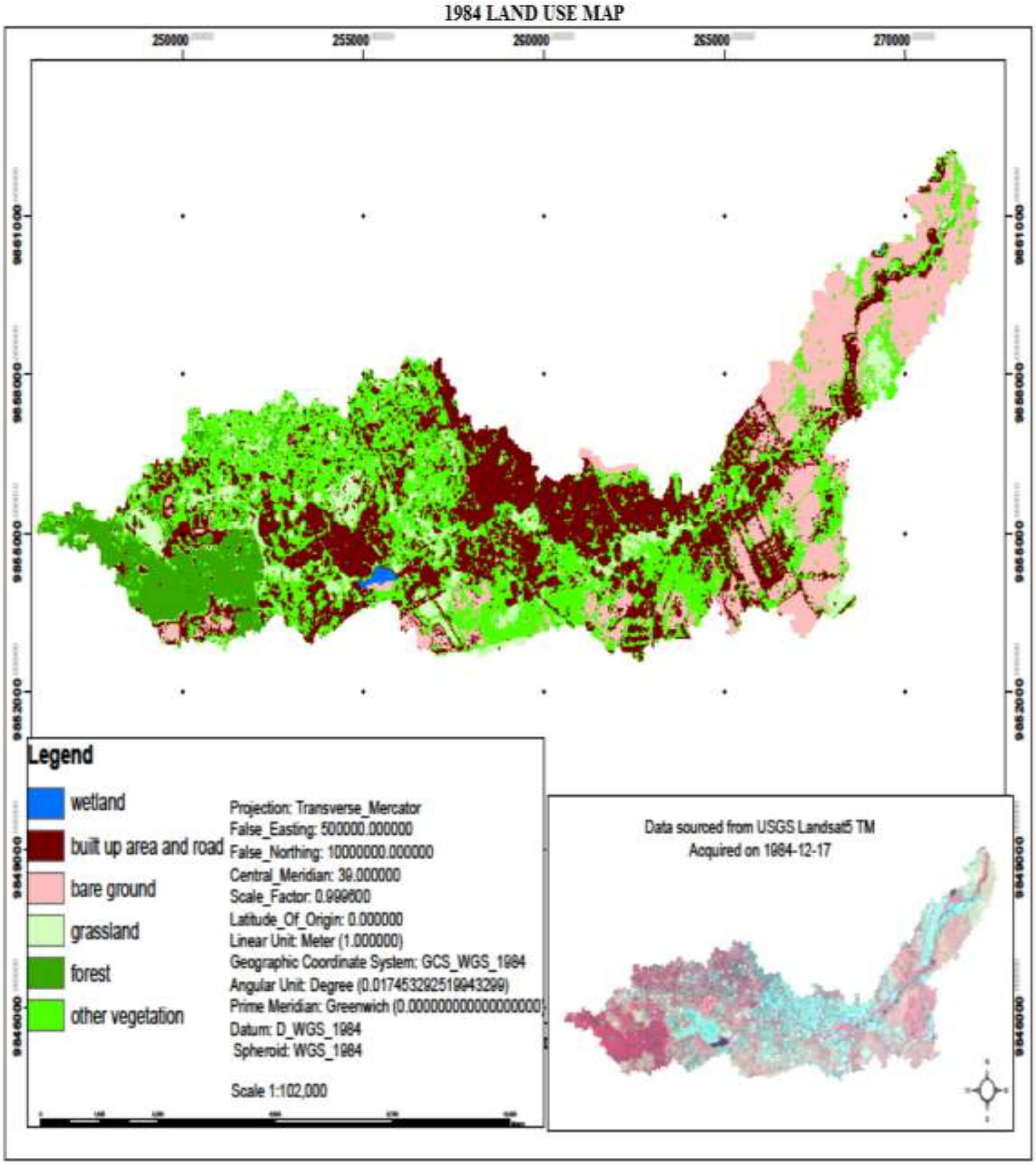
Sep 5th& Dec 17th, 2013.	Kangundo Road Bridge	-Land use	-Grass cover -farming -settlement
		-water level in the river	-river has dry season low flow, high wet weather flow.
		-Flood marks	- flood marks were observed 1.4m high on tree trunks and 58.5m wide
		-Channel widening	- channel is 4.9m wide, direct flow covers a width of 58.5m -clear evidence of channel widening.
		-Channel meandering	- clear evidence of channel meandering
		-Colour of the water	-Water is dark in colour in dry season & relatively clear in wet season
		-Gully erosion	-No evidence of gully erosion
		-Other evidences of erosion	-sedimentation at the inner banks, -cavities and undercutting of the river banks, -Land sliding and collapsing of banks -Channel braiding

APPENDIX VI: SATELLITE IMAGERIES ON LAND USE FOR 1976, 1984, 1995, 2002 and 2013.



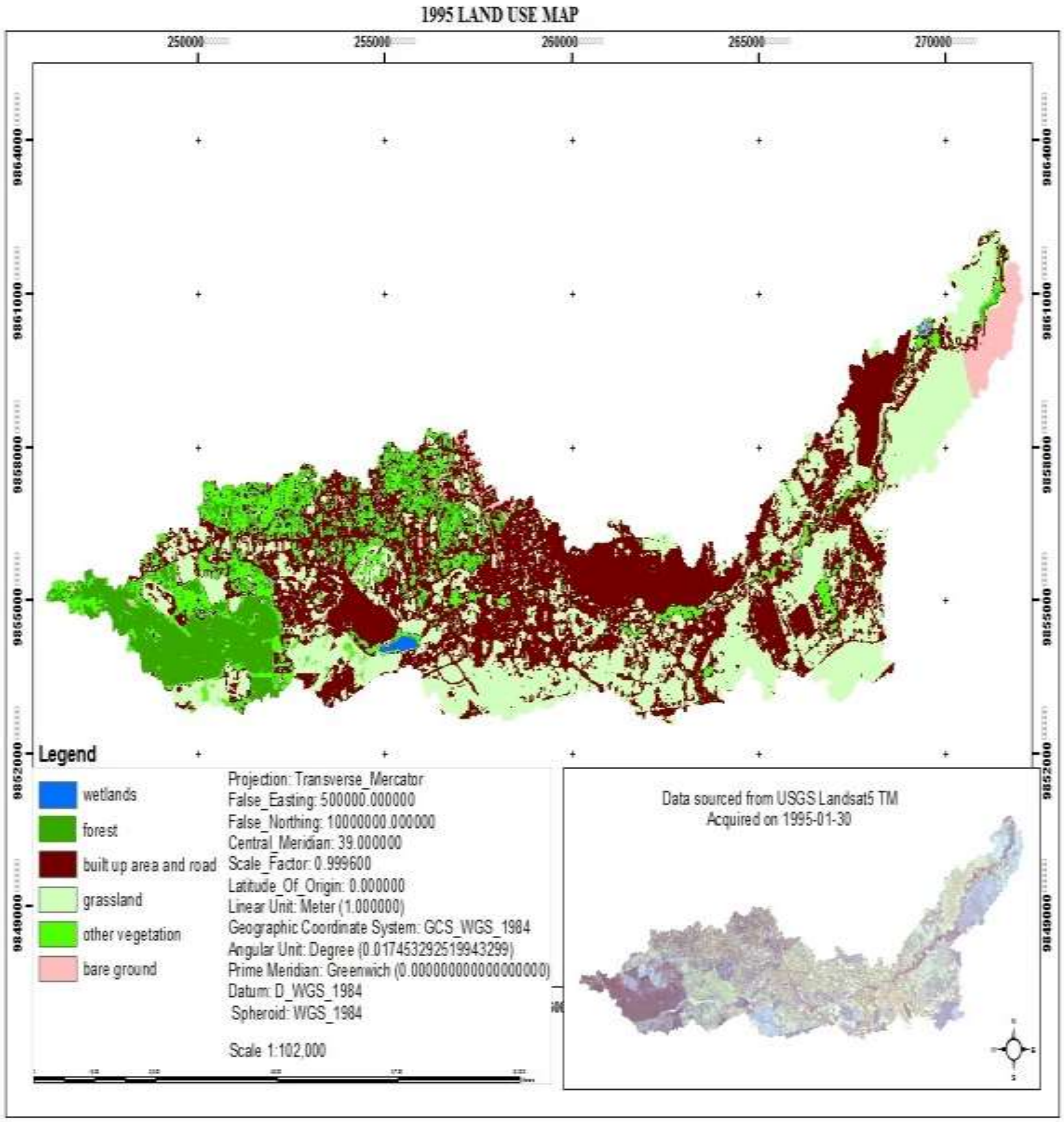
Land Use Satellite Image for 1976

Source: Department of Resource Surveys & Remote Sensing, (2013).



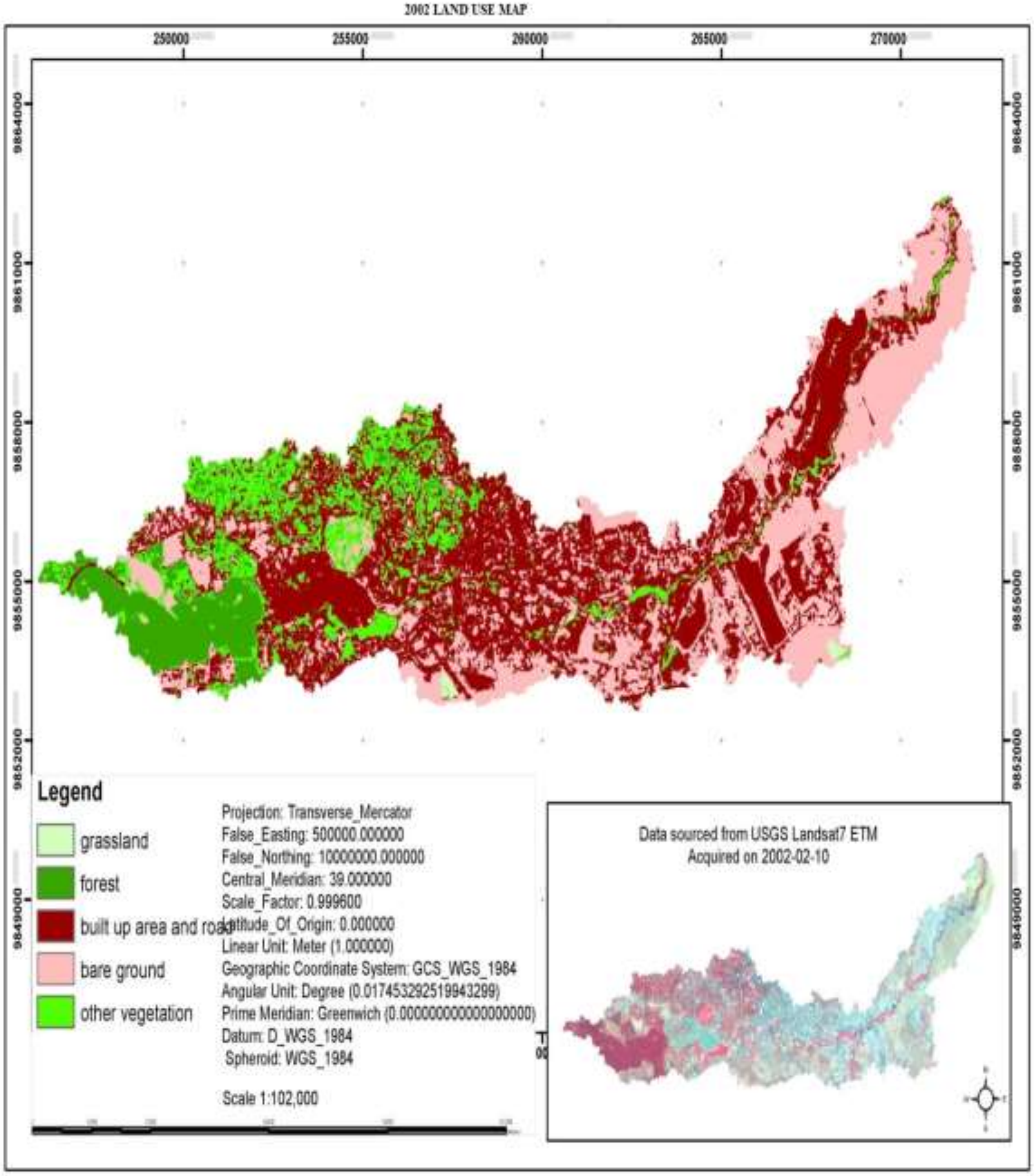
Land Use Satellite Image for 1984

Source: Department of Resource Surveys and Remote Sensing, (2013).



