ASSESSMENT OF SUSPENDED SEDIMENT LOADINGS AND THEIR IMPACT ON THE ENVIRONMENTAL FLOWS OF UPPER TRANSBOUNDARY MARA RIVER, KENYA

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Assessment of Suspended Sediment Loadings and their Impact on the Environmental Flows of Upper Transboundary Mara River, Kenya

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DECLARATION

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

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DEDICATION

To my late father Ben Kiragu Wanjau, now in God's hands yet close to our hearts.

He denied himself luxuries for us to go to school.

To mom Keziah Wanjiru, for encouraging us to be industrious, while keeping our family intact amidst many struggles without complaints.

QUOTE

"When they came to Mara, they could not drink the water because it was bitter".

"Is it not enough for you to drink clear water? Must you also muddy the rest with your feet? Must my flock feed on what you have trampled and drink what you have muddied with your feet?"

(Source: *The Holy Bible, 1984; Exodus* 15: 23-24; Ezekiel 34: 18-19.)

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ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
APHA	American Public Health Association
ASALs	Arid and Semi-arid Lands
BBM	Building Blocks Methodology
Cap 318	Chapter 318 of the Laws of Kenya
Cu	Copper
DNA	Deoxyribonucleic acid
DO	Dissolved Oxygen
EC	Electrical conductivity
EDXRF	Energy-Dispersive XRF Spectrometry
EFA	Environmental Flow Assessment
EFR	Environmental Flow Requirement
EMC	Ecological Management Class
EMCA	Environmental Management and Coordination Act (1999)
EU	European Union
FAO	Food and Agriculture Organization
Fe	Iron
FIU	Florida International University
GEMS	Global Environmental Monitoring System
GIS	Geographical Information System
GLOWS	Global Water for Sustainability
IFR	In-stream Flow Requirement
JKUAT	Jomo Kenyatta University of Agriculture and Technology

LVSCM	Lake Victoria South Catchment Management
Mn	Manganese
NEMA	National Environmental Management Authority, Kenya
NTU	Normalized Turbidity unit
Pb	Lead
PCBs	Polychlorinated biphenyls
RGS	Regular Gauging Station
RQOs	Resource Quality Objectives
$\mathbf{R^2}$	Coefficient of Determination
TBM	Temporary Bench Mark
TDS	Total Dissolved Solids
Ti	Titanium
TSS	Total suspended sediment
US DH-59	US Depth-integrating, Hand-held sampler, developed 1959
US, USA	United States of America
USAID	United States Agency for International Development
V	Vanadium
VicRes	Research around Lake Victoria
W.H.O.	World Health Organization
WREM	Water Resources and Energy Management
WRMA	Water Resources Management Authority
WWF	World Wide Fund for Nature
XRF	X-Ray Fluorescence
Zn	Zinc

ABSTRACT

This study set out to determine the levels and constituents of the suspended sediment loading in the upper basin of the transboundary Mara River in Kenya and how they relate to the environmental flow requirements of the basin. Catchment degradation in the Upper Mara Basin is causing increased runoff, erosion, and sedimentation of the limited water resources in the basin. The Mara River is an international river shared by Kenya and Tanzania which forms part of the larger Upper Nile River Basin. The Mara River is one of the perennial rivers replenishing the waters of Lake Victoria. In this study, baseline data were collected at Nyang'ores River and Amala River, the tributaries of Mara River.

The flow and sediment data were collected over a period of six months between February and July 2007. The total suspended sediment load and corresponding turbidity in the water samples were determined in the laboratory. The concentrations of trace metals in dried sediments were identified by their spectral signatures which provide an indication of the energies based on the intensities of the emitted spectral lines. The main findings were that both tributaries had monthly sediment yields that were almost similar. Nyang'ores River and Amala River had mean sediment concentration of 95.16 mg/l and 97.43 mg/l, respectively. This sediment loading is above the allowable standards of 30 mg/l for discharge into the environment in Kenya.

The recorded levels of Iron concentration at Nyang'ores River and at Amala River were above the recommended Kenyan standards of 0.30 mg/l. Trace metals present during dry weather were the same as those present during the wet season but at higher concentrations. It can be concluded that the increased levels of sediment and metallic pollution in the upper reach could be attributed to poor anthropogenic practices and settlement in forest catchment that resulted in soil erosion, run-off from point sources like rusted metallic articles at the shopping centres, scrap metal dump sites, sludge lagoons upstream and high organic matter in the swamps upstream.

The recommended normal year environmental flow of 1.00-2.00 m^3/s in the Mara was easily met and ample water was available for consumptive use. During a drought year the recommended reserve flows were 0.30-1.00 m^3/s and the environmental flow requirements were not met in most months except September. The conclusion was that land-use practices in the upper catchment may have sufficiently altered the hydrograph of the river that drought year low flows are unnaturally low.

This study recommends restoration of wetlands in the upper catchment to reinstate environmental flow. Total suspended sediment should be reduced and the water treated before consumption. There is need to stop further deforestation, settlement in the catchment and encourage soil conservation, plant environmentally friendly trees, adequately manage storm water and prohibit destruction of the river banks. There should be regular monitoring of the relationships between flow alteration and ecological response before and during environmental flow management, and refine flow provisions accordingly. There is need for further research on dissolved metal pollutants, climate change and watershed modeling to inform policy decisions, land and water development activities.

CHAPTER ONE

1.0. INTRODUCTION

This chapter gives an overview of the study in general, introduces the problem addressed, the objectives and justification against which the study was undertaken.

1.1. Environmental Changes in the Mara River Basin

The Mau complex and Maasai Mara have been in both the local and international news in the recent past. The most important functions in the headwaters are efficient rainwater infiltration and soil conservation, which together ensure that there is the largest possible quantity of clean water in the river during the dry season. These functions translate into benefits to institutions and individuals in the basin such as provision of good water quality for communities, agricultural activities, tourist facilities, mining activities; maintenance of the Mara-Serengeti ecosystem, and reduction of flash floods and droughts. Further, the Mara River provides fish, indigenous plants, fertile alluvial soils and; critical habitat to people and wildlife in the basin. However, in such an arid system, the many demands for these resources are sometimes incompatible. This has made the Mara basin vulnerable to erosion thereby distorting the river hydrology (Mati *et al.*, 2008).

In the past, the Mara River had sufficient water to support important and growing economic activities in agriculture, tourism, mining and aquaculture for Kenya and Tanzania. In recent years, the river's capacity to support these activities has been diminished during the dry season when flows become very low. The future dry-season supply of water in the river depends greatly on proper hydrological functions in the Nyang'ores and Amala tributaries, which form the headwaters of the river.

There is little systematic monitoring of water quality, especially sediment pollution in the Mara River Basin. Sediment transport is a carrier of nutrients, heavy metals and pesticides that adversely affect the water quality in rivers (Machiwa, 2001). The study of river suspended sediments is becoming more important, nationally and internationally because of the increasing need to assess fluxes of nutrients and contaminants to lakes, oceans and across international boundaries.

This research was therefore aimed at assessing the impact of suspended sediment on environmental flows and identifying elements in the sediment of the upper Mara River basin. The methodology used in this study included field surveys, environmental flows assessment and observations of flows and sediments in the two main tributaries - Amala and Nyang'ores.

1.2. Statement of the Problem

Global Environmental Monitoring System (GEMS)/water data indicates that Africa is the least surveyed continent on suspended matter and heavy metal pollution (UNEP, 1991). There has been very little systematic collection of data on water quantity or quality in the Kenyan portion of the Lake Victoria Basin. Remote sensing studies conducted by ICRAF scientists in 1998 had shown a major plume of sediment extending into Lake Victoria from the outlet of the Nyando River (Science online). By routinely monitoring the sediment and nutrient load in the Nyando, Nzoia, Yala and

Sondu-Miriu rivers since 1999, it has been possible to document the magnitude of the problem and compare the Nyando to other Kenyan rivers (Swallow *et al.*, 2003). However, Mara River Basin was considered pristine and not contributing any significant sediment load into Lake Victoria.

Recent studies and GIS-based hydrological models for Mara Basin have shown that there has been extensive deforestation in Mau Escarpment and increased land use change from forestry to agriculture in the watershed (Mutie, 2006). The Mara River Basin is facing serious environmental problems primarily created from wide spread encroachment on protected forests and other fragile ecosystems for settlement and cultivation (WREM, 2008). These specifically include:

(i) Soil erosion and high sediment loads;

(ii) Deforestation resulting from encroachment and human settlement in the Mau forest areas;

(iii) Wildlife human conflicts resulting from large-scale farming that has extended into wildlife corridors;

(iv) Declining water quality and quantity due to poor agricultural practices and excessive water abstractions;

(v) Pollution due to unregulated wastewater discharges, especially from mining activities, poor sanitation facilities and excessive use of agro-chemicals for pest and disease control in crops and livestock;

(vi) Increased frequency and intensity of floods and droughts due to climate variability and land use change and;

(vii) Uncoordinated water resources planning and management processes due to lack of a framework for transboundary water resources management.

1.3. Justification

Recent studies (Mutie, 2006; Njigua, 2006; Hongo, 2000) have identified an accelerated deterioration of the headwater catchments of the Mara which has diminished the river's ability to continue providing year-round benefits to downstream users and ecosystems. The situation is exacerbated by failure to monitor and ensure compliance with established standards. According to local inhabitants, the upper wetlands of the Mara River are shrinking while the lower wetlands have expanded significantly from around 1973-2000 by 387% (Mati *et al.*, 2008).

The increased wetland areas are attributed to backwater flow from Lake Victoria, as a result of sediment build-up downstream as a result of soil erosion in the upper catchments as shown in Figures 1.1. The environmental changes are evident in the satellite imageries of 1986 and 2003 because while the size of lower wetlands increased there was a decrease in size of the upper Mara wetlands and forest cover (Figures 1.2) during the same period.

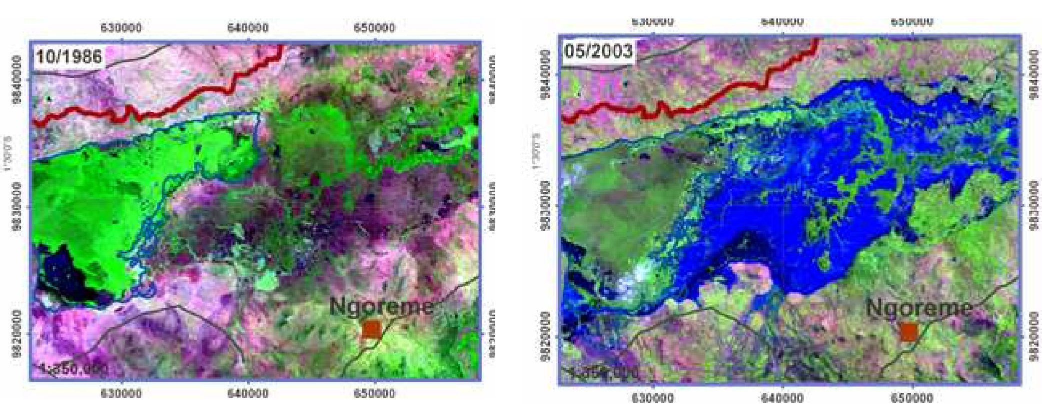
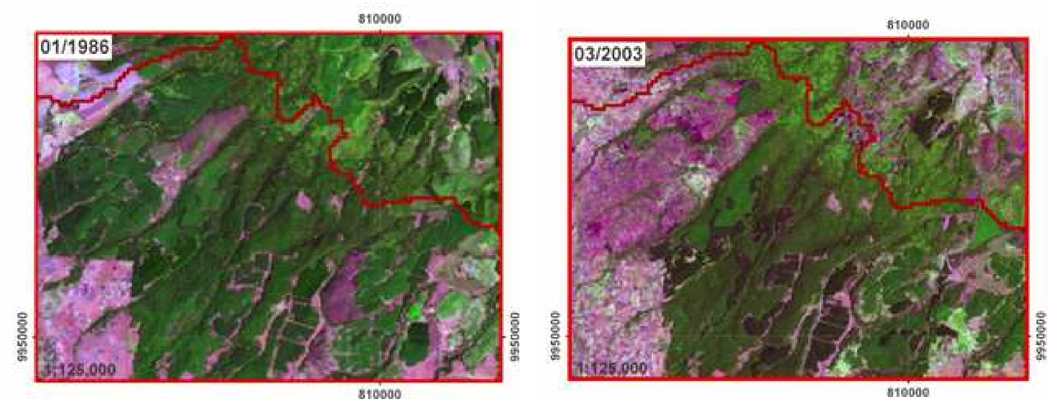


Figure 1. 1. Lower Mara wetlands 1986 and 2003.



Legend	**Land cover classification** (Source: Singler and McClain, 2006).
Green	Forest cover, old tree canopies, reeds
Purple	Succulent vegetation e.g. good cover crops like beans
Black	Deep water in wetland
Blue	Riverine sedimentation
Blue line	River water course
Red line	Water shed boundary

Figure 1. 2. Upper Mara wetlands and forest cover in 1986 and 2003.

The study seeks to add knowledge on suspended sediment pollution in the transboundary Mara River basin for water resources, environmental policy and institutional management. Consequently, due to the importance of the water quality of the upper Mara River to the ecology of the basin, this research on suspended sediment pollution was commissioned and carried out mainly in Kenya.

1.4. Research Questions

The Mara Basin has undergone tremendous changes in land cover over the past few years. The natural forest cover, scrublands and grasslands are being opened up for agriculture and other uses (Mutie, 2006; Njigua, 2006). These phenomena undermine the limited sustainable water resources base in the basin. Suspended sediment loads are transported and altered by the river.