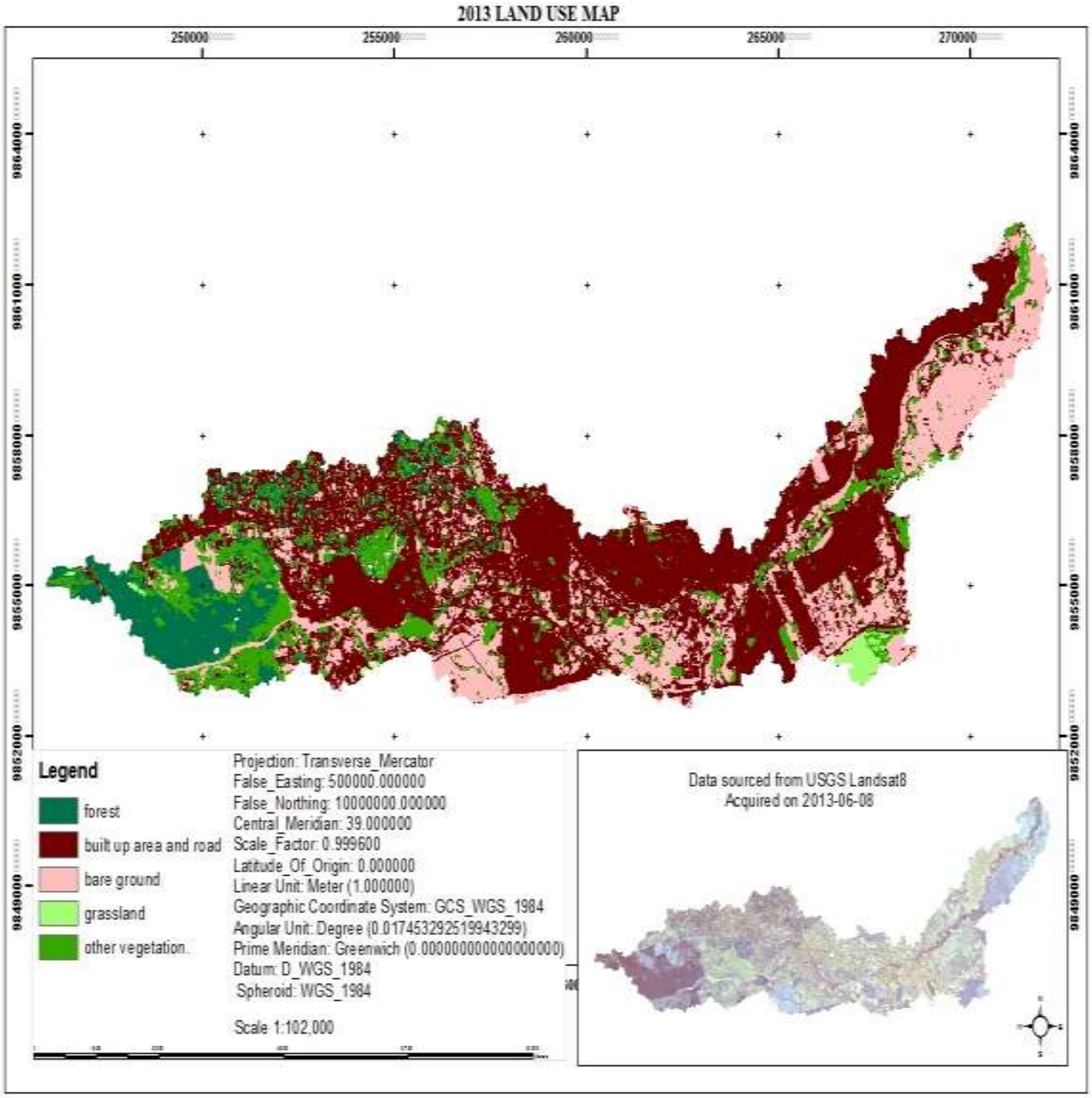
Land Use Satellite Image for 1995

Source: Department of Resource Surveys and Remote Sensing, (2013).



Land Use Satellite Image for 2002

Source: Department of Resource Surveys and Remote Sensing, (2013).



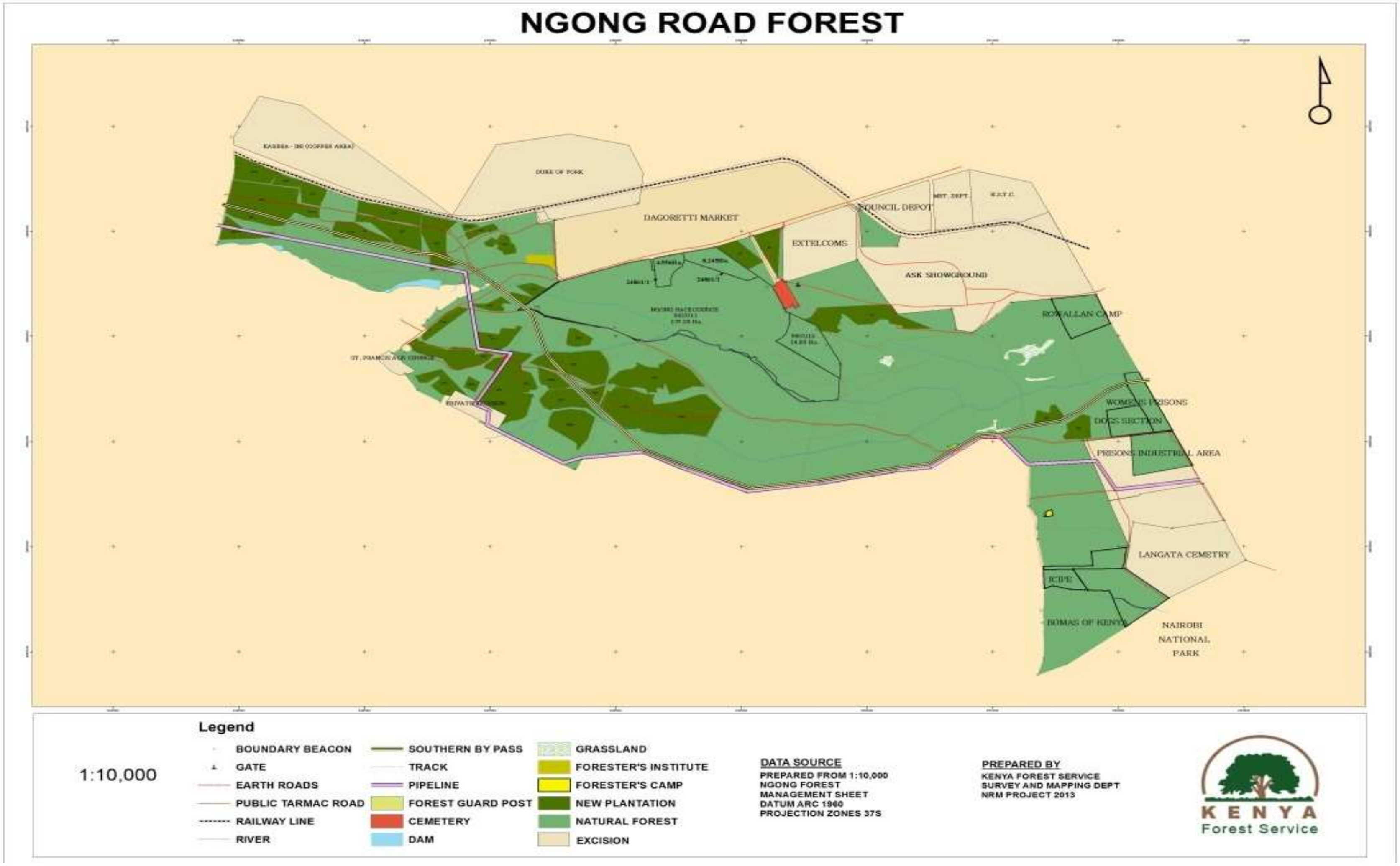
Land Use Satellite Image for 2013

Source: Department of Resource Surveys and Remote Sensing, (2013).

APPENDIX VII: LEGAL AMENDMENTS MADE OVER NGONG ROAD FOREST

1. Proclamation No. 46 of 1946 degazetting 2870 acres of Ngong Road Forest for addition into Royal National Park, currently Nairobi National Park.
2. Proclamation No. 70 of 1949 – degazetting 208 acres of Ngong Road Forest for establishment of Duke of York School.
3. Proclamation No. 21 of 1955 degazetting 124 acres of Ngong Road Forest for the establishment of Langata Cemetery.
4. Legal Notice No. 46 of 1965 degazetting 11.0 acres of Ngong Road Forest for the establishment of War Memorial Cemetery.
5. Legal Notice No. 18 of 1965 degazetting 65 acres of Ngong Road Forest for the establishment of Kenya Science Teachers Training College.
6. Legal Notice No. 35 of 1966 degazetting 23.24 acres of Ngong Road Forest for the establishment of Meteorological Department Headquarters.
7. Legal Notice No.24 of 1969 degazetting 43.5 acres of Ngong Road Forest for establishment of City Council Depot.
8. Legal Notice No. 208 of 1971 degazetting 118.4 hectares of Ngong Road Forest for the establishment of ASK Showground.

APPENDIX VIII: NGONG ROAD FOREST



Ngong Road Forest showing Areas of Excisions

Source: Kenya Forest Service, (2013

APPENDIX IX: DISCHARGE FOR NAIROBI AND MBAGATHI RIVERS 1970 AND 2012

Mean Monthly and Annual Discharges for (m^3/s) for Nairobi River (RGS 3BA 29) for 1970 and 2012.

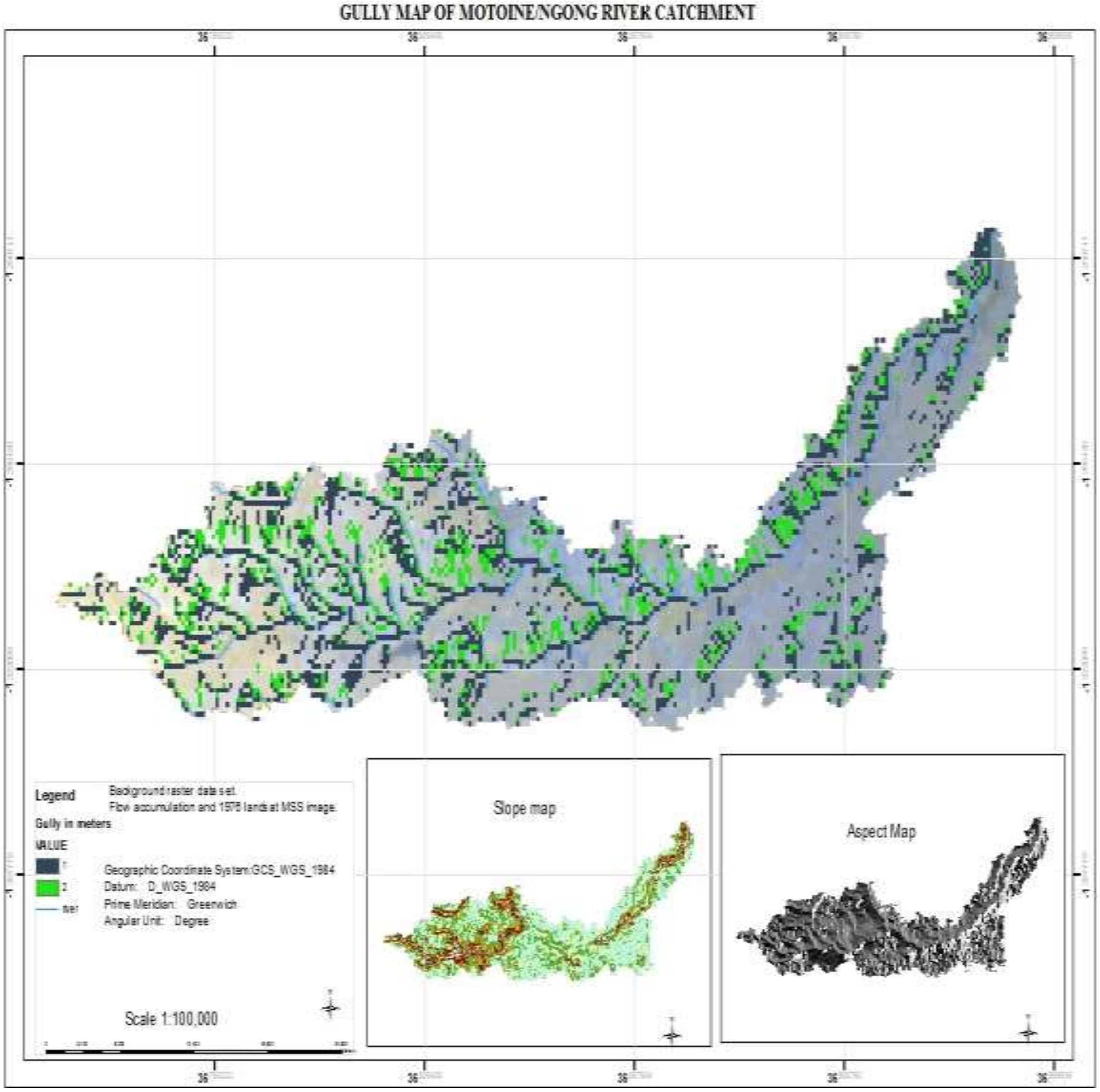
Year/Month	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1970	0.204	0.147	0.125	1.720	0.996	0.543	0.246	0.192	0.148	0.126	0.204	0.125	0.175
2012	0.673	0.617	0.422	8.180	4.512	1.205	1.604	2.172	1.762	0.171	1.124	5.006	2.287

Mean Monthly and Annual Discharges (m^3/s) for Mbagathi River (RGS 3AA04) for 1970 and 2012.

Year/Month	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1970	0.174	0.116	0.110	3.50	2.14	0.675	0.243	0.180	0.144	0.137	0.158	0.100	0.640
2012	0.092	0.226	0.359	2.199	0.173	0.179	0.727	0.602	0.223	0.248	0.376	0.503	0.492

Source: WRMA, (2013)

APPENDIX X: GULLY MAP OF MOTOINE/NGONG RIVER CATCHMENT



Gullies within the Motoine/Ngong River Catchment.

Source: Department of Resource Surveys and Remote Sensing, (2013).

This map shows the extent of gully erosion in the catchment in 1976. Blue color indicates gullies whose depth is 1m, while green represents gullies that are 2m deep.

APPENDIX XI: MONTHLY RAINFALL FROM 1976 TO 2012

Station Number: 9136164. Station Name: Dagoretti Corner

Year/Month	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
1976	22.7	42.3	31	98.7	85.9	46.3	18	18.3	61.1	13.3	177.6	97.4
1977	30.2	75	37.5	498.5	312.9	42.4	51.7	50.7	23.5	45.3	268.1	113.5
1978	143.5	34.2	298.9	257.7	36.8	8.5	11	64.9	15.4	133.6	125.9	128.9
1979	70.8	165.8	143.6	129.3	184	28.5	43.6	10.8	51.4	20.1	107.4	68.8
1980	91.9	13	37.9	105.9	531.5	27.2	2.1	17.3	25.2	250.6	250.6	33.5
1981	14.6	6	139.4	568.6	245.2	11.5	10.5	39.1	38.7	44.7		38
1982	0	19.4	61.7	214.3	218.1	35.9	27	8.5	34.1	151.8	235.1	163.7
1983	5.6	182.1	67.6	172.9	39.2	13.1	16.1	29.2	2.8	52.9	24.9	
1984	4.4	1	6.3	78.5	3.1	6.3	7.8	7.6	30.6	123.2	140.3	73.6
1985	0.1	92.7	131.9	232	72.7	21.6	27.6	5.9	16.1	33.6	111.7	78.5
1986	12.5	0	80.1	239.1	259.1	26.2	1.1	3.7	0.2	28.5	192.5	120.8
1987	44.5	11.8	50.7	327.5	94.3	75.7	1	10	15.1	1.5	157.4	32.1
1988	76	25.3	132.3	388.5	241.8	90.6	13.6	30	14.8	25.5	82.9	145.8
1989	110.2	47.4	80.2	264.7	257.8	28.3	37.9	23.6	52.4	60.4	114.9	204.6
1990	52.7	27.6	215.8	247.5	163.3	9.7	15.7	8.6	24.8		140	92.9
1991	12.3	0	94	148.4	253	23.2	2.8	40.2	3.9	31.6	182.7	125.8
1992	8	73.6	30.2	403	94.4	28.3	40.1	5.3	5.6	51.2	134.9	96.4
1993	275.1	151.8	29.1	25.1	95.2	46.6	1.4	11.9	0	45.4	101.2	108.2
1994	9.9	92.8	59.1	247	114.2	19.8	19.3	53.6	3.4	87.8	245.5	67.7
1995	15.1	116.8	168.2	109.7	210.3	31.3	11.8	15.8	29.2	116.5	95.2	33.2

1996	18.2	45.5	121.4	112.8	89.4	58.3	19.5	28.4	21.9	1.5	167.7	0
1997	1.3	0	0	427.8	132.8	4.9	5	15.3	0.5	155.7	383.8	196.1
1998	345.8	159.4	240.4	110.8	413.7	86.4	105.9	25.1	26	7.9	56.2	68.7
1999	17.6	0.5	185	174.1	25.8	4.4	4.9	61.2	15.9	22.4	286.7	183.7
2000	2.7	0	39.5	107.7	120.3	43.9	4.6	9.2	38.6	25.7	174.7	98
2001	430	31.7	292.6	145	108.9	106.9	25.4	17.6	27.6	35.5	158.7	13.3
2002	43	55.4	89.9	205.2	142.9	0.6	22.5	6.4	26.2	75.2	161.5	262.8
2003	52	15.7	28.6	232.9	247.5	37	2.2	12.3	44.2	70.9	167.4	17.2
2004	133.9	31.7	85.8	311.8	199.2		0.4		23.4		167.9	62
2005	102.8	39	62.9	162.8	243.2	16.5	16.6	12.1	0	45.7	114.4	0.2
2006	8.1	10.8	156.2	307.9	146.5	10.2	4.5	45.1	45	36.6	310.1	180.4
2007	41.7	217.8	63.6	350	168.8	99.9	348.2	78.8	95	70.5	118.1	34.7
2008	45	22.8	132.5	99.8	32.6	2.4	55.1	9	89.4	113.8	172.2	0.5
2009	64.5	20.1	37.9	79.3	158.1	101.5	13.2	3.6	9.1	98.2	79.4	121.1
2010	76.1	107.3	212.3	157.3	354.7	37.7	2.5	35.3	28.9	99.2	109.9	65.1
2011	14.2	125.8	128.5	49.4	85.1	125.8	8.7	41.8	31.8	132.6	162.3	129.2
2012	0	9	5.5	469.1	255.3	25.6	8.6	88.1	11.5	62.8	278	261.7

Source: Meteorological Department, (2013).

APPENDIX XII: ANNUAL AND MEAN MONTHLY RAINFALL FOR DAGORETTI CORNER METEOROLOGICAL STATION.

YEAR	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1892	1993
Annual Rainfall (mm)	713	1549	1259	1024	1386	1156	1170	606	483	824	964	822	1267	1282	999	918	971	891

1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1020	953	684	1323	1646	982	665	1393	1092	928	1016	816	1261	1687	775	786	1286	1035	1475

Source: Meteorological Department, (2013)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual Rainfall
Average Rainfall (mm)	64.78	55.98	102.11	223.26	173.99	38.42	27.24	26.23	26.58	67.76	165.49	97.73	1069.57

Source: Meteorological Department, (2013)

APPENDIX XIII: MOTOINE/NGONG RIVER DISCHARGE (m3/s) AT FOUR GAUGING STATIONS. (Drainage Area 3BA)

WATER RESOURCES MANAGEMENT AUTHORITY

SURFACE WATER SECTION

CURRENT METER GAUGING (*MID-SECTION METHOD)*

NAME OF OBSERVER		Justus Mwaura		***DATE***	**5/9/2013**		
RIVER	**MOTOINE**	***DRAINAGE AREA***	3BA		***STATION*** (See Notes)		Misc
METHOD (Strike out where not applicable): Wading, boat, cableway, bridge (down or up-stream face)							Wading
METER: Make	***SEBA***	W.D.D. No.	***Prop. No.***	1	***Weight***		***Kg***
Time of starting	12.30	***Time of Finishing***	12.50	***Initial Point***	WERB		
GAUGE HEIGHT: at Start		***at Finish***		***MEAN***			
	NOTES	Discharge taken at Line Saba area before it enters the Nairobi Dam					
		37M 025450 UTM 9854120 Alt 1694m					

MEANS AND TOTALS

AREA	sq. m.	MEAN VEL.	m/sec	G.Ht	DISCHARGE

Distance from Initial	Depth	Width	Area	Discharge	Velocity		Time Secs.	Revs	Depth of Observa-tion from	Remarks
					Mean in vertical	At Point				
1.70	0.00	0.00	0.000	0.0000	0.0000	0.0000	30	0		WERB
1.50	0.12	0.20	0.024	0.0021	0.0884	0.1040	30	18	SV	
1.30	0.17	0.20	0.034	0.0110	0.3226	0.3795	30	73	SV	
1.10	0.15	0.20	0.030	0.0114	0.3794	0.4464	30	86	SV	
0.90	0.20	0.20	0.040	0.0140	0.3488	0.4104	30	79	SV	
0.70	0.22	0.20	0.044	0.0180	0.4100	0.4824	30	93	SV	
0.50	0.27	0.20	0.054	0.0155	0.2876	0.3384	30	65	SV	
0.30	0.27	0.20	0.054	0.0085	0.1575	0.1853	30	35	SV	WELB
TOTAL			**0.280**	**0.0805**	**M^3/S**					

NB Co-ordinate at Motoine source at Thogoto forest 37M 0242157 UTM 9857007. A discharge of 0.00103m3/s was recorded.

The measured width of the water course from bank to bank is 0.3 metres.

WATER RESOURCES MANAGEMENT AUTHORITY

SURFACE WATER SECTION

CURRENT METER GAUGING (*MID-SECTION METHOD)*

NAME OF OBSERVER	Justus Mwaura		***DATE***	**5/9/2013**		
RIVER	NGONG	***DRAINAGE AREA***	3BA	***STATION*** (See Notes)		Misc
METHOD (Strike out where not applicable): Wading, boat, cableway, bridge (down or up-stream face)						Wading
METER: Make	***SEBA***	W.D.D. No.	***Prop. No.***	1	***Weight***	***Kg***
Time of starting	10.10AM	***Time of Finishing***	10.40AM	***Initial Point***	WELB	
GAUGE HEIGHT: at Start		***at Finish***		***MEAN***		
NOTES	Discharge taken 100m upstream Kangundo road bridge near Njiru town					
	37M 0271396 UTM 9861765 Alt 1530 m					

MEANS AND TOTALS

AREA	sq. m.	MEAN VEL.	m/sec	G.Ht	DISCHARGE	

Distance from Initial	Depth	Width	Area	Discharge	Velocity		Time Secs.	Revs	Depth of Observa-tion from	Remarks
					Mean in vertical	At Point				
0.10	0.00	0.00	0.000	0.0000	0.0000	0.0000	30	0		WELB
0.30	0.20	0.10	0.020	0.0046	0.2308	0.2715	30	52	SV	
0.70	0.30	0.40	0.120	0.0579	0.4824	0.4824	30	93	0.6	
1.10	0.40	0.40	0.160	0.0788	0.4927	0.4927	30	95	0.6	
1.50	0.40	0.40	0.160	0.0879	0.5493	0.5493	30	106	0.6	
1.90	0.36	0.40	0.144	0.0776	0.5390	0.5390	30	104	0.6	
2.30	0.28	0.40	0.112	0.0298	0.2663	0.2663	30	51	0.6	
2.70	0.27	0.40	0.108	0.0538	0.4978	0.4978	30	96	0.6	
3.10	0.27	0.40	0.108	0.0518	0.4800	0.5647	30	109	SV	
3.50	0.21	0.40	0.084	0.0418	0.4975	0.5853	30	113	SV	
3.90	0.19	0.40	0.076	0.0302	0.3969	0.4670	30	90	SV	
4.30	0.13	0.40	0.052	0.0165	0.3182	0.3744	30	72	SV	
4.60	0.09	0.30	0.027	0.0073	0.2701	0.3178	30	61	SV	
4.80	0.05	0.20	0.010	0.0014	0.1372	0.1614	30	30	SV	
5.00	0.00	0.20	0.000	0.0000	0.0000	0.0000	0	0	SV	WERB
TOTAL			**1.181**	**0.5394**	**M^3/S**					

WATER RESOURCES MANAGEMENT AUTHORITY

SURFACE WATER SECTION

CURRENT METER GAUGING *(MID-SECTION METHOD)*

NAME OF OBSERVER	Justus Mwaura		***DATE***	**17/12/2013**		
RIVER	**Motoine**	***DRAINAGE AREA***	3BA	***STATION*** (See Notes)	MISC	
METHOD (Strike out where not applicable): Wading, boat, cableway, bridge (down or up-stream face)					Wading	
METER: Make	***SEBA***	W.D.D. No.	***Prop. No.***	1	***Weight***	***Kg***
Time of starting	2.39	***Time of Finishing***	2.45	***Initial Point***	WELB	
GAUGE HEIGHT: at Start		***at Finish***		***MEAN***		
	NOTES	Discharge taken at Ngong road bridge				
		X0271397 Y9861770				

MEANS AND TOTALS

AREA sq. m. MEAN VEL. m/sec G.Ht DISCHARGE

Distance from Initial	Depth	Width	Area	Discharge	Velocity Mean in vertical	 At Point	Time Secs.	Revs	Depth of Observa-tion from	Remarks
47.80	0.00	0.00	0.000	0.0000	0.0000	0.0000	30	0	SV	WELB
47.90	0.08	0.10	0.008	0.0023	0.2876	0.3384	30	65	SV	
48.10	0.09	0.20	0.018	0.0048	0.2657	0.3126	30	60	SV	
48.30	0.09	0.20	0.018	0.0000	0.0000	0.0000	30	0	SV	
48.50	0.08	0.20	0.016	0.0017	0.1087	0.1279	30	23	SV	
48.60	0.05	0.10	0.005	0.0015	0.3007	0.3538	30	68	SV	
48.70	0.02	0.00	0.000	0.0000	0.0966	0.1136	30	20	SV	
			0.065	**0.0103**	**M^3/S**					

WATER RESOURCES MANAGEMENT AUTHORITY

SURFACE WATER SECTION

CURRENT METER GAUGING (*MID-SECTION METHOD)*

NAME OF OBSERVER		Justus Mwaura		***DATE***	**17/12/2013**		
RIVER	**Motoine**	***DRAINAGE AREA***	3BA		***STATION*** (See Notes)		MISC
METHOD (Strike out where not applicable): Wading, boat, cableway, bridge (down or up-stream face)							Wading
METER: Make	***SEBA***	W.D.D. No.	***Prop. No.***	1	***Weight***		***Kg***
Time of starting	12.20	***Time of Finishing***	12.35	***Initial Point***	WELB		
GAUGE HEIGHT: at Start		***at Finish***		***MEAN***			
	NOTES	Discharge taken at Line Saba area before it enters the Nairobi Dam					

MEANS AND TOTALS

AREA sq. m. MEAN VEL. m/sec G.Ht DISCHARGE

Distance from Initial	Depth	Width	Area	Discharge	Velocity		Time Secs.	Revs	Depth of Observa-tion from	Remarks
					Mean in vertical	At Point				
46.80	0.00	0.00	0.000	0.0000	0.0000	0.0000	30	0	SV	WELB
46.90	0.15	0.10	0.015	0.0024	0.1616	0.1901	30	36	SV	
47.10	0.15	0.20	0.030	0.0064	0.2133	0.2509	30	48	SV	
47.40	0.23	0.20	0.046	0.0251	0.5456	0.6419	30	124	SV	
47.90	0.24	0.50	0.120	0.0165	0.1372	0.1614	30	30	SV	
48.10	0.22	0.20	0.044	0.0105	0.2395	0.2818	30	54	SV	
48.30	0.20	0.20	0.040	0.0136	0.3401	0.4001	30	77	SV	
48.50	0.15	0.20	0.030	0.0137	0.4581	0.5390	30	104	SV	
48.70	0.10	0.20	0.020	0.0088	0.4406	0.5184	30	100	SV	
48.80	0.00	0.00	0.000	0.0000	0.0000	0.0000	30	0	SV	WERB
			0.345	**0.0971**	**M^3/S**					