The research provides answers to the following questions in the upper Mara Basin:

(i) How much is the sediment pollution loads at Upper Mara River?

(ii) What are the constituent elements in the suspended sediments of the Upper Mara River flows?

(iii) What impact does the sediment pollution have on the environmental flow requirement of the river?

1.5. Objectives of the Study

The main objective of this study was to quantify the level of sediment pollution and its impact on the environmental flow requirement of the upper Mara River in Kenya. The specific objectives were as follows:

1. To assess sediment loads in the Amala and Nyang'ores, tributaries of Mara River.
2. To determine the constituents of suspended sediments during low and high flows in the Upper Mara River
3. To evaluate the impact of sediment pollution on the environmental flow recommendations of the upper Mara River.

CHAPTER TWO

2.0. THE STUDY AREA

This chapter gives background information of the study area, the Mara River Basin.

2.1. Location of the Study Area

The source of the transboundary Mara River is the Mau forest in Rift Valley province of Kenya. Mara River flows 395 km along the boundaries between Bomet and Narok districts, the Masai Mara National Reserve and crosses the Kenya-Tanzania border to discharge into the Mara Bay of Lake Victoria at Musoma in Tanzania (Figure 2.1).

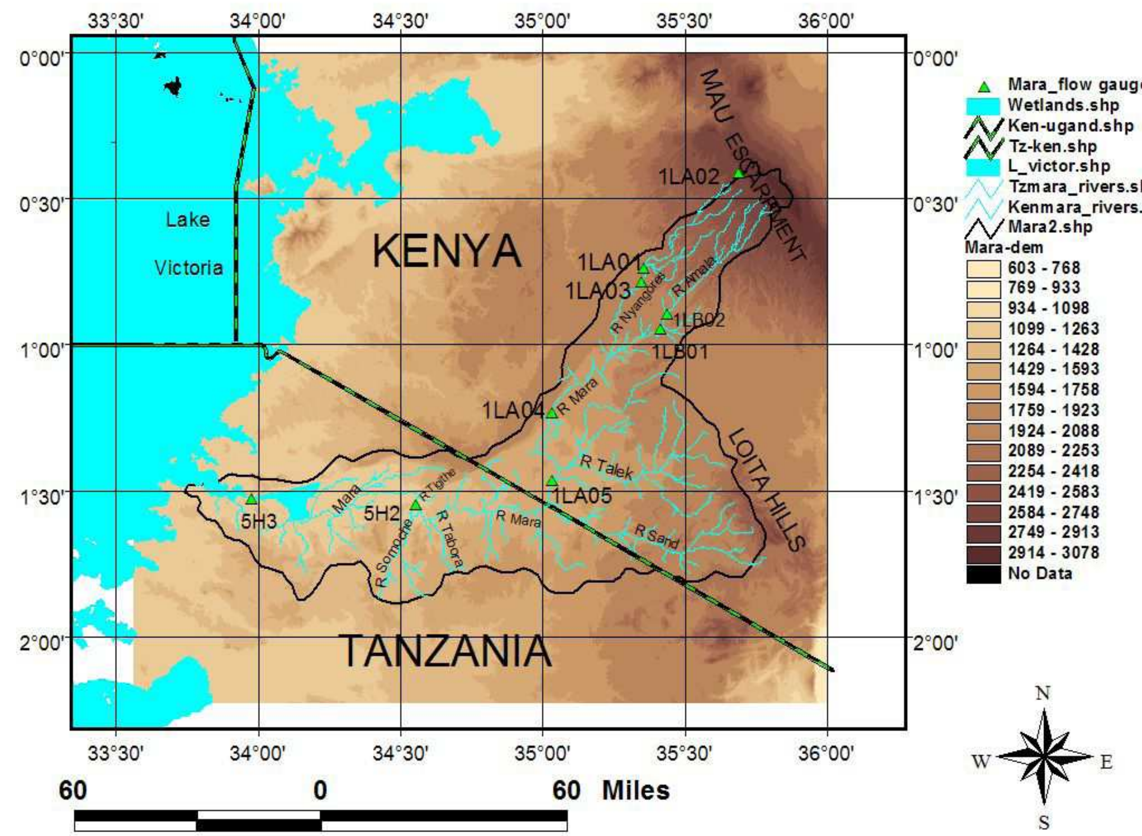


Figure 2. 1. Location of Sampling Sites at Nyang'ores (1LA03) and Amala (1LB02) and other River Gauging Stations in the Mara River Basin.

The Mara Basin is situated between latitudes 0^o 21’S and 1^o54’S and longitudes $33^o42^,$E and 35 $^o54^,$E as shown in Figure 2.1. About 65% of the Mara river basin (16,320 km^2) is in Kenya and 35% (8,030 km^2) in Tanzania. The river has many tributaries such as Amala, Nyangores, Talek, Sand, Mori, Kenyo, Tambora, Nyambire, and Mosirori. The main reason that in recorded history the Mara River has always kept flowing during drought is that the Nyang'ores and the Amala rivers that drain the forested Mau escarpment feed it. Their catchment areas constitute respectively 60% and 40% (Dwasi, 2002) of the Mara River Basin. River Nyangores originates from the Keringet area and most of its feeder streams are now reported seasonal (Krhoda, 2001; Anakeya, 2001). River Amala originates primarily from Napuiyapui swamp and other smaller swamps in Kiptunga forest in the South West Mau escarpment in Nakuru District (Krhoda, 2001).

2.2. Topography and Drainage

The two tributaries, Rivers Amala and Nyang’ores, flow from a northeast to southwest direction down the steep slope of the escarpment then merge in Bomet District to form the Mara River. The upper catchment decreases from 2920 m above sea level (m.a.s.l) to below 2000 m.a.s.l within 100 km. The upper reaches of Amala and Nyang’ores Rivers are characterized by an undulating topography while the combined Mara River flows on a gentler gradient through wooded grasslands utilized for small- and large-scale agriculture as well as livestock keeping (Machiwa, 2002). The stream network are parallel pinnate, linear with numerous first order streams reflecting long parallel ridges on recently formed volcanic soils (Aboud *et al*., 2004).

As the Mara continues into the protected areas of the Maasai Mara Game Reserve and across the Tanzanian border into the Serengeti National Park, it is joined by the Talek River, out of the Loita Plains, and the Sand River. Here the Mara sustains one of the greatest spectacles of the natural world—the annual migration of over one million wildebeest, zebra and antelope who cross the Serengeti during the dry season in search of water and forage. After leaving the protected reserves, the Mara recharges the vast wetland complexes of the Mosirori Swamps with water and nutrients before finally flowing through the Mara Bay into Lake Victoria, ending at an altitude of 1,134 m.a.s.l. From here, these waters begin their second life, as headwaters of the Nile River Basin.

2.3. Climate and Hydrology

The Mau forest is the largest of Kenya's water catchment areas. It is the largest remaining closed canopy forest block in Eastern Africa (Gereta *et al*., 2003). The climate in the Mara River basin varies greatly with the change in altitude. The basin is characterized by the dominant tropical dry/wet dry climate (Mati *et al.*, 2005a). Precipitation regime in the Mara Basin is represented by a mean annual rainfall of 1,400 mm, on the upper-forested parts of the Mau escarpment, 900-1000 mm middle rangelands, and 700-850 mm in the lower Loita hills and plains. It decreases around Musoma with a mean annual value of 600 mm/year. The rainfall seasons are bi-modal, with the long rains occurring in March-April-May and the short rains in October-November.

The basin has a mean annual temperature of 25^0C**.** The lower portion is a dry plain with high evaporation (Valimba *et al.*, 2004). The Southeast Trade Winds (Indian Monsoons) from the Indian Ocean enhance basin rainfall between March and May but weaken considerably between June and September producing a drier summer period (Indeje *et al.*, 2000). The southwest trade winds, also known as the Congo air mass, bring rain from the west in July with storms and hailstorms. Across the basin, rainfall decreases from west to east.

According to Japan International Cooperation Agency report (JICA, 1987), Nyang'ores River has higher flows with a mean annual discharge of 10.4 m^3/sec and drains 679 Km^2 including the steep, densely populated and erosive high potential areas that are mainly Tea-dairy zone (Jaetzold & Schmidt, 1983). The upper catchment area is considered the basin's granary, but soil erosion and loss of soil fertility threaten the potentiality.

2.4. Soils

The type and distribution of soils in the Mara River basin are determined by geology, topography and rainfall (Gereta *et al.*, 2001). In the forested highlands of the Amala and Nyang'ores Sub- basins, Andosols are found (FAO, 1997). These soils are prone to sheet erosion and mass wasting processes. These are soils of volcanic origin and generally form good water aquifers. The soils of the area above the gauging stations are suitable for intensive agricultural production including wheat, barley and zero-grazing. These soils include the shallow but well-drained dark-brown volcanic types found on the mountains and escarpments. On the hills and minor escarpments near the river banks, shallow and excessively drained dark-reddish brown soils are found.

Andosols are very porous, have a low bulk density of less than 0.85 g/cm^3, high organic matter content and susceptible to serious erosion when left bare through cultivation or overgrazing (Muchena *et al*., 1988).

However, with the encroachment into the forests and the increasing population, the steep slopes with very thin soil cover are farmed. In the midlands and lowlands, the most dominant soil type is Nitosols (FAO, 1997). These are soils with high and uniform clay content throughout the horizon, usually 60-80 % or more clay (Muchena *et al*., 1988). These soils are prone to gentle erosion and low fertility due to sheet floods from flanking hills. Alluvial silts and gravel occur along the Mara River while the lower tributaries are clogged with sand after the floods. Erosion and sediment loads to Lake Victoria are reported to be considerable (Machiwa, 2001). Sediment is not only a major water pollutant, but it also serves as a catalyst, carrier and storage agent of other forms of pollution (Julien, 1995).

2.5. Vegetation

The vegetation of Mara Basin is determined primarily by the climate and type of soils. On the highlands are found, the tall (about 26 m) broadleaf and deciduous trees with over 75 % canopy cover (Mutie, 2006). In the lowlands, the vegetation is mainly grassland bush land and woodlands along the banks of Mara River on Kenya-Tanzania border. The grass constitutes 40% of the plant community (Gereta *et al.*, 2001). The grasses are dominated by red oat grass, (*Themeda triandra*), though the wiregrass, (*Pennisetum schimperi*) is common in overgrazed areas. Woody shrubs such as *Croton dichogamous* dominate bush land whereas acacia and *Spiny* *camiphora* species dominate the woodlands. Fast growing eucalyptus trees have been introduced in the riparian zones (Figure 2.2) to the detriment of dry season flows. Natural vegetation is being cleared for agricultural and economic purposes.

Figure 2. 2. Showing a new plantation of eucalyptus trees at the centre of this plate on the banks of the Amala River in the Mau forest.

2.6. Land Use and Management

In the Mara River Basin land tenure system is mixed. The highlands (upper catchments) where the small-scale farmers are found are predominantly private holdings sold by the original title holders. In this upper section of the basin, land is mainly privately owned, with 46% of the population owning the land and having title deeds, and 22% owning the land without title deeds (Aboud *et al.,* 2002). In the middle section and the lowlands, land ownership is still communal, family ranches, or group ranches with an increasing trend towards subdivision into individual holdings.

There is agricultural expansion and intensification including irrigation. Most of the high potential ranches have been leased to commercial wheat farmers (Aboud *et al*., 2002).

In recent years, the government of Kenya has allowed subdivision of group ranches with serious implications for the people and natural resources sustainability within the Mara River Basin. These changes toward cultivation will have significant implications to wildlife that utilize the Mara Game Reserve and adjacent group ranches as dispersal areas. This is despite the legislation that any person who cultivates or destroys the soil or cuts down any vegetation or overgrazes any land lying within 2 meters of a watercourse, shall be guilty of an offence (Republic of Kenya, 2002b). The Environmental Management and Coordination (Water quality) Regulations says that for a watercourse more than 2 meters wide, the distance shall be equal to the width of that watercourse to a minimum of 6 meters and a maximum of 30 meters (EMCA, 1999; Republic of Kenya, 2006a).

The changes brought by human settlements discharging untreated wastewaters, soil erosion and overgrazing are predominantly confined to the Kenyan side of the basin but have serious implications on the Tanzanian side. Mara River's capacity to support ecological activities has been diminished during the dry season when flows become very low and increasing sediment pollution when it rains later.

2.7. Sediment Loss and Surface Water Monitoring in the Mara River

Human population in the Mara River Basin is growing at an annual rate of between 3 to 6 per cent. This has been accompanied by a 55% increase in agricultural lands in fourteen years at the expense of nearly a quarter of the region's forests and grasslands (Mati *et al*., 2005a). In addition to the associated effects of deforestation, water abstractions for agricultural irrigation, industries and livestock demands are on the increase. Many of these are uncontrolled or illegal. There has been an observed increase in water demands of 43% from 1990 to 2000 (Mati *et al*., 2005b). The associated land degradation is a threat to river discharge, the ecosystem, and human activities that depend on the river.

In order to protect surface water resources and optimize their use, soil loss must be controlled and minimized. This requires changes in land use and land management, which may also have an impact on water quality. Control of the siltation rate in reservoirs and rivers requires that adequate data are available at the design stage. Unfortunately, there are major gaps in the water resources data in the Mara River Basin. Some of the gauges are vandalized or washed away by floods **(**WREM, 2008).
It is noted that except for the short period of systematic sediment monitoring undertaken during the 1980s, the latter monitoring period has been an adhoc undertaking which does not provide sufficient data for effective management considering the sensitive issues being associated with the Mau Forest and Escarpment. If left uncorrected, the continuing degradation of the basin threatens the livelihoods of the people as well as the viability of the rich biodiversity of flora and fauna in the Mara River Basin, including the world famous Maasai Mara-Serengeti ecosystem and the Masurua Swamp.