WATER RESOURCES MANAGEMENT AUTHORITY

SURFACE WATER SECTION

CURRENT METER GAUGING (*MID-SECTION METHOD)*

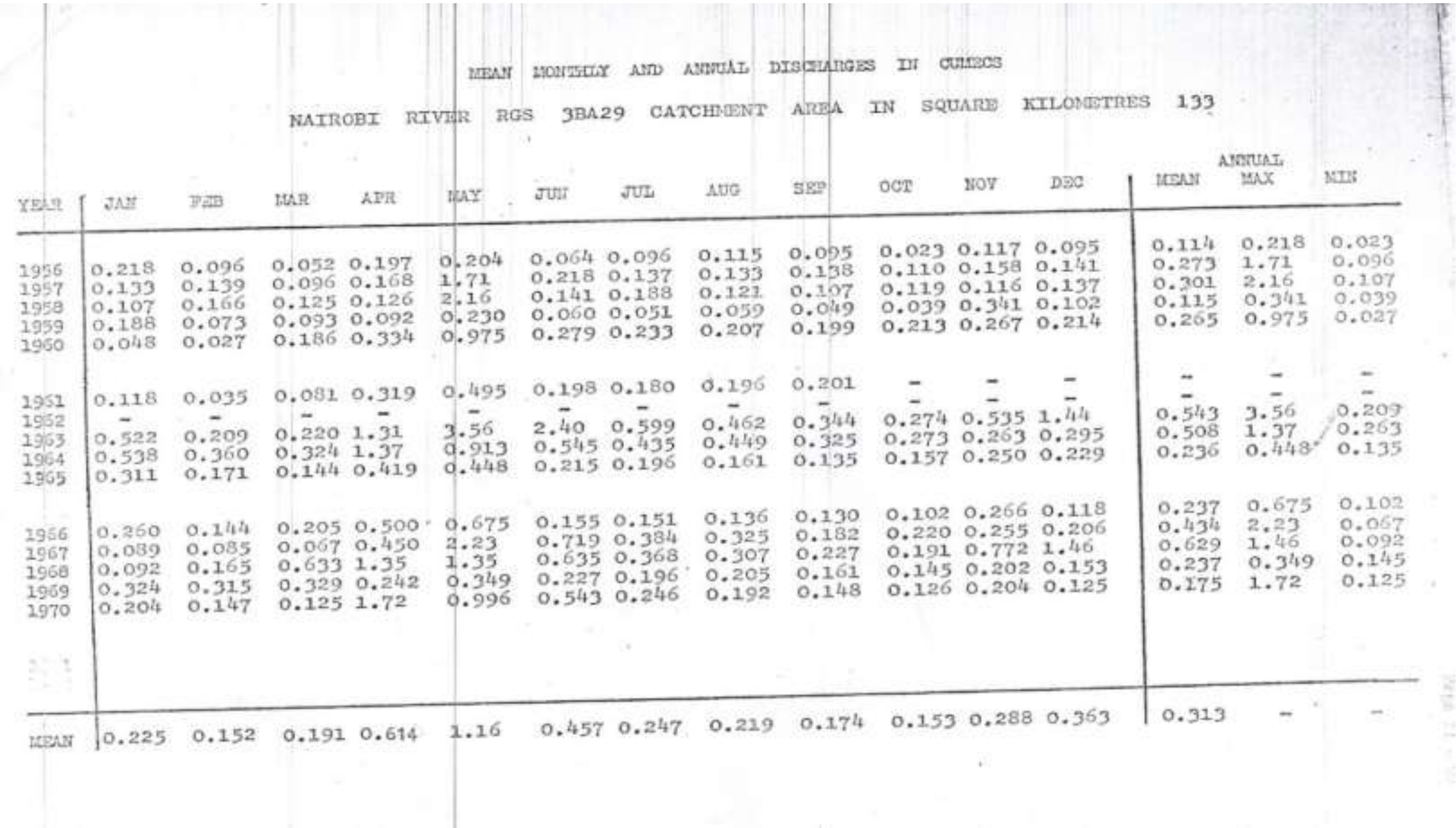
NAME OF OBSERVER	JUSTUS MWAURA			***DATE***	**17/12/2013**		
RIVER	**NGONG**	***DRAINAGE AREA***	3BA	***STATION*** (See Notes)	MISC		
METHOD (Strike out where not applicable): Wading, boat, cableway, bridge (down or up-stream face)					Wading		
METER: Make	***SEBA***	W.D.D. No.		***Prop. No.***	1	***Weight***	***Kg***
Time of starting	9.59	***Time of Finishing***	10.19	***Initial Point***	WERB		
GAUGE HEIGHT: at Start		***at Finish***		***MEAN***			
	NOTES	Discharge take appro. 100m upstream Kangundo road bridge.					
		X 0271395 Y 9861767					

MEANS AND TOTALS

AREA	sq. m.	MEAN VEL.	m/sec	G.Ht		DISCHARGE

Distance from Initial	Depth	Width	Area	Discharge	Velocity Mean in vertical	 At Point	Time Secs.	Revs	Depth of Observa-tion from	Remarks
43.30	0.00	0.00	0.000	0.0000	0.0000	0.0000	30	0		WELB
43.60	0.10	0.30	0.030	0.0034	0.1128	0.1327	30	24	SV	
44.00	0.12	0.50	0.060	0.0051	0.0844	0.0993	30	17	SV	
44.50	0.15	0.50	0.075	0.0088	0.1169	0.1375	30	25	SV	
45.00	0.22	0.50	0.110	0.0188	0.1710	0.1710	30	32	0.6	
45.50	0.27	0.50	0.135	0.0450	0.3332	0.3332	30	64	0.6	
46.00	0.33	0.50	0.165	0.0584	0.3538	0.3538	30	68	0.6	
46.50	0.42	0.50	0.210	0.1132	0.5390	0.5390	30	104	0.6	
47.00	0.54	0.50	0.270	0.1622	0.6007	0.6007	30	116	0.6	
47.50	0.57	0.50	0.285	0.1888	0.6624	0.6624	30	128	0.6	
48.00	0.69	0.50	0.345	0.2214	0.6419	0.6419	30	124	0.6	
48.50	0.66	0.50	0.330	0.2933	0.8888	0.8888	30	172	0.6	
49.00	0.45	0.50	0.225	0.1803	0.8013	0.8013	30	155	0.6	
49.40	0.33	0.40	0.132	0.0820	0.6213	0.6213	30	120	0.6	WERB
TOTAL			2.372	**1.3806**	**M^3/S**					

APPENDIX XIV: DISCHARGE FOR NAIROBI RIVER (RGS 3BA29) BETWEEN 1956 AND 1970



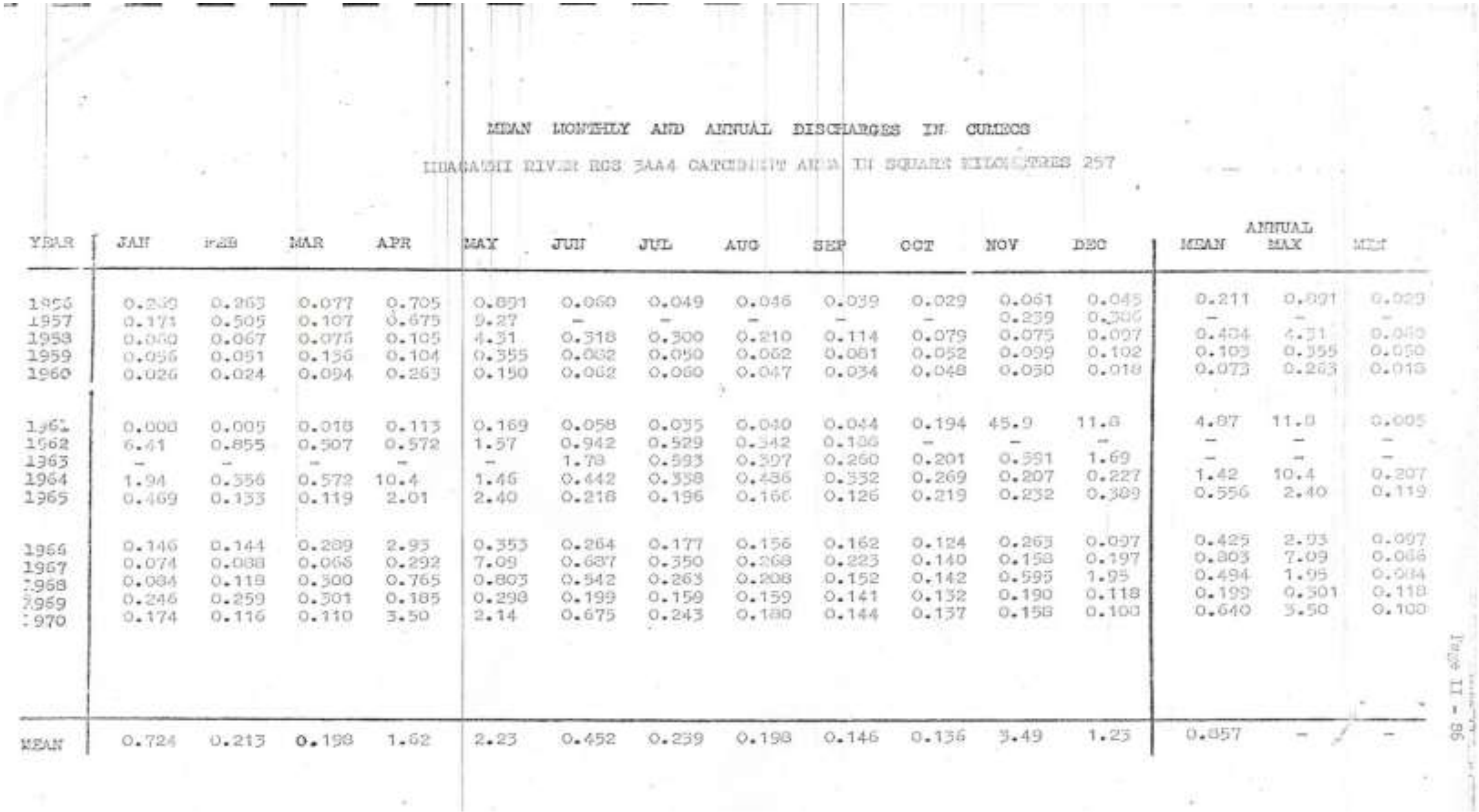
MEAN MONTHLY AND ANNUAL DISCHARGES IN CUMECS

NAIROBI RIVER RGS 3BA29 CATCHMENT AREA IN SQUARE KILOMETRES 133

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	ANNUAL MAX	ANNUAL MIN
1956	0.218	0.096	0.052	0.197	0.204	0.064	0.096	0.115	0.095	0.023	0.117	0.095	0.114	0.218	0.023
1957	0.133	0.139	0.096	0.168	1.71	0.218	0.137	0.133	0.138	0.110	0.158	0.141	0.273	1.71	0.096
1958	0.107	0.166	0.125	0.126	2.16	0.141	0.188	0.121	0.107	0.119	0.116	0.137	0.301	2.16	0.107
1959	0.188	0.073	0.093	0.092	0.230	0.060	0.051	0.059	0.049	0.039	0.341	0.102	0.115	0.341	0.039
1960	0.048	0.027	0.186	0.334	0.975	0.279	0.233	0.207	0.199	0.213	0.267	0.214	0.265	0.975	0.027
1961	0.118	0.035	0.081	0.319	0.495	0.198	0.180	0.196	0.201	-	-	-	-	-	-
1962	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1963	0.522	0.209	0.220	1.31	3.56	2.40	0.599	0.462	0.344	0.274	0.535	1.44	0.543	3.56	0.209
1964	0.538	0.360	0.324	1.37	0.913	0.545	0.435	0.449	0.325	0.273	0.263	0.295	0.508	1.37	0.263
1965	0.311	0.171	0.144	0.419	0.448	0.215	0.196	0.161	0.135	0.157	0.250	0.229	0.236	0.448	0.135
1966	0.260	0.144	0.205	0.500	0.675	0.155	0.151	0.136	0.130	0.102	0.266	0.118	0.237	0.675	0.102
1967	0.089	0.085	0.067	0.450	2.23	0.719	0.384	0.325	0.182	0.220	0.255	0.206	0.434	2.23	0.067
1968	0.092	0.165	0.633	1.35	1.35	0.635	0.368	0.307	0.227	0.191	0.772	1.46	0.629	1.46	0.092
1969	0.324	0.315	0.329	0.242	0.349	0.227	0.196	0.205	0.161	0.145	0.202	0.153	0.237	0.349	0.145
1970	0.204	0.147	0.125	1.72	0.996	0.543	0.246	0.192	0.148	0.126	0.204	0.125	0.175	1.72	0.125
MEAN	0.225	0.152	0.191	0.614	1.16	0.457	0.247	0.219	0.174	0.153	0.288	0.363	0.313	-	-

Source: National Water Master plan, (1992)

APPENDIX XV: DISCHARGE FOR MBAGATHI RIVER BETWEEN 1956 AND 1970.



MEAN MONTHLY AND ANNUAL DISCHARGES IN CUMECS

MBAGATHI RIVER RGS 3AA4 CATCHMENT AREA IN SQUARE KILOMETRES 257

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	ANNUAL MAX	ANNUAL MIN
1956	0.239	0.263	0.077	0.705	0.891	0.060	0.049	0.046	0.039	0.029	0.061	0.045	0.211	0.891	0.029
1957	0.171	0.505	0.107	0.675	9.27	–	–	–	–	–	0.239	0.306	–	–	–
1958	0.060	0.067	0.075	0.105	4.31	0.318	0.300	0.210	0.114	0.079	0.075	0.097	0.404	4.31	0.060
1959	0.056	0.051	0.156	0.104	0.355	0.082	0.050	0.062	0.081	0.052	0.099	0.102	0.103	0.355	0.050
1960	0.026	0.024	0.094	0.263	0.150	0.062	0.060	0.047	0.034	0.048	0.050	0.018	0.073	0.263	0.018
1961	0.008	0.005	0.018	0.113	0.169	0.058	0.035	0.040	0.044	0.194	45.9	11.8	4.87	11.8	0.005
1962	6.41	0.855	0.507	0.572	1.57	0.942	0.529	0.342	0.106	–	–	–	–	–	–
1963	–	–	–	–	–	1.78	0.593	0.397	0.260	0.201	0.591	1.69	–	–	–
1964	1.94	0.356	0.572	10.4	1.46	0.442	0.358	0.436	0.332	0.269	0.207	0.227	1.42	10.4	0.207
1965	0.469	0.133	0.119	2.01	2.40	0.218	0.196	0.166	0.126	0.219	0.232	0.389	0.556	2.40	0.119
1966	0.146	0.144	0.289	2.93	0.353	0.264	0.177	0.156	0.162	0.124	0.263	0.097	0.425	2.93	0.097
1967	0.074	0.088	0.066	0.292	7.09	0.687	0.350	0.268	0.223	0.140	0.158	0.197	0.803	7.09	0.066
1968	0.084	0.118	0.300	0.765	0.803	0.542	0.263	0.208	0.152	0.142	0.595	1.95	0.494	1.95	0.084
1969	0.246	0.259	0.301	0.185	0.298	0.199	0.159	0.159	0.141	0.132	0.190	0.118	0.199	0.301	0.118
1970	0.174	0.116	0.110	3.50	2.14	0.675	0.243	0.180	0.144	0.137	0.158	0.100	0.640	3.50	0.100
MEAN	0.724	0.213	0.198	1.62	2.23	0.452	0.239	0.198	0.146	0.136	3.49	1.23	0.857	–	–

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Source: National Water Master plan, (1992)

APPENDIX XVI: DISCHARGE FOR NAIROBI AND MBAGATHI RIVERS FROM 1960 TO 2013

Discharge for Mbagathi (RGS 3AA04) River

No.	**Date**	**Gauge Height (m)**	**Discharge (m^3/s)**
1	1/2/1960	-	0.0422
2	1/3/1974	-	0.0382
3	27/6/1974	-	0.1787
4	7/4/1976	-	0.0146
5	20/4/1976	-	0.0694
6	5/2/1985	-	0.0714
7	20/5/2010	-	2.1991
8	3/12/2010	-	0.33
9	28/2/2011	-	0.0206
10	16/8/2011	-	0.6023
11	8/12/2011	-	0.6754
12	27/1/2012	0.490	0.0923
13	24/4/2012	1.470	7.3428
14	30/5/2012	0.800	0.1728
15	31/7/2012	0.700	0.7267
16	3/9/2012	0.610	0.2229
18	27/3/2013	0.520	0.3593

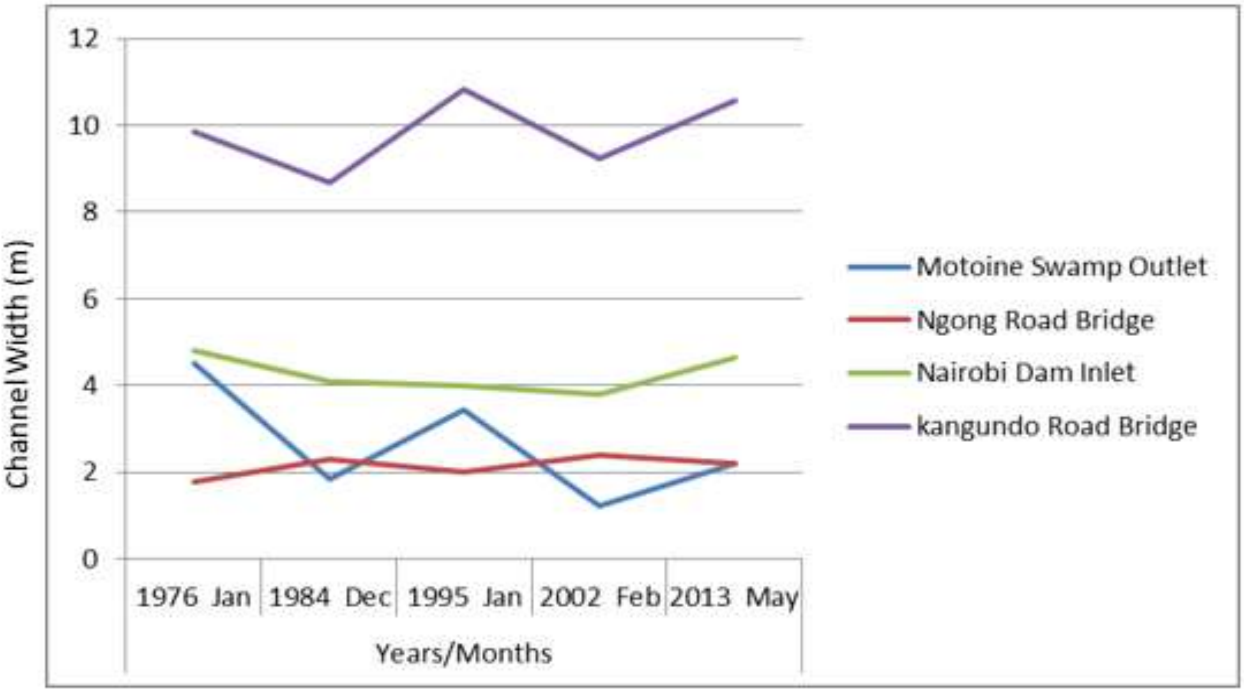
Source: Water Resources Management Authority, (2013).

Discharge for Nairobi River (Museum) RGS 3BA29

No.	Date	Discharge (m^3/s)
1	21/5/2010	0.8048
2	29/7/2010	1.6042
3	27/4/2011	0.8676
4	17/8/2011	1.3215
5	7/12/2011	5.0067
6	27/1/2012	0.673
7	27/3/2012	0.4223
8	25/4/2012	8.18
9	31/5/2012	4.5123
9	1/8/2012	2.1724
10	3/9/2012	1.7618
11	8/1/2013	0.0995
12	27/3/2013	1.1339

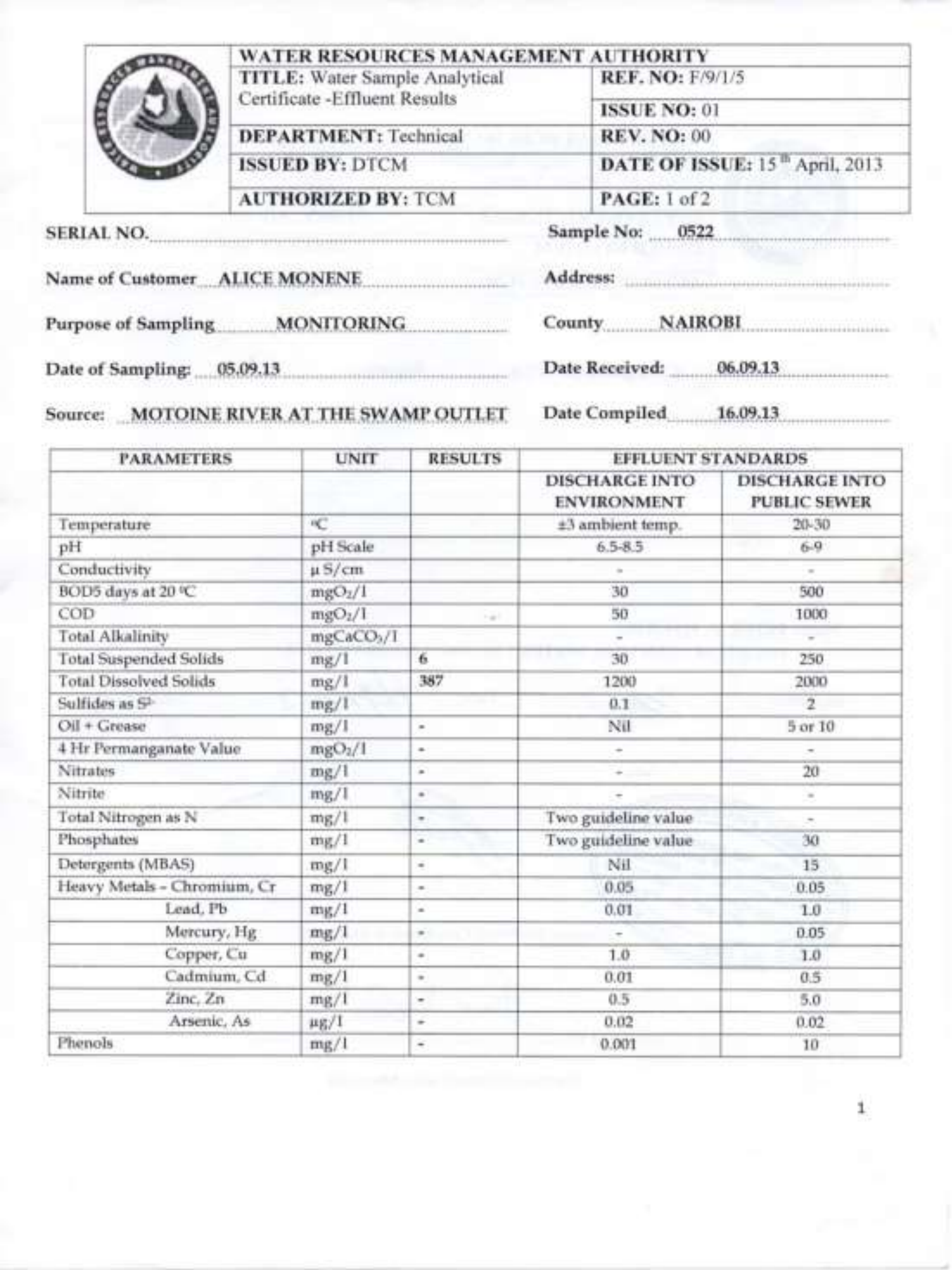
Source: Water Resources Management Authority, 2013

APPENDIX XVII: MOTOINE/NGONG RIVER CHANNEL WIDTHS AT FOUR SAMPLED POINTS FROM 1976 TO 2013



Source: Researcher, (2013).

APPENDIX XVIII: DRY SEASON LABORATORY RESULTS FOR WATER QUALITY ANALYSIS FOR MOTOINE/NGONG RIVER AT FOUR SAMPLING POINTS (Drainage Area 3BA).



WATER RESOURCES MANAGEMENT AUTHORITY	
TITLE: Water Sample Analytical Certificate -Effluent Results	**REF. NO:** F/9/1/5 **ISSUE NO:** 01
DEPARTMENT: Technical	**REV. NO:** 00
ISSUED BY: DTCM	**DATE OF ISSUE:** 15th April, 2013
AUTHORIZED BY: TCM	**PAGE:** 1 of 2

SERIAL NO.

Sample No: 0522

Name of Customer ALICE MONENE

Address:

Purpose of Sampling MONITORING

County NAIROBI

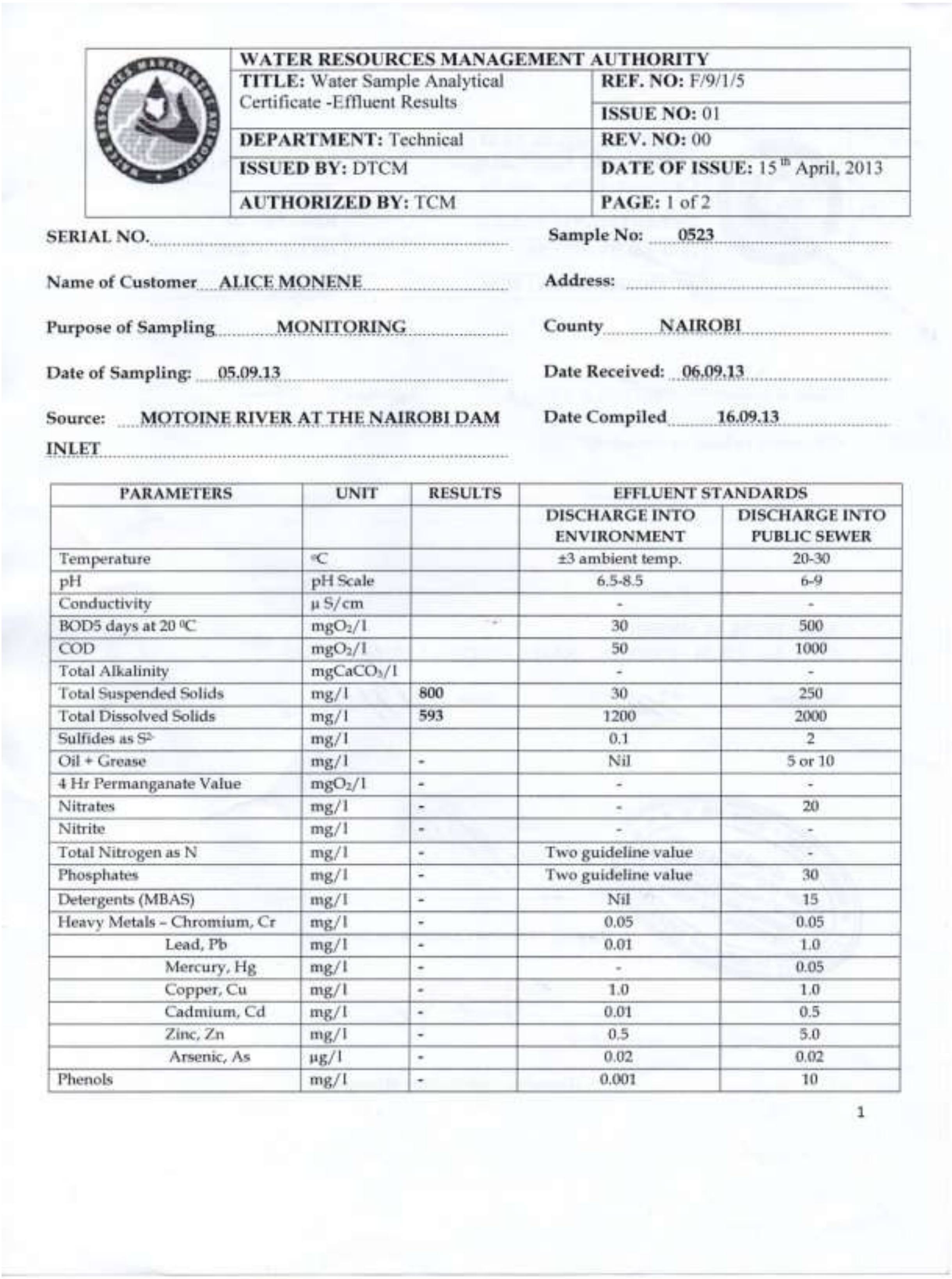
Date of Sampling: 05.09.13

Date Received: 06.09.13

Source: MOTOINE RIVER AT THE SWAMP OUTLET

Date Compiled 16.09.13

PARAMETERS	UNIT	RESULTS	EFFLUENT STANDARDS	
			DISCHARGE INTO ENVIRONMENT	DISCHARGE INTO PUBLIC SEWER
Temperature	°C		±3 ambient temp.	20-30
pH	pH Scale		6.5-8.5	6-9
Conductivity	µ S/cm		-	-
BOD5 days at 20 °C	mgO_2/l		30	500
COD	mgO_2/l		50	1000
Total Alkalinity	$mgCaCO_3/l$		-	-
Total Suspended Solids	mg/l	6	30	250
Total Dissolved Solids	mg/l	387	1200	2000
Sulfides as S^{2-}	mg/l		0.1	2
Oil + Grease	mg/l	-	Nil	5 or 10
4 Hr Permanganate Value	mgO_2/l	-	-	-
Nitrates	mg/l	-	-	20
Nitrite	mg/l	-	-	-
Total Nitrogen as N	mg/l	-	Two guideline value	-
Phosphates	mg/l	-	Two guideline value	30
Detergents (MBAS)	mg/l	-	Nil	15
Heavy Metals - Chromium, Cr	mg/l	-	0.05	0.05
Lead, Pb	mg/l	-	0.01	1.0
Mercury, Hg	mg/l	-	-	0.05
Copper, Cu	mg/l	-	1.0	1.0
Cadmium, Cd	mg/l	-	0.01	0.5
Zinc, Zn	mg/l	-	0.5	5.0
Arsenic, As	µg/l	-	0.02	0.02
Phenols	mg/l	-	0.001	10



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DEPARTMENT: Technical	**REV. NO:** 00
ISSUED BY: DTCM	**DATE OF ISSUE:** 15th April, 2013
AUTHORIZED BY: TCM	**PAGE:** 1 of 2

SERIAL NO. ……………………

Sample No: 0523

Name of Customer ALICE MONENE

Address: ……………………

Purpose of Sampling MONITORING

County NAIROBI

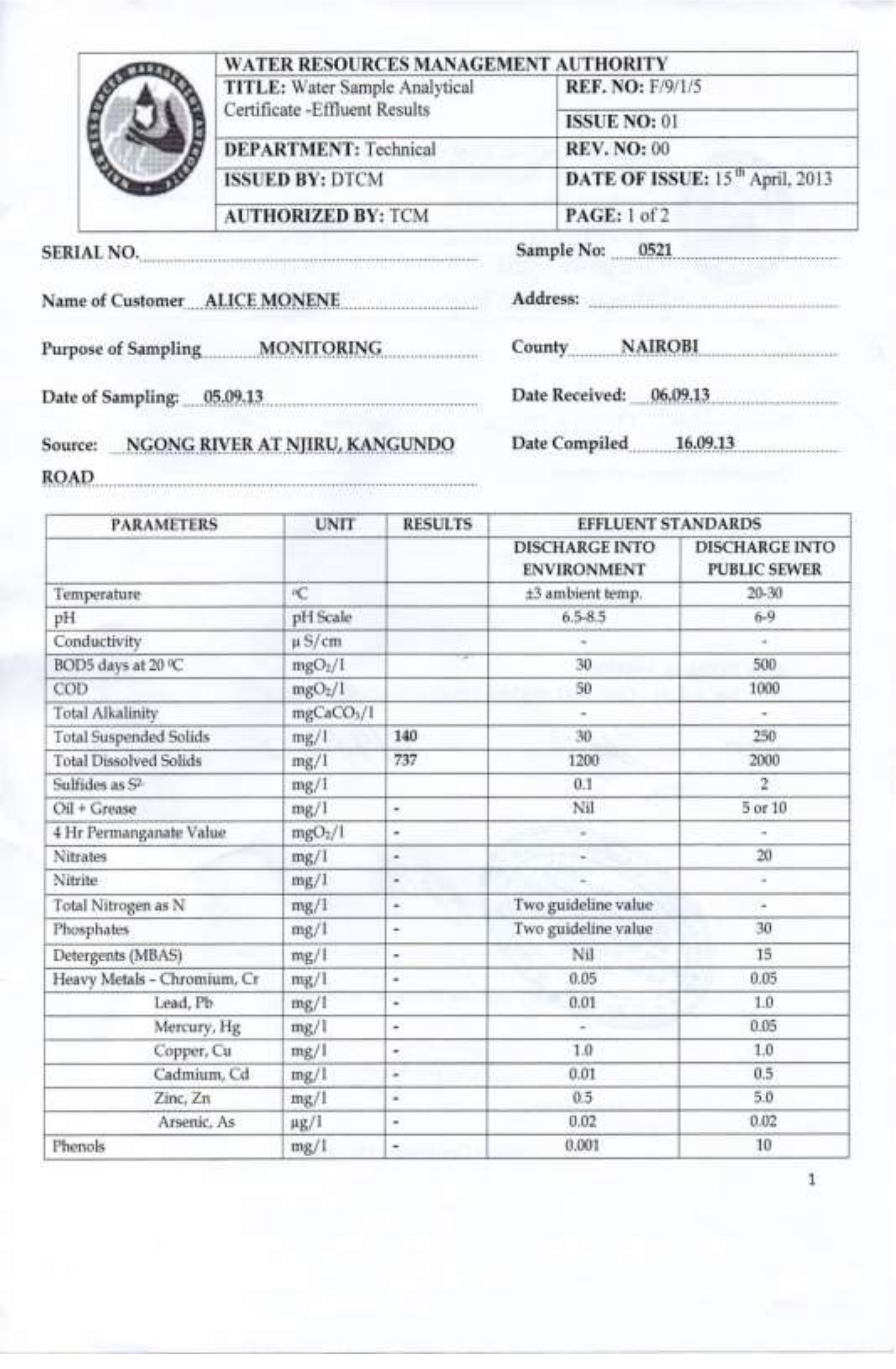
Date of Sampling: 05.09.13

Date Received: 06.09.13

Source: MOTOINE RIVER AT THE NAIROBI DAM INLET

Date Compiled 16.09.13

PARAMETERS	UNIT	RESULTS	EFFLUENT STANDARDS	
			DISCHARGE INTO ENVIRONMENT	DISCHARGE INTO PUBLIC SEWER
Temperature	°C		±3 ambient temp.	20-30
pH	pH Scale		6.5-8.5	6-9
Conductivity	µ S/cm		-	-
BOD5 days at 20 °C	mgO_2/l		30	500
COD	mgO_2/l		50	1000
Total Alkalinity	$mgCaCO_3/l$		-	-
Total Suspended Solids	mg/l	800	30	250
Total Dissolved Solids	mg/l	593	1200	2000
Sulfides as S^{2-}	mg/l		0.1	2
Oil + Grease	mg/l	-	Nil	5 or 10
4 Hr Permanganate Value	mgO_2/l	-	-	-
Nitrates	mg/l	-	-	20
Nitrite	mg/l	-	-	-
Total Nitrogen as N	mg/l	-	Two guideline value	-
Phosphates	mg/l	-	Two guideline value	30
Detergents (MBAS)	mg/l	-	Nil	15
Heavy Metals – Chromium, Cr	mg/l	-	0.05	0.05
Lead, Pb	mg/l	-	0.01	1.0
Mercury, Hg	mg/l	-	-	0.05
Copper, Cu	mg/l	-	1.0	1.0
Cadmium, Cd	mg/l	-	0.01	0.5
Zinc, Zn	mg/l	-	0.5	5.0
Arsenic, As	µg/l	-	0.02	0.02
Phenols	mg/l	-	0.001	10



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	TITLE: Water Sample Analytical Certificate -Effluent Results	**REF. NO:** F/9/1/5
		ISSUE NO: 01
	DEPARTMENT: Technical	**REV. NO:** 00
	ISSUED BY: DTCM	**DATE OF ISSUE:** 15th April, 2013
	AUTHORIZED BY: TCM	**PAGE:** 1 of 2

SERIAL NO.

Sample No: 0521

Name of Customer ALICE MONENE

Address:

Purpose of Sampling MONITORING

County NAIROBI

Date of Sampling: 05.09.13

Date Received: 06.09.13

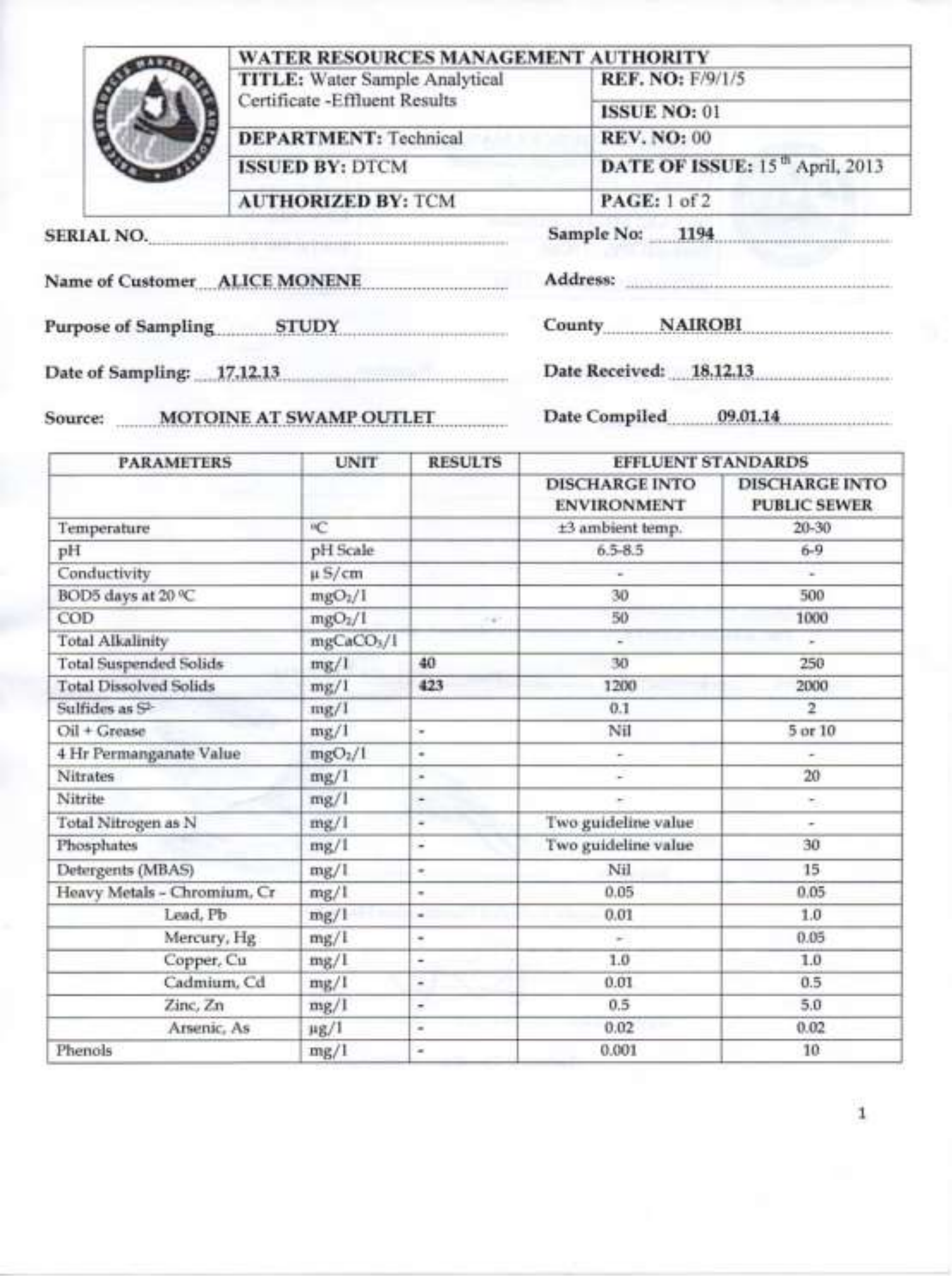
Source: NGONG RIVER AT NJIRU, KANGUNDO ROAD