CHAPTER THREE

3.0. LITERATURE REVIEW

This chapter gives a review of existing literature on sediment pollution and environmental flows assessment.

3.1. Food and Water Security: An Environmental and Engineering Challenge

Food insecurity has become a major concern in Kenya especially in the drought prone Arid and Semi Arid Lands (ASAL). Migration of people from densely populated high and medium potential areas to ASALs is aggravating this situation with the recurrent drought due to high rainfall variability and the high demand for water. The population grew from 8.93 million people in 1963 to the 38 million in 2008 and was projected to rise to approximately 63 million persons by the year 2030 (Republic of Kenya, 2007). Unless water availability is improved, many conflicts in rural Kenya will be resource-based with a bias towards shared water sources and national cohesion will therefore have a water dimension.

The combination of many human activities in the Mara basin has contributed to massive degradation of land in the basin area such that average discharge in rivers has been steadily declining during the dry seasons over the years, with increased flash floods, and high sediment transport during rainy seasons (Machiwa, 2002). This may result in a serious threat to the functioning and growth of the economic activities in the basin. It is therefore imperative to identify the pollution sources, especially the sediment sources, and assess the pollution levels in the Mara River system.

3.1.1. Environmental Flows and the impact of Sediment Loss

Although strict definitions of environmental flows vary, the most current and widely held definition was developed during the second international conference on environmental flows and released as the Brisbane Declaration (2007). Environmental flows describe “the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and human livelihoods and well-being that depend on these ecosystems” (Brisbane Declaration, 2007). Thus, environmental flows are the unallocated flows intentionally preserved in a river. Currently, excess sediment inputs are a threat to Lake Victoria and environmental flows of the rivers feeding it (ILEC, 2005). The Mara-Serengeti ecosystem will be under threat if environmental flows are not provided for and if upstream development is not controlled (Dwasi, 2002). Since the environment is not a consumptive use, provision of environmental flows will increase the downstream flows to help sustain the ecosystem.

Catchment degradation will invariably affect surface water availability as rivers and reservoirs will dry up and the remaining waters are heavily polluted. This threat can originate from land clearance, and from poor land use and riparian management in the basin (Mati *et al.*, 2005b). In extreme cases, sediments can altar the health of aquatic ecosystems such as infilling of a lake which in extreme cases, can destroy wetlands, reduce the penetration of light into water column, and act as a carrier of nutrients and other pollutants.

Over half a century, the Mara River Basin has undergone large changes in land cover.

Wetlands and savannah forests have been drained, cleared and turned into land for agriculture or grazing (Machiwa, 2002; Dwasi, 2002; IUCN, 2000). Consequently, there are shorter periods of rains and faster evaporation leading to chemical dissolution and oxidation of organic matter, faster runoff depleting the soil nutrients, eroding the landscapes and causing eutrophication of the receiving wetlands and waters, including Lake Victoria (LVEMP/COWI, 2000). Some of the main causes identified for the area's deterioration are a result of population growth and the associated increasing demand for agricultural land, drinking water and sanitation, construction and fuel materials (wood and charcoal). These increasing demands put pressure on resources and have promoted land use changes and inappropriate agricultural practices in the area.

3.2. Importance of Sediment in Rivers and Reservoirs

3.2.1. Sediment Transport in Rivers and Reservoirs

The loose non-cohesive material through which a river flows is generally called sediment or alluvium (Garde and Raju, 1995). Ordinarily this does not include ice, logs of wood or organic material floating on the surface. This fragmented material is transported, suspended or deposited by water or accumulated in the beds by other natural agents. As the hydraulic forces exerted on sediment particles in the river exceed the threshold condition for beginning of motion, coarse sediment particles move in contact with the bed surface (Julien, 1995). Finer particles are brought into suspension when turbulent velocity fluctuations are sufficiently large to maintain the particles within the mass of fluid without frequent bed contact (Bartram and Ballace, 1996). Bed load amounts to about 5 to 25% of the suspended load (Simons and Senturk, 1992).

Storms and erosion are most likely the cause of increased turbidity and total suspended solids (TSS) levels. One of the most serious environmental problems is erosion and the consequent loss of topsoil. Although erosion is a natural phenomenon, the rate of soil loss is greatly increased by poor agricultural practices which, in turn, result to increased suspended sediment loads in freshwaters. Loss of topsoil results in an economic loss to farmers, equivalent to hundreds of millions of US dollars annually, through a reduction in soil productivity (Bartram and Ballace, 1996). Many of the conflicts between water development and environmental sustainability are conflicts to balance farming in the upper catchments and environmental conservation and maintain the required quantity and quality of water at the right time (World Bank, 2004).

Efforts have been made in the past five decades to understand the mechanics of movement of the material in running water and attempts made to apply this knowledge to solve engineering problems (Garde and Raju, 1995). The World Bank (World Bank, 2004) has indicated that owners of dams have realized that substantial amounts of storage (0.5-1.0% globally) are lost each year due to sedimentation and that sediment management in catchments and dams is vital to maintaining asset value. Monitoring data for sediment transport and productivity within reservoirs is therefore required for accurate calculations of sediment transport and deposition and for the management of major reservoirs (Mutreja, 1986).

3.2.2. Sedimentation and Water Quality

Water must be treated as a resource that spans multiple uses in a river basin, particularly to maintain sufficient flows of sufficient quality at the appropriate times to offset upstream abstraction and pollution and sustain the downstream social, ecological, and hydrological functions of watersheds and wetlands (Davis and Hirji, 2003). Sediment transport affects water quality and its suitability for human consumption or use in various enterprises. The problem associated with sediment transport is that they act as a carrier for nutrients especially phosphorus, heavy metals and pesticides that adversely affect the water quality in rivers and lakes (Machiwa, 2001). The communities in the basin utilize the Mara River and each has a vision for the desired state of the river as indicated in Appendix 1.

Numerous industries cannot tolerate even the smallest amount of sediment in the water that is necessary for manufacturing processes, and the public pays a large price for the removal of sediments in such water. Sedimentation is of vital concern in the conservation, development, and utilization of soil and water resources. Suspended bacteria, protozoa and viruses are major causes of diseases while algae, colloids, silt, clay and humus introduce color, odour and turbidity in water.

Previous baseline survey in the Mara Basin (Singler and McClain, 2006) showed that nutrient concentrations appear to be causing eutrophication in the wetlands at the mouth of the river. Mercury and PCBs have a tendency to accumulate in organisms and along food chains, so even low concentrations in water may result in harmful accumulations in wildlife and people. Beyond the physical effects, increased sediment loads may also alter the chemistries of aquatic systems. Contaminated sediments can have lethal effects on benthic (bottom-dwelling) organisms or can be ingested affecting higher trophic levels. Disturbances (i.e., dredging) can re-suspend contaminated sediments, exposing organisms in the water to potentially toxic contaminants.

3.3. Constituents of Suspended Sediments

3.3.1. Characterization of Elements in Suspended Sediments

Physical impurities occur in three progressively finer states: suspended, colloidal and dissolved. Suspended matter is the dry solids present in water while colloids are finer particles that remain in suspension even when the water is virtually at rest. A substantial fraction of the total dissolved solid load (TDS) in a flow is tied up on the exchange phase and hence trapped in the basin along with sediment. In some cases, a negative trapping efficiency will exist based on equilibrium chemistry, and resulting from re-suspension of sediment and diffusion of chemicals from previously deposited sediment (Haan *et al.*, 1994).

A chemical/elemental analysis is carried out on dry material of known weight from TSS measurements. Each element has a unique electronic configuration and x-rays can irradiate some of the electrons orbiting the atomic nuclei and transit them to higher energy orbital (Sparks, 1978). The vacancy created in the respective orbital shell is replaced by another electron transiting from a higher energy level. This transition is accompanied by an emission of an x-ray photon; referred to as secondary radiation. The emitted secondary radiation has a characteristic of that element. X-ray fluorescence is this process of atoms emitting secondary x-rays in response to excitation by a primary x-ray source.

3.3.2. Heavy metals Pollution in Rivers

Essential heavy metals are generally considered to be less toxic than non-essential metals (Bartley, 1993). Metals such as cadmium, chromium, copper, iron, nickel, lead and zinc exhibit aquatic toxicity when present above recommended standards in that they can contaminate surface and ground water bodies, soil, plant, aquatic life and man, through bioaccumulation. Generally, trace amounts of metals are always present in freshwaters from the weathering of rocks and soils. In addition, industrial wastewater discharges and mining are major sources of metals in freshwaters. Through precipitation and atmospheric deposition, significant amounts also enter the hydrological cycle through surface waters. When discharged at increased concentration, these metals can have severe toxicological effects on aquatic environment and humans (Merian, 1991). The suspended sediment is mainly responsible for the transport of chemicals adsorbed on particles. For suspended sediment quality, the primary interest is the chemistry associated with the silt + clay (<0.63 µm) fraction, where sampling is greatly simplified because this fraction is not normally depth-dependent (Bartram and Ballace, 1996).

3.4. Environmental Flows in Water Resources Allocation

When planning water related development projects featuring significant water abstraction like irrigation and major flow regulation like reservoirs and hydropower, special priority must be given to allocating environmental flows that preserve the wide array of ecological services that downstream people depend upon. Environmental flows are therefore the balancing point between resources and conservation in water allocation programs. Climate change is a major challenge. The rainfall three-year moving average series is indicative of long-term rainfall trends and persistence (WREM, 2008). Analysis shows droughts and wet years tend to persist. Furthermore, a general downward trend is observed in Kenya since the 1990s. Such a trend can potentially be attributed to the deforestation of the Mau complex which serves as Mara's water tower, or to a regional climate change, or both.

There are few comprehensive studies done in Sub-Saharan countries to determine environmental flows. Studies have been carried out in South Africa, Swaziland, and Tanzania. The studies show that there is no agreed value for environmental flow requirements (EFR). The value depends on the river's characteristics. In Ngwavuma River in Swaziland, a study carried out by Frenken and Bousquet (1997) recommended a figure of 20% of the flows of the river while Njigua (2006) used an arbitrary figure of 5% of the Minimum Annual Runoff for the Mara River.

3.4.1. The Challenge of Allocating Environmental Flows for Rivers in Kenya

The "reserve" water amounts to an environmental flow as the Kenya Water Act 2002 defines the reserve as "that quantity and quality of water required to satisfy basic human needs, for all people who are or may be supplied from a particular water resource, and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the water resource" (Republic of Kenya, 2002a). The

National Environmental Management Authority (NEMA) in the water quality regulations (Republic of Kenya, 2006a) defines the "water resource quality" as the quality of all the aspects of a water resource; the character and condition of the in-stream and riparian habitat; the characteristics, condition and distribution of the aquatic biota and the quantity, pattern, timing, water level and assurance of in-stream flow. This seems to be different from the concept of "the reserve" in the Water Master plan where the "river maintenance flow" is to preserve aqua-ecology of river and assumed to correspond to the recorded daily minimum runoff of the river (Republic of Kenya, 1992).

In- stream flow was an earlier, less-comprehensive term used for environmental flows, usually focused on flows for fish (Davis and Hirji, 2003). Maintenance In-stream flow requirement (IFR) as water for all ecosystem functions to allow plants and animals to reproduce in most years. Drought IFR is to maintain species without supporting reproduction. Minimum flow (or residual) was a general term used for a flow required to maintain some feature of a river ecosystem. From these definitions, the following in-stream flows are not environmental flows: hydropower releases, irrigation releases, navigation water, dilution of pollution, release of wastewater and inter-basin transfer.

The Minister in charge of water affairs is required to determine "the reserve" or the "environmental flow requirement" (EFR) for the whole or part of each water resource. The challenge lies in implementing this provision while taking into account both aspects of the reserve and conflicting standards. In the case of water development projects, environmental flow assessment and sedimentation should therefore be an essential component of an environmental assessment especially developing methods and capacity for the determination of reserves and reviewing all existing water allocations to ensure that the reserve water is catered for.

3.4.2. The Building Block Methodology of Environmental Flow Assessment

Environmental flows are not just “flows for nature” (Davis and Hirji, 2003). Ultimately, society chooses which scenario is most acceptable, and in this way identifies a river’s desired future condition. Many different methodologies exist worldwide; however, the Building Block Methodology, refined in field studies in South Africa during the 1990’s, is among the most widely applied holistic methods that address both the structure and function of all components of the river ecosystem (King *et al*., 2000).

The Building Block Methodology is based on the understanding that river ecosystems have evolved under a given flow regime. Consequently, the native animals and vegetation compositing the ecosystem can cope with naturally occurring low-flow conditions, and may even require these lows to function properly. Similarly, the ecosystem may rely on naturally occurring higher flows and floods as indicated in Table 3.1.

Table 3. 1. Environmental Flow Building Blocks for Rivers.

Block	Definition	Functions
1. Drought Year Low Flows	The low flow requirements during the driest month of a drought year	Maintain hydrological connectivity in the system, maintain inundation of critical habitats (e.g., riffles), sustain flow-sensitive species and provide natural variability to maintain diverse species assemblage
2. Drought Year High Flows	The low flow requirements in the wettest month of a drought year	Maintain active channel flows to inundate benches , sustain emergent vegetation and permit fish passage over obstacles
3.Maintenance Year Low Flows	The low flow requirements during the driest month of a maintenance year	Provide natural variability to maintain diverse species assemblage
4.Maintenance Year High Flows	The low flow requirements during the wettest month of a maintenance year	Cue migration and spawning in fishes, inundate macrophytes and emergent vegetation along banks, displace dominant competitors and allow drift of species into new habitats, promoting increases in species diversity and maintain groundwater recharge for riparian species
5. Small Annual Floods (freshes)	Small pulses of higher flow that occur in the drier months and maintain active channel features and flush out organic matter thus improving water quality	Cue spawning and migration in fishes, inundate surrounding floodplains to facilitate lateral migration of fauna , facilitate nutrient transfer between floodplains and the river, allow germination and seed dispersal of riparian vegetation, prevent sediment build-up on river bed, increasing habitat variability for invertebrates,.
6. Major Flood Events	Major peaks in the river's flow level that occur at a given recurrence interval	Maintain macro channel features and provide diversity of physical habitats, scour bed of sediment deposits and inundate and recharge larger floodplain, allowing for nutrient transfer

(Source: King *et al.*, 2000).

The Building Block Methodology (King *et al*., 2000) is a more scientific approach to Environmental Flow Assessment (Appendix 2 and 3). First (low flow or base flow) building block of a river's flow regime defines whether the river is perennial or non-perennial as well as timing of wet and dry seasons. This block includes the minimum flow requirements during the driest months of a year, the minimum flows during the wettest months, and geomorphologically and ecologically important floods. These minimum flow levels and floods are recommended for both drought years, when flow levels are below normal and the management objective is to simply ensure the basic survival of the system, and maintenance years, when flow levels are high enough that normal ecological processes are maintained (Maintenance EFR).

Subsequent building blocks add essential higher flows. The second block consists of small annual floods that flush out stagnant pools and inundate riparian zones, as well as less frequent but larger floods, that serve to maintain natural channel structure and inundate the larger floodplain. The third building block includes the spawning and migration freshes. All species would potentially be able to breed.

The fourth building block allows for the survival of species and important ecosystem processes for a number of sensitive species for which breeding conditions would not be met (King *et al.,* 2000). For example, the environmental guilds of fish present in the river (Welcomme *et al*., 2006). Both *Labeo* and *Barbus* are characterized by species that require relatively high dissolved oxygen levels and generally migrate along the river channel.

CHAPTER FOUR

4.0. RESEARCH METHODOLOGY

This chapter describes the procedures and methods used to estimate the suspended sediment loads, turbidity, trace metals and the environmental flow assessment.

4.1. Assessment of the Suspended Sediment Pollution

The two tributaries, Amala and Nyang'ores Rivers, drain the forested Mau escarpment in a south-westward direction as described in Figures 2.1 and 4.1.

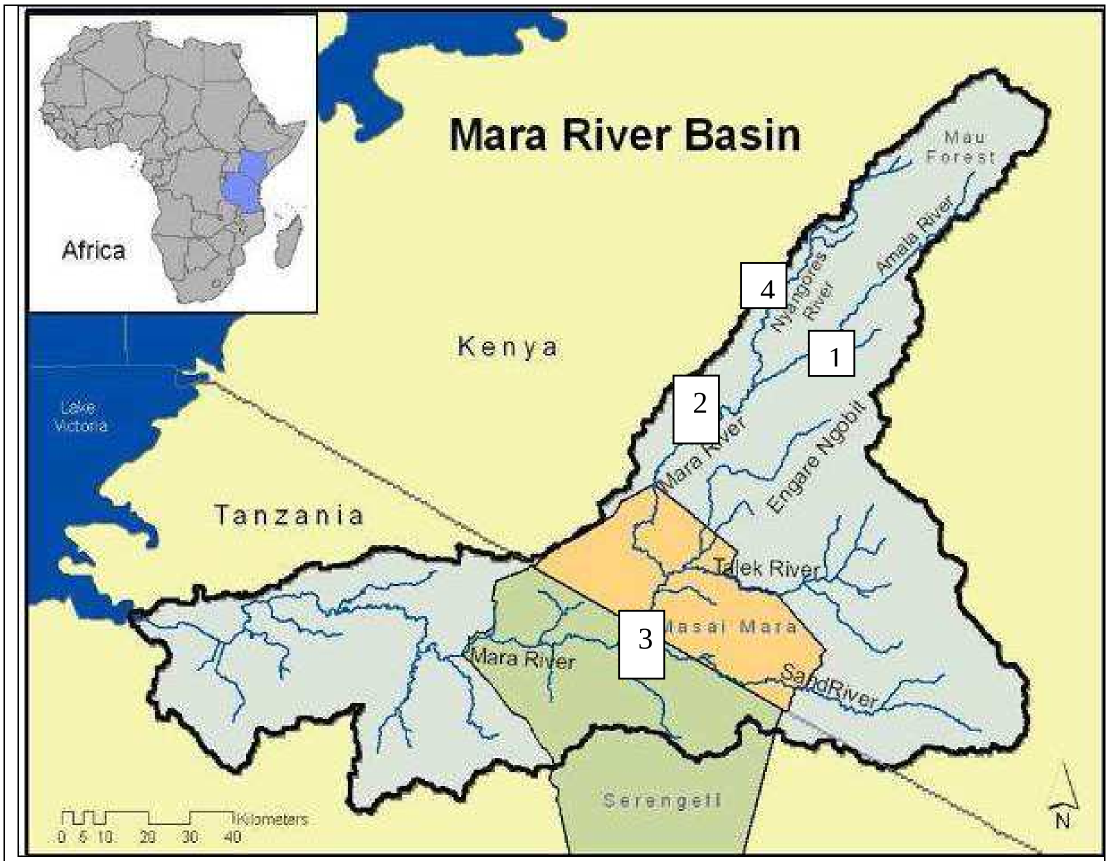


Figure 4. 1. Location of sediment sampling sites and sites for EFA during the study period.

Sampling for suspended sediment loads was done at two river gauging stations

(RGS): site 1, Amala RGS 1LB02 (longitude 35.438, latitude-0.897) on Kapkimolwa bridge and site 4, Nyang'ores RGS 1LA03 (longitude 35.330, latitude-0.780) located 1 km from Bomet town on the Nyang'ores River bridge. The site 1 at Amala River and sites 2 and 3 were used for the Environmental Flow Assessment as described in section 4.3. Baseline and reconnaissance surveys of the Mara basin were carried out and historical data collected from the Ministry of Water and Irrigation. Rainfall data was collected from the Kenya Meteorological Department. Data from the routine river flow measurements that were carried out during the study was analyzed for any relationships between the discharge and sediment loading. The river discharge gauging and sediment sampling were done over a period of 6 months from February to July 2007.

4.1.1. Flow and Sediment Sampling Procedures

Sediment loads of rivers are normally estimated by establishing a rating curve between discharge and sediment load or using a rating equation, $Q = aH^b$, where Q is the river discharge in m^3/sec H is the gauge height in metres and a, b are constants (JICA, 1987). The rating curve relationship is suitable for estimating the effects of land use and management activities on suspended sediments. In some rivers there is a moderately good relationship between suspended sediment concentration and discharge, i.e. the higher the discharge the higher the suspended sediment concentration. This relationship does not give importance to such factors as sediment size, watershed characteristics, and pattern of discharge variation.

Water agencies often need to estimate suspended sediment load on an annual basis, but wish to reduce the amount of field sampling required to determine suspended sediment concentration. The sediment discharge may also be different for the rising and falling stages of the flood discharges (Bartram and Ballace, 1996). The sediment–rating curve displays the rate of sediment transport as a function of the flow discharge. A comparison with field sediment discharge measurements is essential in the analysis of sediment- rating curves derived from several transport formulas commonly used in engineering practice.

Turbidity and Total Suspended Sediments (TSS) are measures of the level of suspended solids in water, which may be mineral or organic material (ATSDR, 2005). High levels of turbidity and TSS reduce light penetration in the water column, which may then reduce photosynthesis by submerged aquatic plants. Turbidity is the optical effect caused by dispersion of and interference with light rays passing through water containing small particles in suspension. Suspended sediments may be silt extracted from soil, surface wash containing suspended organic and mineral matter, precipitated carbonate in all waters, Aluminium hydrated in treated waters, precipitated iron oxide in corrosive water, microscopic organisms and similar material (ATSDR, 2005).

Sampling methods for measurements of the quantity of sediment in transport are different than for measurement of sediment quality (Bartram and Ballace, 1996). For bottom sediments it may be necessary to collect deposited sediments with minimum disturbance in order not to lose the fine material on the sediment surface, or because the vertical distribution of the sediment components is important, such as during establishment of historical records or depositional rates. In deep waters, this necessitates the use of grabs or corers used (Chapman, 1996).

There are four main types of samplers for sediments: integrated samplers, instantaneous grab samplers, pump samplers, and sedimentation traps. A depth-integrating sampler traverses the complete depth of the stream and back at a uniform rate and collects a sample, which has a concentration equal to the average concentration in the vertical (Garde and Raju, 1995). The average of these analyses is the mean cross-sectional suspended sediment concentration used to develop a rating curve, which is a regression of suspended sediment concentration as a function of discharge (Haan *et al.*, 1994). Due to statistical assumptions and Bernoulli random variable, a 95% confidence limit for annual flow peaks and 99% confidence limit for low flows are acceptable.

The three depth–integrating samplers most commonly used are the US DH-48 sampler (weight 20N) used in small streams for wading. The US DH-59 sampler is used for larger depth by suspending it by bridge crane (Figure 4.2 and 4.3) and at lower velocities and the US DH-49 sampler (weight 276N) suited for use with cable suspension system. The use of depth–integrating samplers is restricted to depths smaller than 4.5 metres (Garde and Raju, 1995).

Figure 4. 2. Preparing a bridge crane to lower USDH-59 Sediment Sampler after current meter (in the foreground) has been used in gauging.

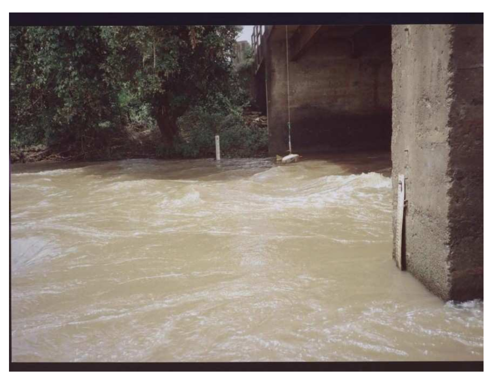


Figure 4. 3. The Sampler is suspended by a bridge crane during flooding at the Kapkimolwa (Amala) Bridge.

The suspended sediment sampling was carried out using USDH-59 sampler suspended on a cable controlled by the bridge crane during floods or mounted on the current meter- wading rod. Sampling was by wading during low flows when the water depth was less than 0.6 m and lowered with a rope for larger depths during floods. During floods a weight was added to the current meter and a bridge crane or boat used during the gauging (Figures 4.4; 4.5; 4.6 and 4.7).

Figure 4. 4. Wading at Nyang'ores River.

Figure 4. 5. Wading at Kapkimolwa Bridge.

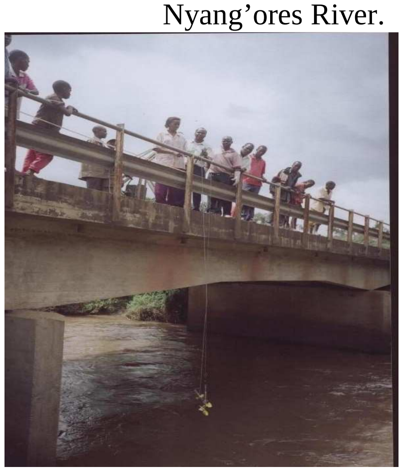


Figure 4. 6. Bridge crane at Nyang'ores River bridge to lower current meter.

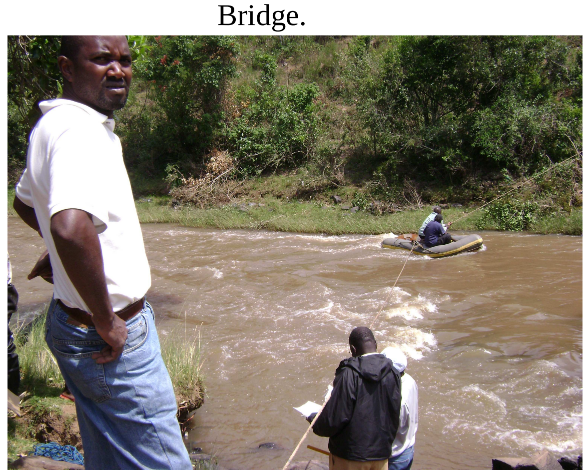


Figure 4. 7. Using a boat at Kapkimolwa

River flow discharges were computed from measurements of velocity and depth at a cross section near the recorder downstream of the bridge (Linsley, 1988). The mid-section method (Mutreja, 1986) of discharge calculation was used to compute discharge (equation 1). It assumes that the mean velocity for the vertical *i* represents the mean velocity in the cross section, from half-way to the preceding vertical (i-1) to halfway to the next vertical (i+1). Incremental discharge for each measurement is computed as

$$q_i = v_i\left(\frac{b_{i+1} - b_i}{2} + \frac{b_i - b_{i-1}}{2}\right)d_i = v_i\left(\frac{b_{i+1} - b_{i-1}}{2}\right)d_i \quad \textbf{(1)}$$

Where ***q*** is discharge (m^3/s),

b is distance (m) from the riverbank,

d is the depth (m) of the vertical and

v is the velocity in (m/s).