Date Compiled 16.09.13

PARAMETERS	UNIT	RESULTS	EFFLUENT STANDARDS	
			DISCHARGE INTO ENVIRONMENT	DISCHARGE INTO PUBLIC SEWER
Temperature	°C		±3 ambient temp.	20-30
pH	pH Scale		6.5-8.5	6-9
Conductivity	µ S/cm		-	-
BOD5 days at 20 °C	mgO_2/l		30	500
COD	mgO_2/l		50	1000
Total Alkalinity	mg$CaCO_3$/l		-	-
Total Suspended Solids	mg/l	140	30	250
Total Dissolved Solids	mg/l	737	1200	2000
Sulfides as S^{2-}	mg/l		0.1	2
Oil + Grease	mg/l	-	Nil	5 or 10
4 Hr Permanganate Value	mgO_2/l	-	-	-
Nitrates	mg/l	-	-	20
Nitrite	mg/l	-	-	-
Total Nitrogen as N	mg/l	-	Two guideline value	-
Phosphates	mg/l	-	Two guideline value	30
Detergents (MBAS)	mg/l	-	Nil	15
Heavy Metals - Chromium, Cr	mg/l	-	0.05	0.05
Lead, Pb	mg/l	-	0.01	1.0
Mercury, Hg	mg/l	-	-	0.05
Copper, Cu	mg/l	-	1.0	1.0
Cadmium, Cd	mg/l	-	0.01	0.5
Zinc, Zn	mg/l	-	0.5	5.0
Arsenic, As	µg/l	-	0.02	0.02
Phenols	mg/l	-	0.001	10

1

APPENDIX XIX: WET SEASON LABORATORY RESULTS FOR WATER QUALITY ANALYSIS FOR MOTOINE/NGONG RIVER AT FOUR SAMPLING POINTS Drainage Area 3BA)



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	TITLE: Water Sample Analytical Certificate -Effluent Results	**REF. NO:** F/9/1/5
		ISSUE NO: 01
	DEPARTMENT: Technical	**REV. NO:** 00
	ISSUED BY: DTCM	**DATE OF ISSUE:** 15th April, 2013
	AUTHORIZED BY: TCM	**PAGE:** 1 of 2

SERIAL NO.

Sample No: 1194

Name of Customer ALICE MONENE

Address:

Purpose of Sampling STUDY

County NAIROBI

Date of Sampling: 17.12.13

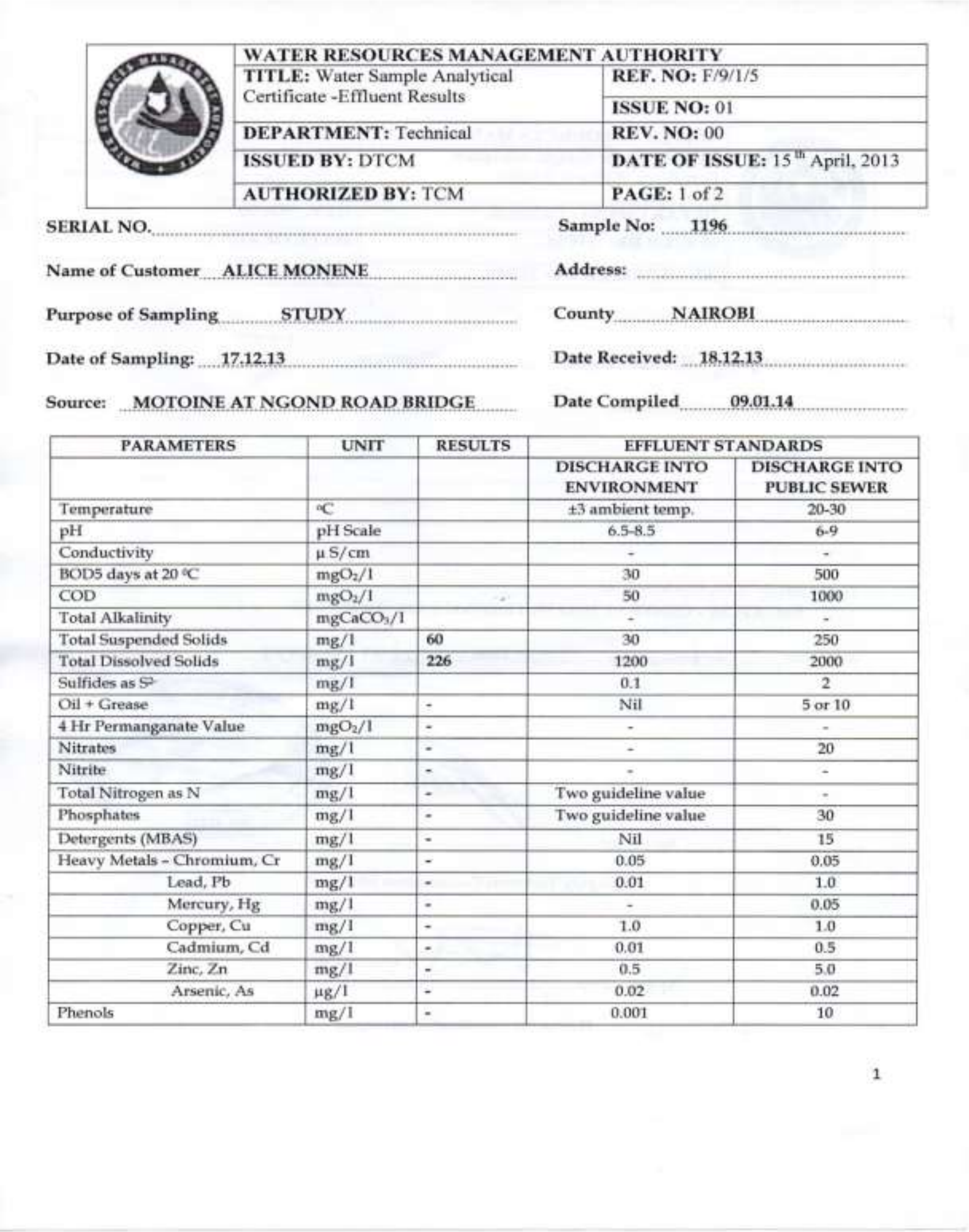
Date Received: 18.12.13

Source: MOTOINE AT SWAMP OUTLET

Date Compiled 09.01.14

PARAMETERS	UNIT	RESULTS	EFFLUENT STANDARDS	
			DISCHARGE INTO ENVIRONMENT	DISCHARGE INTO PUBLIC SEWER
Temperature	°C		±3 ambient temp.	20-30
pH	pH Scale		6.5-8.5	6-9
Conductivity	µ S/cm		-	-
BOD5 days at 20 °C	mgO_2/l		30	500
COD	mgO_2/l		50	1000
Total Alkalinity	mg$CaCO_3$/l		-	-
Total Suspended Solids	mg/l	40	30	250
Total Dissolved Solids	mg/l	423	1200	2000
Sulfides as S^{2-}	mg/l		0.1	2
Oil + Grease	mg/l	-	Nil	5 or 10
4 Hr Permanganate Value	mgO_2/l	-	-	-
Nitrates	mg/l	-	-	20
Nitrite	mg/l	-	-	-
Total Nitrogen as N	mg/l	-	Two guideline value	-
Phosphates	mg/l	-	Two guideline value	30
Detergents (MBAS)	mg/l	-	Nil	15
Heavy Metals - Chromium, Cr	mg/l	-	0.05	0.05
Lead, Pb	mg/l	-	0.01	1.0
Mercury, Hg	mg/l	-	-	0.05
Copper, Cu	mg/l	-	1.0	1.0
Cadmium, Cd	mg/l	-	0.01	0.5
Zinc, Zn	mg/l	-	0.5	5.0
Arsenic, As	µg/l	-	0.02	0.02
Phenols	mg/l	-	0.001	10

1



WATER RESOURCES MANAGEMENT AUTHORITY	
TITLE: Water Sample Analytical Certificate -Effluent Results	**REF. NO:** F/9/1/5
	ISSUE NO: 01
DEPARTMENT: Technical	**REV. NO:** 00
ISSUED BY: DTCM	**DATE OF ISSUE:** 15th April, 2013
AUTHORIZED BY: TCM	**PAGE:** 1 of 2

SERIAL NO. ....

Sample No: 1196

Name of Customer ALICE MONENE

Address: ....

Purpose of Sampling STUDY

County NAIROBI

Date of Sampling: 17.12.13

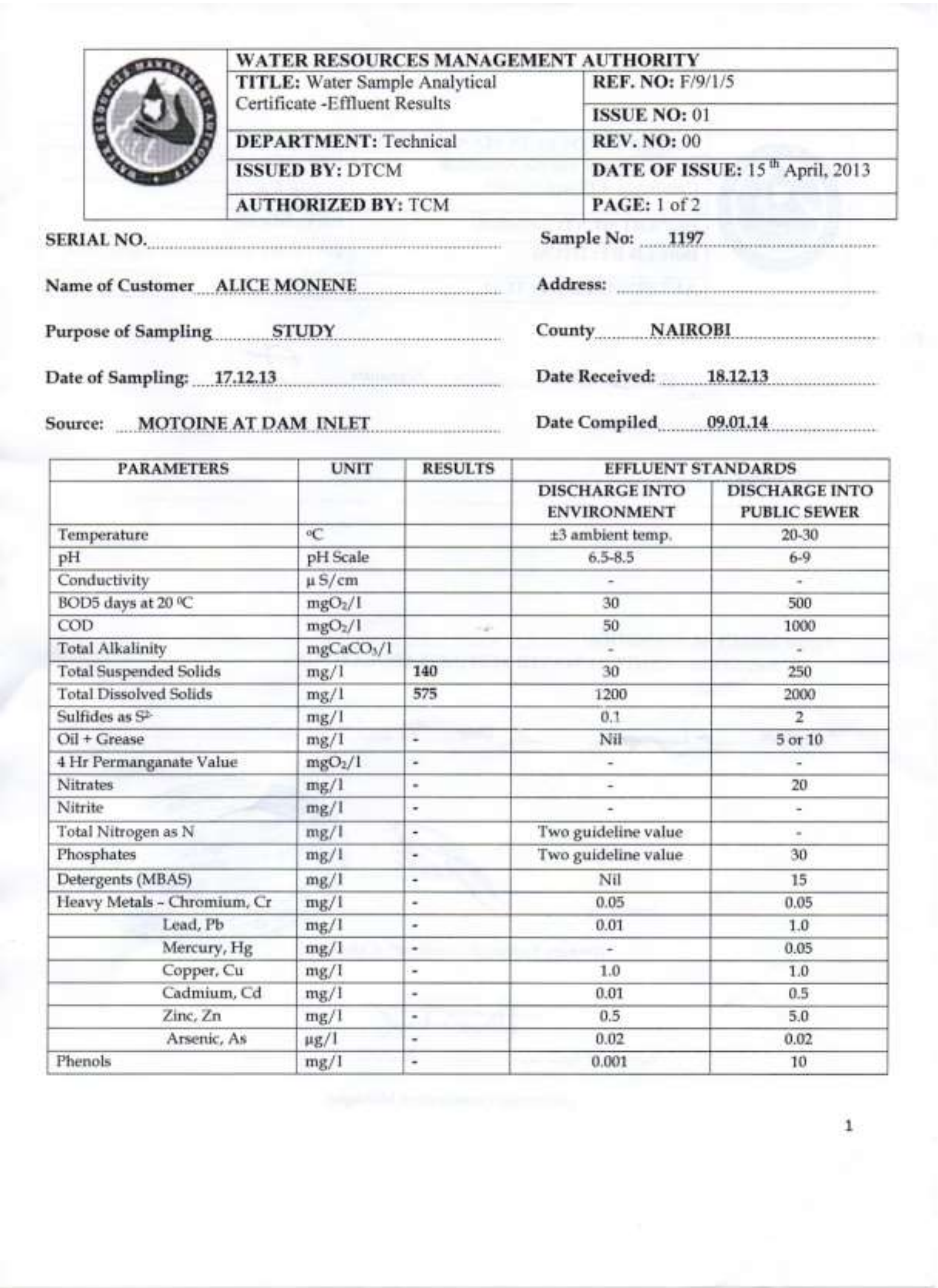
Date Received: 18.12.13

Source: MOTOINE AT NGOND ROAD BRIDGE

Date Compiled 09.01.14

PARAMETERS	UNIT	RESULTS	EFFLUENT STANDARDS	
			DISCHARGE INTO ENVIRONMENT	DISCHARGE INTO PUBLIC SEWER
Temperature	°C		±3 ambient temp.	20-30
pH	pH Scale		6.5-8.5	6-9
Conductivity	µ S/cm		-	-
BOD5 days at 20 °C	mgO$_2$/l		30	500
COD	mgO$_2$/l		50	1000
Total Alkalinity	mgCaCO$_3$/l		-	-
Total Suspended Solids	mg/l	60	30	250
Total Dissolved Solids	mg/l	226	1200	2000
Sulfides as S^{2-}	mg/l		0.1	2
Oil + Grease	mg/l	-	Nil	5 or 10
4 Hr Permanganate Value	mgO$_2$/l	-	-	-
Nitrates	mg/l	-	-	20
Nitrite	mg/l	-	-	-
Total Nitrogen as N	mg/l	-	Two guideline value	-
Phosphates	mg/l	-	Two guideline value	30
Detergents (MBAS)	mg/l	-	Nil	15
Heavy Metals - Chromium, Cr	mg/l	-	0.05	0.05
Lead, Pb	mg/l	-	0.01	1.0
Mercury, Hg	mg/l	-	-	0.05
Copper, Cu	mg/l	-	1.0	1.0
Cadmium, Cd	mg/l	-	0.01	0.5
Zinc, Zn	mg/l	-	0.5	5.0
Arsenic, As	µg/l	-	0.02	0.02
Phenols	mg/l	-	0.001	10

1



	WATER RESOURCES MANAGEMENT AUTHORITY	
	TITLE: Water Sample Analytical Certificate -Effluent Results	**REF. NO:** F/9/1/5
		ISSUE NO: 01
	DEPARTMENT: Technical	**REV. NO:** 00
	ISSUED BY: DTCM	**DATE OF ISSUE:** 15th April, 2013
	AUTHORIZED BY: TCM	**PAGE:** 1 of 2

SERIAL NO.