The verticals for suspended sediment samples were located according to standard procedures by Garde and Raju (1995). The velocity was measured at vertical sections spaced at 1 m interval across the river using the SEBA current meter. The velocity in each vertical was observed at 0.6 of the depth from the surface. At a third of the distance from the banks and in the midpoint, a depth-integrated sample was taken using a 400ml bottle: noting the transit time required by the nozzle of the sampler (from US DH-59 sampler table for the velocity of flow at that vertical, calculated during the earlier discharge measurement).

Using US DH-59 sampler table to check the standard transit rate, a suspended sediment sample was taken at each of the intervals (Appendix 4). Because each vertical had a different depth and velocity, the time to lower and lift varied with each vertical sampled. The 400 ml sampler bottle was filled according to standard procedures (Guy and Norman, 1970). The objective was to fill the sampler to about 90 per cent capacity because if the sampler is completely full when it emerges from the water the sample will be biased because the apparatus will have stopped sampling at the point at which it filled up (Bartram and Ballace, 1996).

Since coarser particles tend to have lower concentrations of metals, nutrients and organic micro pollutants, samples were collected of fraction less than 63 µm with which most metals tend to be associated (Bartram and Ballace, 1996). All sampling bottles were acid-cleaned, rinsed twice with distilled water and rinsed twice with sample water prior to collection. The three samples were composited into a single 1 litre HDPE bottle and labeled at the site as shown in Figures 4.8 and 4.9 and taken for determination of total suspended solids in the laboratory.

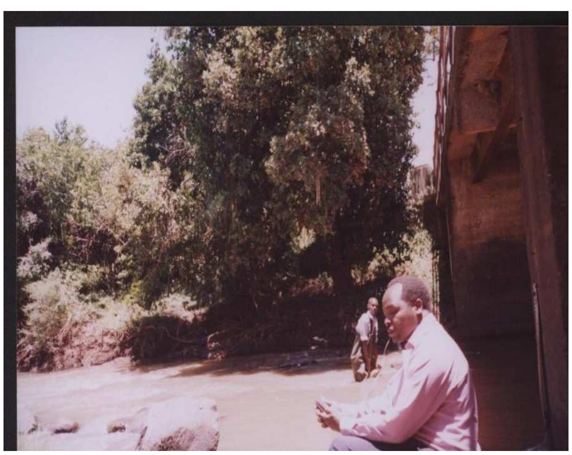


Figure 4. 8. Sample collection

Figure 4. 9. 1-litre Sediment Sample bottles

All Samples for this study were transported and analysed at Jomo Kenyatta University of Agriculture and Technology for Total Suspended Solids (TSS). The frequency was determined according to Garde and Raju (1995) and Guy and Norman (1970).Measurements were done once a week or within 24 hours during the rains. 132 samplings were done making 44 composite samples (22 samples per river) over the period and recorded in standard hydrological sheets and analyzed (Appendices 4 and 5).

4.1.2. Laboratory Procedures for determining sediment concentration

The concentration of suspended sediment in the water samples was determined in the laboratory using the method described in Bartram and Ballace (1996) and APHA methodology No. 2540D (A.P.H.A, 1995). The sand concentration was negligible and not required separately, so a known volume of raw water was filtered through a pre-weighed 0.45 µm pore diameter filter paper. The 1-Litre sample was agitated and sub-sampled into 200ml and analyzed for suspended sediment concentration with a vacuum filtration apparatus as shown in Figure 4.10.

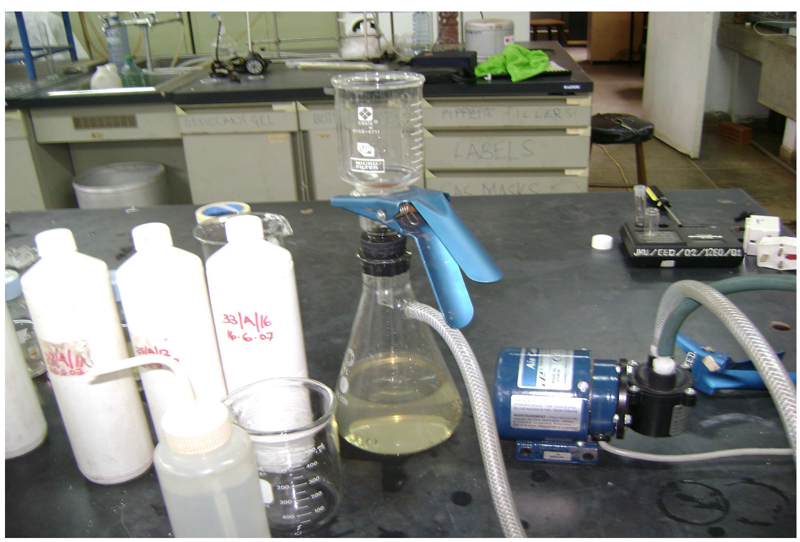


Figure 4. 10. Vacuum filtration apparatus for determining Total Suspended Sediment.

The suspended sediment concentration was then calculated according to equation 2:

Total Suspended Solids concentration, in (mg/l)

$$C = [W\ \text{sand} + \text{silt} + \text{clay}/V\ \text{sample}] \times 10^6 \qquad (2)$$

Where, **C** is the Total Suspended Solids concentration

W is the weight (g) of sediment and

V is the volume (ml) of measured quantity of water sample.

According to Bartram and Ballace (1996), discharge measurements, Q, and suspended sediment concentration (C) can be used to calculate suspended sediment load (SSL) in tonnes per day as shown in equation 3:

$$SSL = Q \times C \times 0.0864 \qquad (3)$$

If sand concentration is required separately, a known volume [*V* sample (ml)] of well-mixed sample is first passed through a 62-µm-mesh sieve. After weighing, the results can be expressed as in equations 4 and 5 as follows:

$$\text{Sand Concentration (mg/l)} = (W\ \text{sand}/\ V\ \text{sample}) \times 10^6 \qquad (4)$$

$$\text{Clay + silt Concentration (mg/l)} = (W\ \text{clay + silt}/\ V\ \text{sample}) \times 10^6 \qquad (5)$$

A Statistical Analysis of flow and total suspended solids was carried out by Instat for Windows. Instat programme for Windows was adequate for the required statistics like mean, medians, minimum, maximum and coefficient of variation. The sediment rating curve generated could be applied to estimate daily sediment yield as long as the Upper Mara Basin remain relatively intact and close to pristine conditions.

4.1.3. Determination of Turbidity and Water Treatment

The turbidity was measured with a nephelometer. All reagents used for turbidity were of a grade described in APHA standard manual No.2130B for Nephelometer (APHA, 1995). All glassware and polyethylene were properly cleaned with acid – cleansing reagents and rinsed thoroughly with distilled de-mineralized water. The water to be measured was placed in a standard container, where defined quantities of reagents were mixed to produce a fine precipitate (ATSDR, 2005).

Complete water treatment can be achieved by the addition of lime to make the water slightly alkaline, followed by the addition of coagulants like Alum (Aluminium Sulphate). Flocculation and coagulation assist in removing contaminants in the water causing turbidity, colour, odour and taste which cannot be removed by sedimentation alone. Most colours can be removed by treatment with ferric sulphate or ferric chloride. The resultant precipitate can be removed by sedimentation and filtration (Figure 4.11).

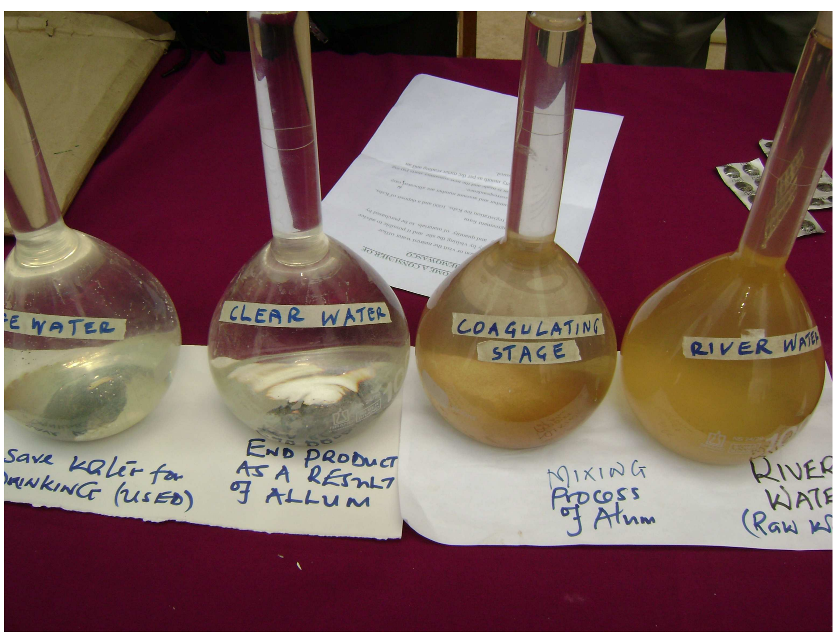


Figure 4. 11. Water treatment to reduce the turbidity of Nyang'ores River samples.

4.2. Assessment of the Heavy Metals in Suspended Sediment Pollution

Normally, chemical analysis is performed on dry material. The concentrations of trace metals from 12 dried sediments samples after TSS analysis shown in Figure 4.12 were analyzed using an X-Ray Fluorescence spectrometer in the University of Nairobi. This is an elemental and chemical analysis for investigation of metals and building materials for research in geochemistry, forensic science and archaeology. The selection was based on the typical hysteresis effect observed in suspended sediment as described by Bartram and Ballace (1996). For each river, two dried samples were analyzed when flow increased, two when it reached a peak, and then two when it decreased.

Figure 4. 12. Dried product samples used in X-Ray Fluorescent analysis for trace metals.

4.2.1. Energy Dispersive X-Ray Fluorescence (EDXRF) Methodology

The fundamental parameter method as described by Sparks (1978) was used. Energy-dispersive XRF spectrometry (EDXRF) was used to analyze trace elements present in the preserved dry sediment samples from Beryllium (Be) to Uranium (U) and beyond at trace levels up to 100 %. EDXRF includes special electronics and software modules to take care that all radiation is properly analyzed in the detector and therefore provide a lower cost alternative for element analysis as compared with such techniques as atomic absorption spectrophotometer (AAS). The emission of the characteristic radiation can be induced either by the impact of accelerated particles such as electrons, protons, alpha- particles and ions or by x-ray photons emitted by a radioactive source on an x-ray machine. In this study, ^{109}Cd source was used.

In this study, laboratory analysis began with the optimization of the x-ray fluorescent system. During optimization the following were done: first, setting of the optimum bias voltage, secondly, shaping the time constant at which best detector resolution is achievable and, lastly, setting the optimum irradiation time for the loaded filters (for this study 2000 seconds was found appropriate). The Figure 4.13 shows a set up of the EDXRF analytical system. It is made up of two main parts; the x-ray excitation source and the x-ray spectrometer. The later part consists of Spectroscopy amplifier, (Canberra Model 2026) and Si (Li) detector (Canberra 7300). It is also fitted with a high voltage bias supply; (EG cortex type 459) and a Pre-amplifier (Canberra Model 11008).

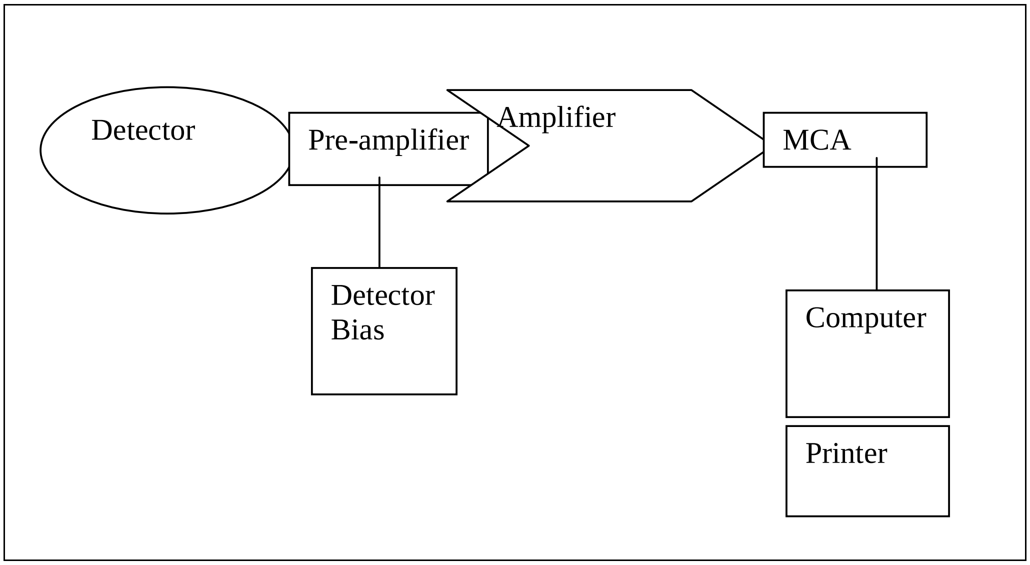


Figure 4. 13. The Electronic set up of an XRF system.

For optimum conditions, liquid nitrogen is used to cool the detector. Analog Digital Converter (ADC) (Canberra Model 80750) and a Canberra computer based Multi-Channel analyzer (MCA) are used for data acquisition and spectrum analysis.

The limitations of EDXRF methodology are:

1). Fluorescent x-rays can be easily absorbed by the sample itself (self-absorption), this requires close match of the sample matrix to that of the calibration standards.

2). Sample fusions enhances the XRF measurements technique by minimizing particle size effects but sometimes refractory minerals dissolve slowly and do not give satisfactory fusions.

4.3. Environmental Flow Assessments in Rivers

As more countries invest in water resources infrastructure such as dams and canals, there is an increasing need to assess the water requirements of river reaches and lakes to ensure that they continue to provide resources for human use (ILEC, 2005).

Provision of water for environmental purposes is still assigned a low priority in water resources management, and the condition of freshwater ecosystems worldwide continues to deteriorate (Rosenberg *et al*., 2000). Yet environmental flows will protect the rivers from drying up due to lack of water, loss of ecosystems and can also help revive critical floods in overused rivers. Environmental Flow Assessments (EFAs) are becoming the global standard for determining the amount of water required for sustaining aquatic ecosystems.

Many developed countries now regularly report on river health, using classifications for river reach conditions that are defined under national water or environmental policies and legislation. Man-made flow changes can be caused by direct manipulation- such as damming or abstraction of water- or by activities in the surrounding catchment that affect river flow, such as deforestation and land use changes. The resulting changes to the river do not have to be left to chance, but can be predicted and managed so that they stay within acceptable limits. This is possible because rivers can be managed to exist at different levels of condition (King *et al*., 2000).

4.3.1. Steps in the Environmental Flow Assessment (EFA)

The assessment of flows and suspended sediment pollution was done as part of the Environmental Flow Assessment (EFA) exercise concurrently with partners from GLOWS and Worldwide Fund for Nature (WWF) (EFA-MRB, 2008). It involved Ministry of Water personnel in gathering of data and the term “reserve” was used to correspond to the Water Act and the language of the local water offices. The Kenya

Water Act (Republic of Kenya, 2002a) and Tanzania Water Policy 2002 give a mandate that before allocating water for extractive or hydropower uses, water authorities must set aside a “reserve” flow. The reserve required to satisfy basic human needs for all people who are or may be supplied from the water resource is defined as a minimum of 25 l/day/person and was compared with historical runoff in the upper Mara River system (EAC 2009, Hoffman *et al.* 2009).

Site selection for environmental flow assessment (EFA) was done through geomorphological surveys that classified the river into three uniform macro-reaches based on gradient, channel pattern and bed structure. During initial field visits, a representative site for each of macro-reach was chosen. This study was done in the upper Mara catchment reach. Consultations on the site’s ability to resist disturbance and capability to recover from disturbance were held at the site or in the office (Figure 4.14 and 4.15).

Figure 4. 14. Geomorphologic macro-reach 1 survey for channel pattern and flow structure at Amala river.

Figure 4. 15. Consultations were done with lead experts in Environmental Flows and partners near the sites in Narok Town.

The selected sites exhibit fluvial processes characteristic of the macro-reach, as well as incorporate the interests of multiple stakeholders in the basin. The water allocated to the environmental flows should also satisfy basic human needs as well, accounting for both quantity and quality components of the river reserve. The Building Blocks Methodology (BBM) was adopted as the best choice because it uses structured, science-based approaches to determine how much water must be left in the river to protect the aquatic ecosystems and meet Resource Quality Objectives (RQOs).

To align the EFA process with the Lake Victoria South Catchment Management Strategy, the physical and biological components at EFA Sites 1, 2 and 3 were ranked according to their present and desired future ecological state (King *et al.*, 2000).

Site 1, Kapkimolwa Bridge (1860 m a.s.l) represented the upper Mara Basin. The land around this site was dominated by small-scale settlement with the main land use practices being subsistence farming and cattle rearing. Amala River joins the Nyang'ores River downstream of Site 1 to form the Mara River (Figure 4.16). Site 2 at Mara Safari Club (1687 m a.s.l) at the boundary of Maasai Mara Game Reserve represented the Middle Mara River. The land outside the reserve was a mixture of large-scale irrigation farming and wildlife ranching. The other main economic activity within the area is tourism.

1 

2 

3 

Figure 4. 16. The Macro-reaches for EFA at the Upper Mara River for Locations 1, 2, and 3.

Site 3 at the New Mara Bridge (1470 m. a.s.l); at the Kenya-Tanzania border between the Maasai Mara game reserve and Serengeti National Park represented the lower reach. Because this site is within the two major protected areas of Kenya and Tanzania, the only land use in the vicinity was wildlife rangeland and the only economic activity was tourism.

4.3.2. Identification of Environmental Flow Indicators for Mara River

The procedure followed in the Mara Building Blocks Methodology (BBM) is in six (6) main steps carried out in two main stages:

Stage 1: Engineering tasks:

1) Reconnaissance – Desktop assessment of issues, ecological reserve and habitat integrity. The sites were assigned an Ecological Management Category (EMC), summarizing the overall objective or desired state for each site. Each class is a

different level of degradation such as A (near natural or pristine); B (slightly modified); C (moderately modified): D (largely modified); E (seriously modified) and F (critically modified) (King *et al.*, 2000).

2) Pre-Feasibility- Impact assessment of each option and comprehensive reserve assessment using the BBM. Status of critical indicators was related to in-stream flow levels using hydrological and hydraulic analysis to ensure that indicators can be sustained in the long run (King *et al.*, 2000).

The critical indicators are:

1. Presence of natural sediment generation processes.
2. Occurrence of a variety of in-stream and riparian habitats to provide habitat for a variety of species.
3. Presence of sensitive species that reflect suitable water quality levels.
4. Adequate provision of human needs by water resources.

The focus was on critical indicators that could be used in future monitoring to determine if in-stream flows are sufficient to maintain desired ecological processes. Maintenance of these processes is critical to the health of both the river and the human communities that depend on it (King *et al*., 2000).

Stage 2: Additional BBM tasks:

3) Feasibility- This involves refinement of ecological reserve yields analysis, catchment water budget and scenario meetings.

4) Design- Baseline survey for monitoring the programme is done.

5) Construction- Baseline studies are continued while monitoring is commenced.

6) Operation- Complete monitoring of reserve flows; validation of ecological reserve and adjustment if necessary

In order to appropriately target management activities, the Lake Victoria South Catchment Management Strategy (LVSCMS) identifies Resource Quality Objectives (RQOs) for each of the catchment’s major river basins (Source: Republic of Kenya, 2006b). These RQOs were matched with the BBM classification according to natural hydrological boundaries, social and economic development patterns and communal interests of the people. The water resources were classified as being of high (1), medium (2) or low (3) importance to ecology (E), livelihood (L) and commercial development (C). According to this strategy, the Upper Mara was categorized E1L1C3, indicating the area is critical for both ecological concerns related to water resources management, as well as for small-scale subsistence farming, although commercial development is relatively unimportant. The Lower Mara was ranked E1L2C3, indicating a high importance for ecological purposes, and medium importance for livelihood activities, with a majority of the population still dependent on water resources for subsistence farming; however, commercial activity was still relatively unimportant.

Aquatic invertebrates are very sensitive indicators of water quality and flow regime in rivers and overall ecological health of the system. Species used in these surveys included insects, worms, mollusks and crustaceans that occur on the riverbed or along the channel margins. Aquatic invertebrates were sampled at all sites using a variety of methods, and a total score was calculated for each site that accounted for the number of different taxa present, the sensitivity of those taxa to water quality and their abundance.

At each of the 3 EFA sites, a 65-75-meter straight stretch of the river was marked that included runs, pools and riffles, in order to capture the variability in habitat types and hydraulic regimes (Figure 4.17). The geometry of each transect was carefully surveyed in each site.

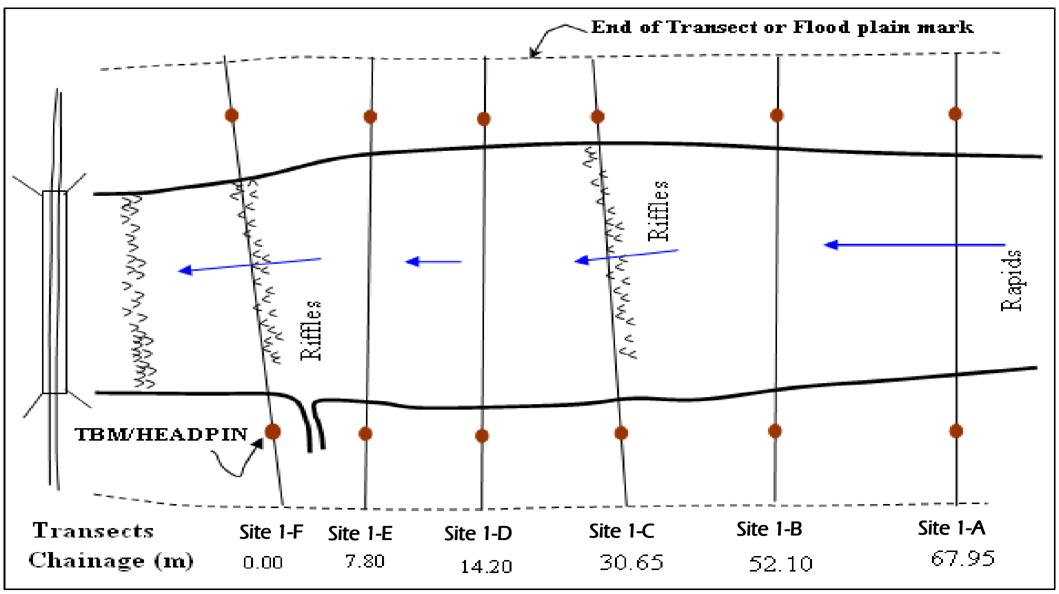


Figure 4. 17. Six transects surveyed at EFA Site 1 along Amala River.

Although fisheries are not a substantial component of people's livelihood in the upper or middle stretches of the Mara River, fish populations are excellent indicators of the health of a river's flow regime, in terms of water quantity and quality, which in turn provides other important services to people. Fish were sampled (Figure 4.18) in these surveys after a standardized period of time of 6 hours, the nets were hauled and data was collected on number and abundance of species, length and weight of individuals, and reproductive condition using gillnets placed in the river at each study site.

Figure 4. 18. Gillnets at Kapkimolwa Bridge, Macro-reach 1 during the EFA exercise in July 2007.

Fish species were also characterized according to their environmental guild, a classification system that groups species that respond similarly to changing hydrology and geomorphology (Welcomme *et al*., 2006).

During the EFA, other physical and chemical parameters (temperature [˚C], electrical conductivity [EC], total dissolved solids [TDS], salinity, dissolved oxygen [DO] and pH) were measured on-site with an YSI 556 handheld multimeter probe shown in Figure 4.19.

Figure 4. 19. Measuring various parameters using YSI 556 handheld multimeter probe.

Finally, the EFA study was concluded in October, 2007, after determining the flow regime needed to meet the RQOs. Based on the average flows during key months of the year, the ecological and human requirements were extrapolated across the entire year in a manner that simulated the natural shape of the river's historical hydrograph. The modified hydrograph, with associated floods, serves as the reserve.

The recommended reserve flow levels account for only 25% on average of recorded flows during maintenance (normal) years. The reserve accounts for, on average, just 35% of the average monthly flow recorded over the years that flow data were available for Mara Mine gauging station during maintenance.

CHAPTER FIVE

5.0. RESULTS AND DISCUSSION

This chapter presents the findings of the study comprising sediment loads, constituents of suspended sediment pollution and environmental flow assessments.

5.1. Hydrology and Rainfall

The available historical flow data for the years 1955-2007 from the Ministry of Water and Irrigation for 3 regular gauging stations were analyzed (Figure 5.1). Comparison was made between the flow duration curves derived for two river gauging stations located on the upper part of the basin (1LA03 - Nyangores and 1LB02 - Amala) and a third located in the lower part of the basin (5H2 - Mara Mines).

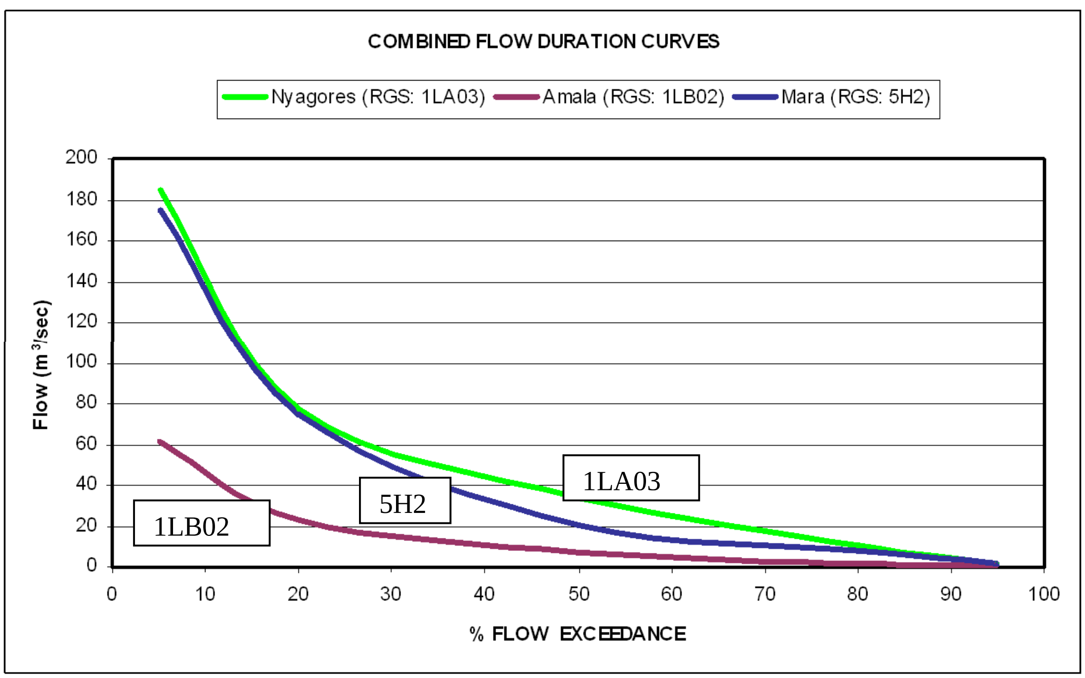


Figure 5. 1. Combined flow duration curves for 3 RGS on Mara River from 1955 to 2007.