Sample No: 1197

Name of Customer ALICE MONENE

Address:

Purpose of Sampling STUDY

County NAIROBI

Date of Sampling: 17.12.13

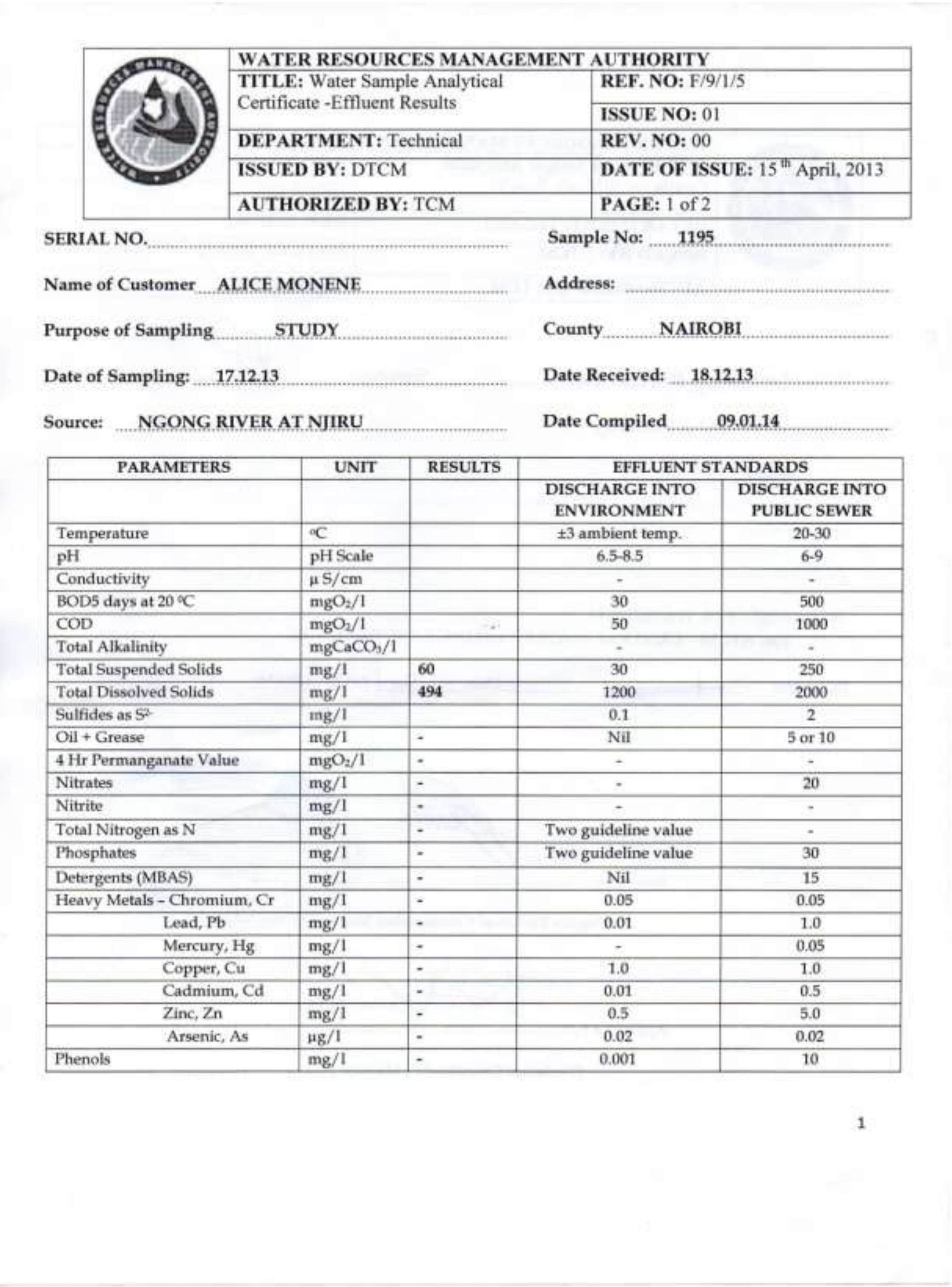
Date Received: 18.12.13

Source: MOTOINE AT DAM INLET

Date Compiled 09.01.14

PARAMETERS	UNIT	RESULTS	EFFLUENT STANDARDS	
			DISCHARGE INTO ENVIRONMENT	DISCHARGE INTO PUBLIC SEWER
Temperature	°C		±3 ambient temp.	20-30
pH	pH Scale		6.5-8.5	6-9
Conductivity	µ S/cm		-	-
BOD5 days at 20 °C	mgO_2/l		30	500
COD	mgO_2/l		50	1000
Total Alkalinity	$mgCaCO_3/l$		-	-
Total Suspended Solids	mg/l	140	30	250
Total Dissolved Solids	mg/l	575	1200	2000
Sulfides as S^{2-}	mg/l		0.1	2
Oil + Grease	mg/l	-	Nil	5 or 10
4 Hr Permanganate Value	mgO_2/l	-	-	-
Nitrates	mg/l	-	-	20
Nitrite	mg/l	-	-	-
Total Nitrogen as N	mg/l	-	Two guideline value	-
Phosphates	mg/l	-	Two guideline value	30
Detergents (MBAS)	mg/l	-	Nil	15
Heavy Metals - Chromium, Cr	mg/l	-	0.05	0.05
Lead, Pb	mg/l	-	0.01	1.0
Mercury, Hg	mg/l	-	-	0.05
Copper, Cu	mg/l	-	1.0	1.0
Cadmium, Cd	mg/l	-	0.01	0.5
Zinc, Zn	mg/l	-	0.5	5.0
Arsenic, As	µg/l	-	0.02	0.02
Phenols	mg/l	-	0.001	10

1



WATER RESOURCES MANAGEMENT AUTHORITY	
TITLE: Water Sample Analytical Certificate -Effluent Results	**REF. NO:** F/9/1/5 **ISSUE NO:** 01
DEPARTMENT: Technical	**REV. NO:** 00
ISSUED BY: DTCM	**DATE OF ISSUE:** 15th April, 2013
AUTHORIZED BY: TCM	**PAGE:** 1 of 2

SERIAL NO.

Sample No: 1195

Name of Customer ALICE MONENE

Address:

Purpose of Sampling STUDY

County NAIROBI

Date of Sampling: 17.12.13

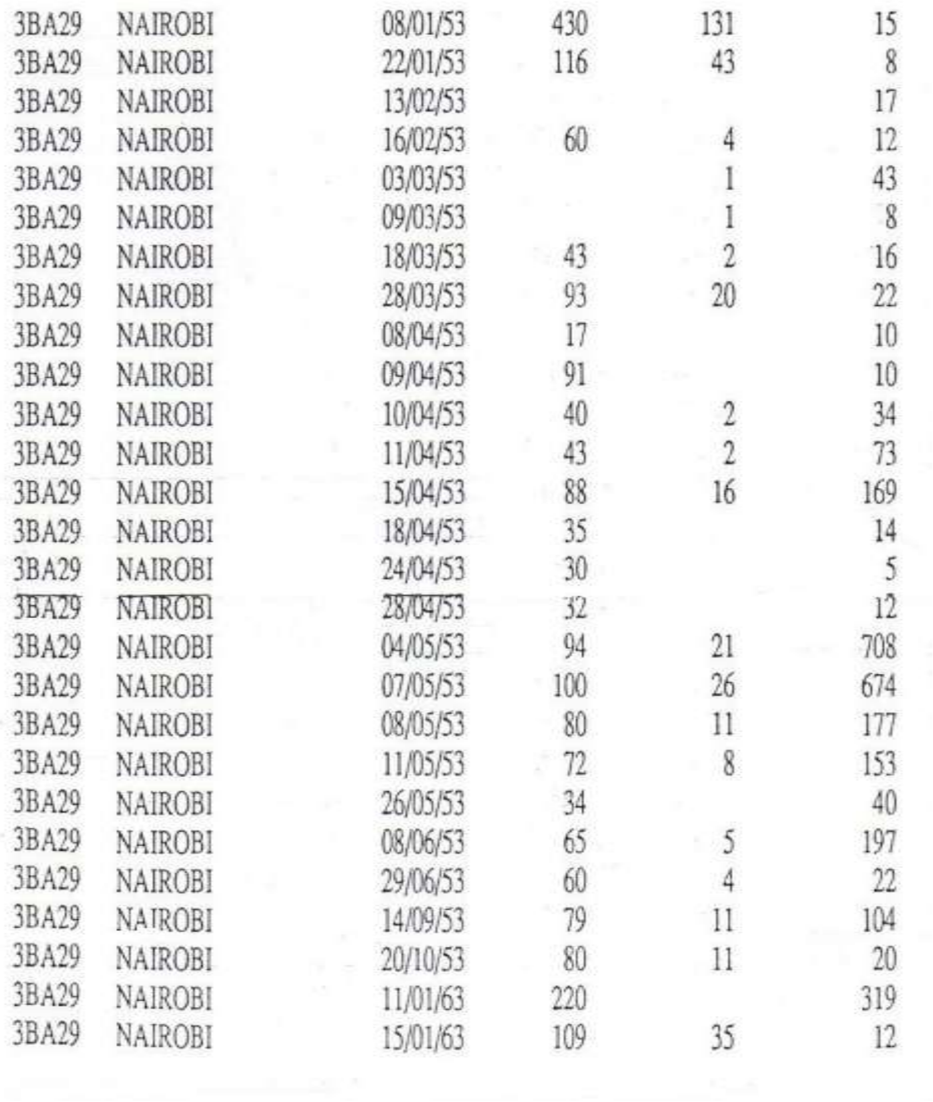
Date Received: 18.12.13

Source: NGONG RIVER AT NJIRU

Date Compiled 09.01.14

PARAMETERS	UNIT	RESULTS	EFFLUENT STANDARDS	
			DISCHARGE INTO ENVIRONMENT	DISCHARGE INTO PUBLIC SEWER
Temperature	°C		±3 ambient temp.	20-30
pH	pH Scale		6.5-8.5	6-9
Conductivity	$\mu S/cm$		-	-
BOD5 days at 20 °C	mgO_2/l		30	500
COD	mgO_2/l		50	1000
Total Alkalinity	$mgCaCO_3/l$		-	-
Total Suspended Solids	mg/l	60	30	250
Total Dissolved Solids	mg/l	494	1200	2000
Sulfides as S^{2-}	mg/l		0.1	2
Oil + Grease	mg/l	-	Nil	5 or 10
4 Hr Permanganate Value	mgO_2/l	-	-	-
Nitrates	mg/l	-	-	20
Nitrite	mg/l	-	-	-
Total Nitrogen as N	mg/l	-	Two guideline value	-
Phosphates	mg/l	-	Two guideline value	30
Detergents (MBAS)	mg/l	-	Nil	15
Heavy Metals - Chromium, Cr	mg/l	-	0.05	0.05
Lead, Pb	mg/l	-	0.01	1.0
Mercury, Hg	mg/l	-	-	0.05
Copper, Cu	mg/l	-	1.0	1.0
Cadmium, Cd	mg/l	-	0.01	0.5
Zinc, Zn	mg/l	-	0.5	5.0
Arsenic, As	µg/l	-	0.02	0.02
Phenols	mg/l	-	0.001	10

APPENDIX XX: SEDIMENT DISCHARGE FOR NAIROBI RIVER (RGS 3BA29)



Station code	River Name	Sampling Date	Water Level (cm)	Discharge (m^3/s)	Suspended Load (ppm)
3BA29	NAIROBI	08/01/53	430	131	15
3BA29	NAIROBI	22/01/53	116	43	8
3BA29	NAIROBI	13/02/53			17
3BA29	NAIROBI	16/02/53	60	4	12
3BA29	NAIROBI	03/03/53		1	43
3BA29	NAIROBI	09/03/53		1	8
3BA29	NAIROBI	18/03/53	43	2	16
3BA29	NAIROBI	28/03/53	93	20	22
3BA29	NAIROBI	08/04/53	17		10
3BA29	NAIROBI	09/04/53	91		10
3BA29	NAIROBI	10/04/53	40	2	34
3BA29	NAIROBI	11/04/53	43	2	73
3BA29	NAIROBI	15/04/53	88	16	169
3BA29	NAIROBI	18/04/53	35		14
3BA29	NAIROBI	24/04/53	30		5
3BA29	NAIROBI	28/04/53	32		12
3BA29	NAIROBI	04/05/53	94	21	708
3BA29	NAIROBI	07/05/53	100	26	674
3BA29	NAIROBI	08/05/53	80	11	177
3BA29	NAIROBI	11/05/53	72	8	153
3BA29	NAIROBI	26/05/53	34		40
3BA29	NAIROBI	08/06/53	65	5	197
3BA29	NAIROBI	29/06/53	60	4	22
3BA29	NAIROBI	14/09/53	79	11	104
3BA29	NAIROBI	20/10/53	80	11	20
3BA29	NAIROBI	11/01/63	220		319
3BA29	NAIROBI	15/01/63	109	35	12