The curves presented in Figure 5.1 indicate that high flow magnitudes up to 25%

flow exceedence are fairly comparable for Nyang'ores and Mara Mines. This shows that Nyang'ores River contributes much of the high flows reaching the lower part of Mara River. On the other hand, medium flow levels at Nyang'ores are higher than those observed at Mara Mines, in spite of the added Amala flow. This indicates considerable abstractions and channel flow losses between RGS 1LA03 and 5H2. The gauges in Amala RGS are not installed to measure beyond 1.5 m.

The flow increases and decreases in accordance to the two main wet seasons. The short rains season occurs during the months of October, November, and December, and the long rains season occurs from March through May. The January-February period receives very little rainfall compared to the main two seasons, except in the upper catchment. Spatial patterns of rainfall variations within a year show remarkable differences in the Basin in terms of monthly amounts and months of high rainfall. Most parts of the basin receive more than 50 millimeters (mm) of rain per month. Rainfall regimes are typically uni-modal in the upper basin region (Mau Escarpment), where mean annual rainfall varies between 1000 mm to 1750 mm and highest rainfall occurs during April through August.

5.1.1. Stage-Discharge Relationship at Nyang'ores River

Figure 5.2 shows the stage-discharge relationship at RGS 1LA03, Nyang'ores River with coefficient of determination, R^2, of **0. 8357**. The fitted equation for station 1LA03 is:

$$\textbf{Stage (m)} = -0.1165 + 0.3698 * \log \textbf{Discharge } (m^3/s) \qquad \textbf{(1)}$$

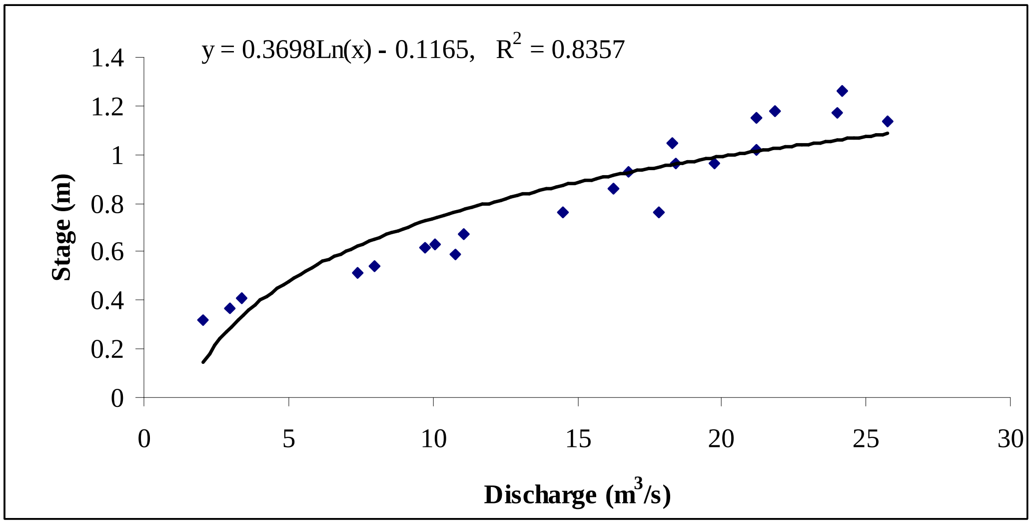


Figure 5. 2. Stage-Discharge Relation at RGS 1LA03, Nyang'ores River.

The stage at 1LA03 increases at a faster rate up to a discharge of about 10 m^3/s then rises steadily thereafter due to increase in the width of the river. The curve is generally satisfactory when the gauge site is well maintained and the stream is not subject to too rapid fluctuation of the stage (Mutreja, 1986). Flows are likely to increase well above 25 m^3/s. Extrapolation beyond the highest recorded high water or lowest recorded low water can be subject to risk and indefinite errors. The most common methods for the extension of stage-discharge curve are: Steven's method, logarithmic method and $\sqrt{S}/n$ method (Mutreja, 1986).

During prolonged rainstorms, discharge and turbulence increased and a progressive increase in the quantity of suspended material present in the water. In the East African forests, increased turbidity and TSS values may also be attributed to deforestation and insufficient soil conservation practices in agricultural areas (Bugenyi and Balirwa, 2003). There was evidence of scouring at the wading site for low measurements (200 m downstream of bridge) and undergrowth of vegetation at the bridge (site for flood measurements) and a well maintained gauge reading site (5 m from bridge). These slight differences of sampling and stage reading sites might alter the RGS statistics and there is need to select another site where sampling and stage reading is done at both low and high flows.

5.1.2. Stage-Discharge Relationship at Amala River

Figure 5.3 shows the stage-discharge relationship at 1LB02, Amala River. The stage – discharge rating curve for 1LB02, Amala River had a coefficient of determination, R^2, of **0. 8513**. The fitted equation for the range of data was:

Stage (m) = 0.0497 + 0.2785* log Discharge) (m^3/s) **(2)**

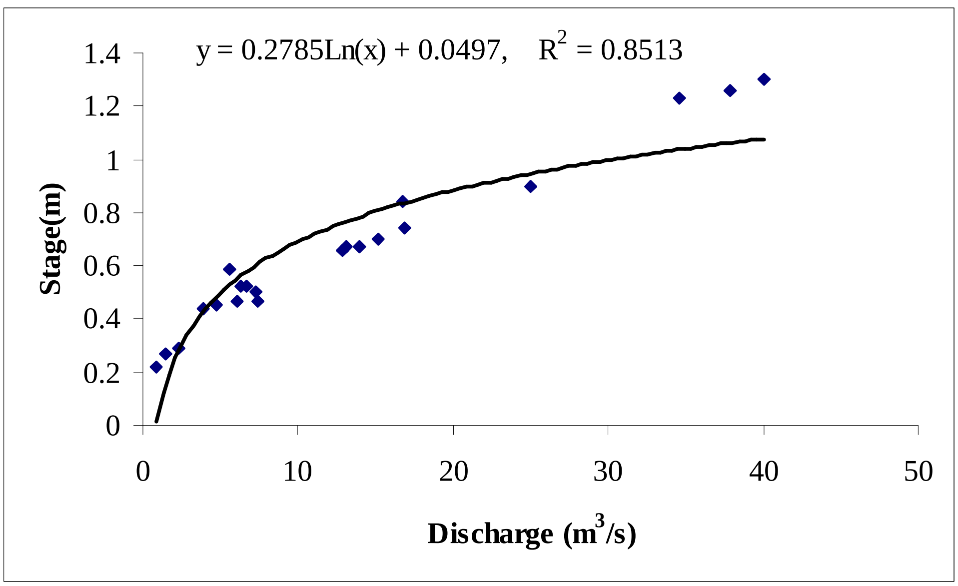


Figure 5. 3. Stage-Discharge Relation at RGS 1LB02, Amala River.

During the rising stage of the river, the velocity and discharge are greater than they are for the same stage when the discharge is constant because of a change in the bed roughness and water surface slope (Mutreja, 1986). However, Amala River shows steep slopes and the gauging and discharge measurements were taken at the same site during high and low flows. The gauging site was a more permanent control (on the downstream of a bridge) and not subject to variations in bed roughness and therefore the simple rating curve is satisfactory.

5.2. Sediment Loading in the Amala and Nyang'ores Rivers

5.2.1. The Suspended Sediments in Nyang'ores and Amala Rivers

Tables 5.1 and 5.2 show the mean daily sediment concentration of Nyang'ores River at ILA03 was 95.16 ± 12.68 mg/l and that of Amala River at 1LB02 was 97.43 ± 12.46 mg/l while the medians were almost the same at 84.5 mg/l and 85 mg/l respectively. Detailed results of data analysis are recorded in Appendix 5. The highest sediment concentration observations were 268.5 mg/l in Nyang'ores River and 258 mg/l in Amala River.

Table 5. 1. The Flows, Sediment and Turbidity for Nyang'ores River at RGS ILA03.

River	**Nyang'ores**		
Statistics (from 22 samples)	Flow (m^3/s)	Sediment concentration (mg/l)	Turbidity (NTU)
Minimum flow (4/4/07)	2.05	35.50	45
Maximum sediment(5/17/07)	18.29	268.50	250
Maximum flow (6/16/07)	25.76	102.50	110
Daily Mean	14.79	95.16	110
Standard error of mean	1.54	12.68	10
Daily Median	16.49	84.5	90
Coefficient of Variation (c.v)	49.0%	62.5%	44.5%

Table 5. 2. The Flows, Sediment and Turbidity for Amala River at RGS 1LB02.

River	**Amala**		
Statistics (from 22 samples)	Flow (m^3/s)	Sediment concentration (mg/l)	Turbidity (NTU)
Minimum flow (4/4/07)	0.89	61.50	60
Maximum sediment (4/13/07)	3.92	258.00	290
Maximum flow (6/16/07)	39.99	146.00	160
Daily Mean	12.73	97.43	130
Standard error of mean	2.51	12.46	13
Daily Median	7.36	85	115
Coefficient of Variation (c.v)	92.7%	60.0%	47.7%

The sediment concentration for Nyang'ores ranged from 35.5 mg/l to 268.5 mg/l. while the sediment loading for the Amala River ranged from 26.4 mg/l to 258 mg/l. Suspended sediment load (SSL) were calculated from the discharge measurements (Q) and suspended sediment concentration (*C*) (equation 3). From the results of the 44 samples (Appendix 5), Nyang'ores River had a mean loading of 128.47 ± 20.15 tonnes/day while Amala River was 131.70 ± 38.56 tonnes/day. This level of sediment loading shows that Mara River is still near pristine conditions compared to other Kenya Rivers. For example, in a study in the Tana Estuary between 2001 and 2003, it was reported that total daily sediment load varied from 2796 tonnes/day during the dry season to 24,322 tonnes /day during the rainy season (Kitheka *et al*., 2003).

Table 5.3 summarizes the existing sediment load measurements in the Mara River system before this study. Comparing the sediment loads during the study period with the historic data, there is a general increase in sediment yield in the upper catchment.

Table 5. 3. Record of Sediment Load in the Upper Mara River, Kenya, before 2007.

River Gauging Station	**Sampling Date**	**Discharge**		**Sediment Loading**
		Gauge	Flows	
	Month/Day/Year	(m)	(m^3/s)	(tons/day)
Nyang'ores River				
1LA03	06/27/1980	0.48	6	39.4
"	07/25/1980	0.52	10	45.8
"	10/27/1980	0.20	2	2.9
"	12/20/2000	0.47	7	29.1
"	04/12/2001	1.16	21	190.4
"	08/31/2001	0.61	10	36.8
"	03/23/2002	0.40	4	32.0
"	09/30/2002	0.39	4	3.8
"	11/28/2003	0.30	2	2.0
"	06/05/2004	0.41	5	5.1
Amala River, 1LB02	12/19/2000	0.36	3	11.7
"	09/30/2002	0.24	2	1.5
"	07/22/2003	0.66	10	44.2
"	11/28/2003	0.26	2	2.2

Source: (Republic of Kenya, 1992; WREM, 2008).

The sediment loading decreased to a minimum in the dry period from February to March before the long rains and then the loading remained at mean discharge in April- May before reaching a maximum in June (Figure 5.4). The trend of sediment loading could be expected to repeat the April-May-June cycle and have another peak in October-November as this area has bimodal rainfall. There is some July-August rain from the west due to the Congo air mass. The higher sediment yield in the Nyang'ores River could explain the increasing problem of siltation in the Tenwek dam (Terer, 2005), 15 km upstream of 1LA03 and associated increase in river turbulence suspending bed load sediment upstream of 1LA03 site.

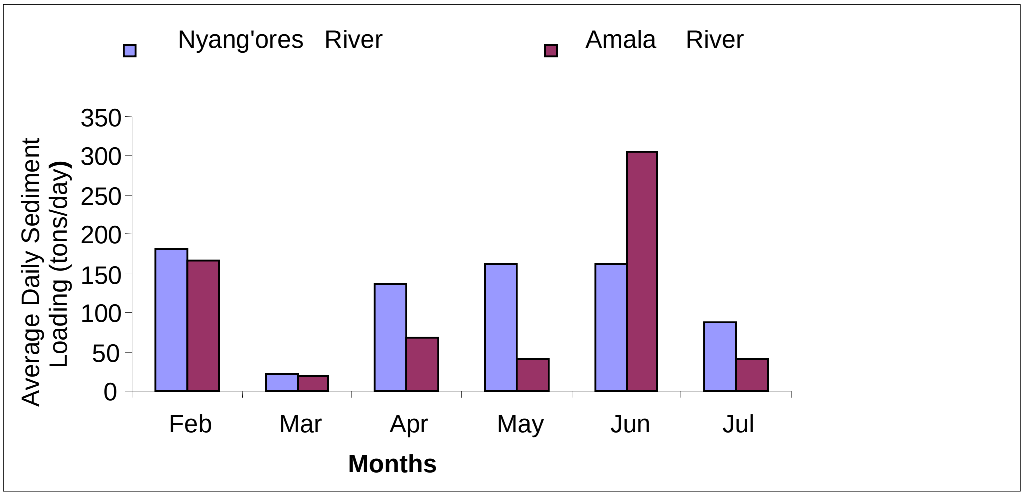


Figure 5. 4. Mean sediment loads for the two stations during the Study.

The high concentration of suspended material at Amala in June was caused by an increase in erosion. A visit made upstream of Kapkimolwa Bridge (1LB02) as far as Matecha Gauging Site in Mau Forest revealed sediment pollution even at the uppermost reach of Amala River. This was attributed to increased agricultural activities and growing commercial centres along the rivers.

With turbidity ranging from 45 NTU to 250 NTU (a mean of 110 NTU) for Nyang'ores River and a range of 28 NTU to 290 NTU for Amala River (a mean of 130 NTU); a comparison was done with four other rivers in Lake Victoria basin (Swallow et al., 2003) shown in Figure 5.5. These average turbidity figures for Mara River lie between the levels of Nyando and Nzoia Rivers. The Nyando river basin is a major source of sediment and phosphorous flowing into Lake Victoria. Of the eleven rivers draining into Lake Victoria, the Mara River Basin is fast becoming the second major source of sediment transport and the sediment concentrations in the Mara River likely to be three times higher than those of Sondu River (Swallow et al., 2003).

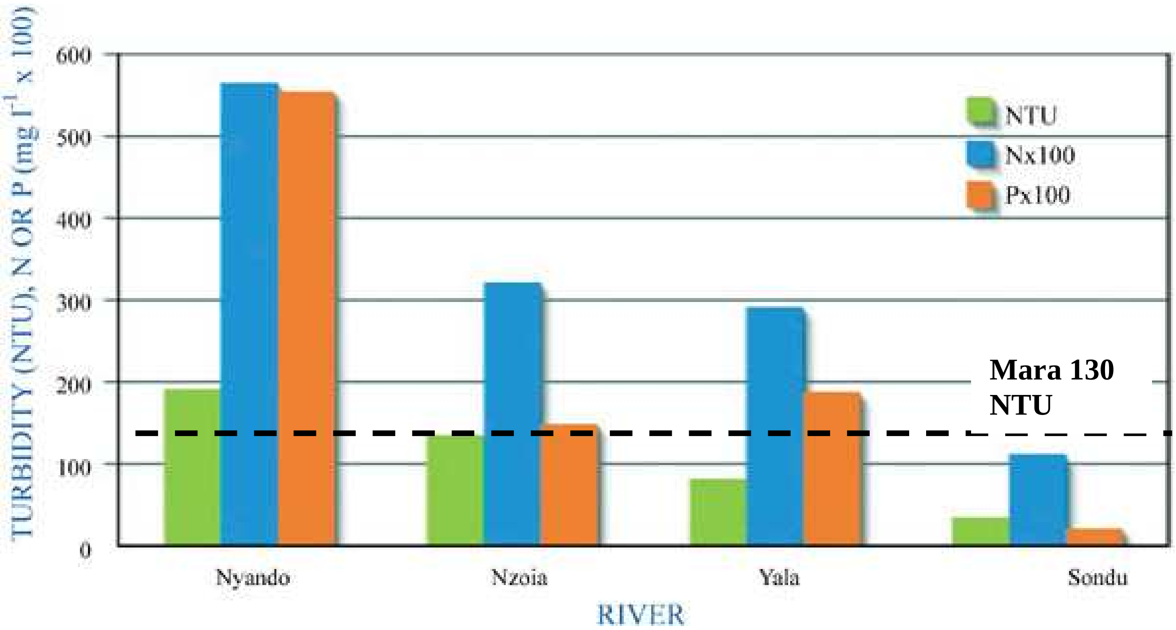


Figure 5. 5. Comparison of turbidity, Nitrogen and Phosphorus rates in four major Kenyan rivers in the Lake Victoria Basin over three successive years (2000-2002).

The riverbanks, upstream of 1LA03 and 1LB02 sampling points, showed some degree of terracing, along with the presence of areas prone to intermittent flooding. Both sites also had active channel banks and in-stream sandbars, indicating the occurrence of active processes such as erosion and sediment deposition (Figure 5.6). There was evidence of soil erosion and the problems this had caused such as the development of gullies in the farms and along cattle tracks near the town (Figure 5.7). The main cause of soil erosion can be attributed to surface runoff from within the farms, from outside their farms and steepness of the farms. There was evidence of substantial quantities of sediment on the riverbeds which gets introduced into the river by erosion processes, and is available to be taken into suspension due to turbulence in the event of increased flow. This could explain the high sediment concentrations on 13/4/07 after a storm preceded by dry period as shown in Table 5.2.

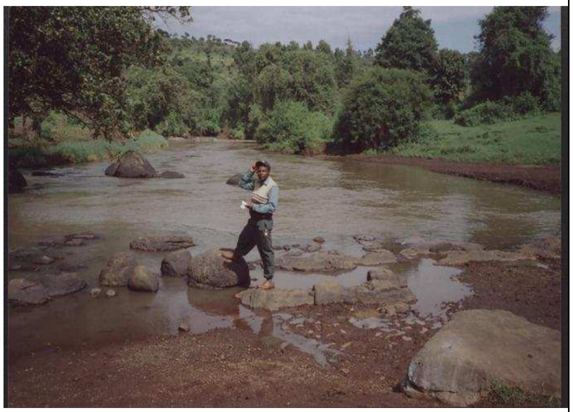


Figure 5. 6. Evidence of terracing and sediment deposition on the upper right and left banks and sandbars (foreground) near Matecha Bridge, upstream of 1LB02.

Figure 5. 7. Gully formation and soil erosion along access road to Bomet Town, upstream of 1LA03.

The average daily sediment loading indicates that the variability of sediment generation flow is more in Amala (c.v of 92.7%) than in Nyang'ores River (c.v of 49.0%). A Statistical Analysis presented in a Box plot by Instat for Windows is shown in Appendix 6.

The results indicated that the difference between means is -2.27 mg/l within a standard error of difference of 17.78 mg/l with 42 degrees of freedom. There was no significant difference between the means of the two tributaries. The potential for sediment generation at these two Regular Gauging Stations (RGS) was the same during the period of study for the two sub-basins. The sediment loading in the two tributaries behaved in a similar manner because: (1) the suspended sediment was caused by erosion from the same rainfall, (2) similar anthropogenic and cultural practices took place upstream at about the same period and (3) the two sub-basins have same major soils. Therefore similar proper land and water management practices should be implemented along both tributaries.

5.2.2. Sediment Rating Curve at Bomet Bridge in Nyang'ores River

The trend in total suspended sediment presented a simple linear regression on log-log graph with a coefficient of determination (R^2) of **0.5887** showing little variation of sediment concentration in Nyang'ores River in Figure 5.8. The fitted equation within the sampled range is:

Sediment Concentration (mg/l) = 19.77 + 22.42 *Log Discharge, (m^3/s) (3)

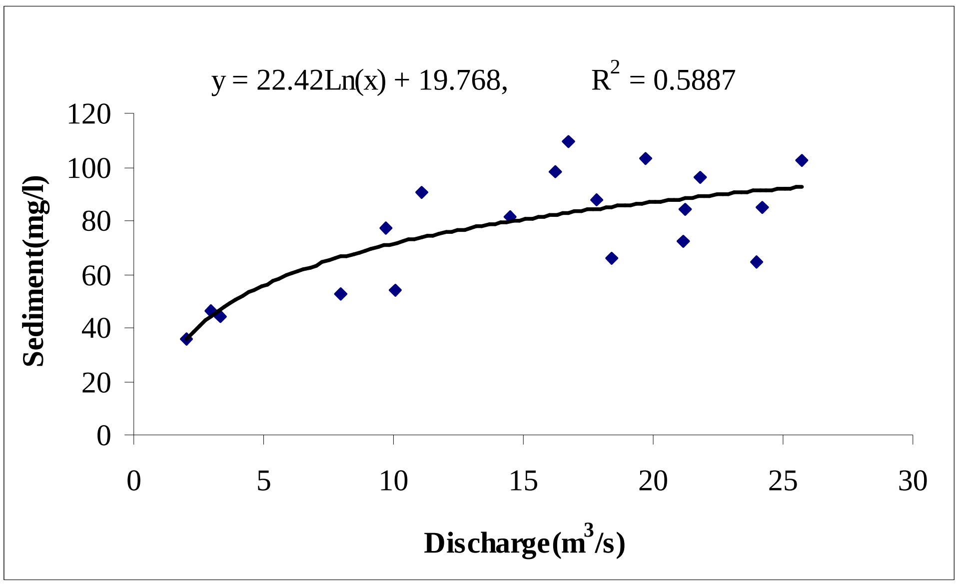


Figure 5. 8. Nyang'ores River Sediment Rating Curve.

These series of discharge and sediment measurements indicate a more or less constant sediment concentration increase, reaching a peak (close to the mean and the median) at a flow of 15 m^3/s. This was due to hysteresis effect caused by a plot of seasonal data or impact of hydraulic characteristics of the 1LA03 site.

This study was done in periods of low to increasing flows. Higher concentrations occurred after a long, dry period or in dry months when vegetation is not able to hold back soil particles that are being eroded. Sometimes the trend toward higher peak flows may be an indicator of urbanization (Haan *et al.*, 1994). However, when these results are used to estimate mean annual sediment yield, the errors in sediment rating tend to compensate and satisfactory results are obtained for sufficiently long record as indicated in Linsley (1988)

Wading was done 200 m downstream from the bridge at a straight section of the river. The site of wading had better hydraulic parameters and could explain why the low flows had a better linear relationship. Further investigations of the Nyang'ores River revealed that the Nyang'ores Bridge is located 5 m downstream of the weir for the Bomet Town Water Supply. Literature shows that weir reservoirs act as effective sinks for suspended matter resulting in reduced suspended matter quantities and depleted nutrients (UNEP, 1991). This could be the phenomenon interfering with flows at the river gauging station at Bomet Bridge (1LA03).

5.2.3. Sediment Rating Curve at Kapkimolwa Bridge in Amala River

When simple regression was applied to the sediment concentration and flow data, a sediment rating curve presented in Figure 5.9 was obtained. The goodness of fit represented by R^2 was **0.5112**. The fitted equation was then (equation 4):

Sediment Concentration (mg/l) = 28.182 + 31.007*Log Discharge) (m^3/s) (4)

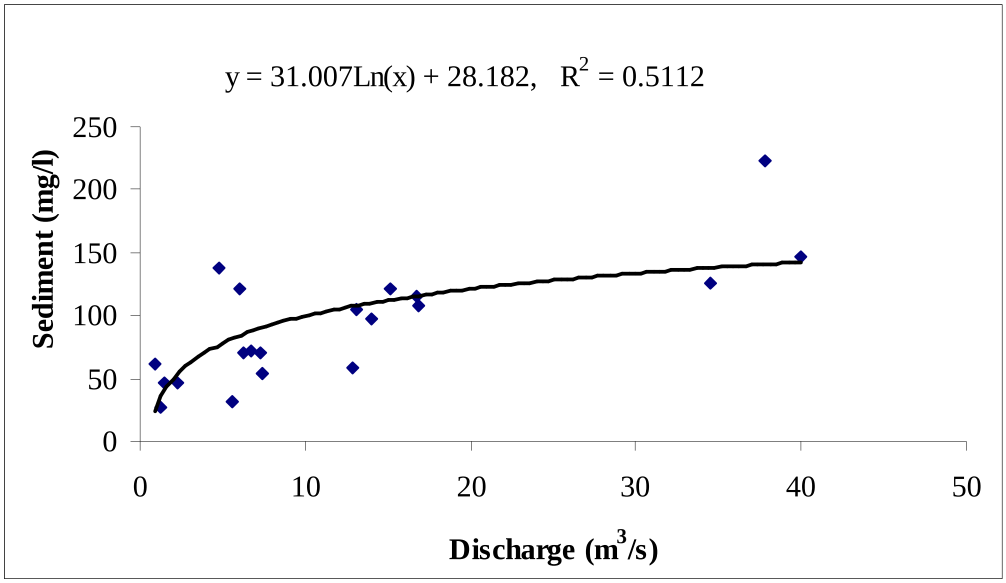


Figure 5. 9. Amala River Sediment Rating Curve.

A box plot of the data before conducting any detailed statistical analysis indicated the highest observations as having values more than 2.5 standard deviations from the mean and could be regarded as outliers (Stern *et al.*, 2006). However, discarding outliers in hydrology (unless due to recording error) can cause one to underestimate the true variability of the data. In flood frequency determinations, it is generally assumed the data are measured without error (Haan *et al.*, 1994). Hence only two measurements (3.92, 258 and 24.95, 47) were not included in the regression and regarded as outliers.

There were many areas along the riverbank without vegetation and showing deep gullies forming along moderately trampled human and animal trails and car washing sites. There is evidence of significantly high levels of erosion along the Amala River, with the riverbank showing deep undercutting (Figure 5.10).

Figure 5. 10. Deep gullies formed along the riparian zone by human, animal and wildlife trails at Amala river.

5.2.4. Sediment and Turbidity Relationship

Figure 5.11 shows the Sediment-turbidity relationship in Nyang'ores River while Figure 5.12 depicts the situation in Amala River. The regression analysis for Nyang'ores River produced a good equation ($R^2 = 0.9341$):

Turbidity (NTU) = 32.62 + 0.7558 * Sediment (mg/l) **(5)**

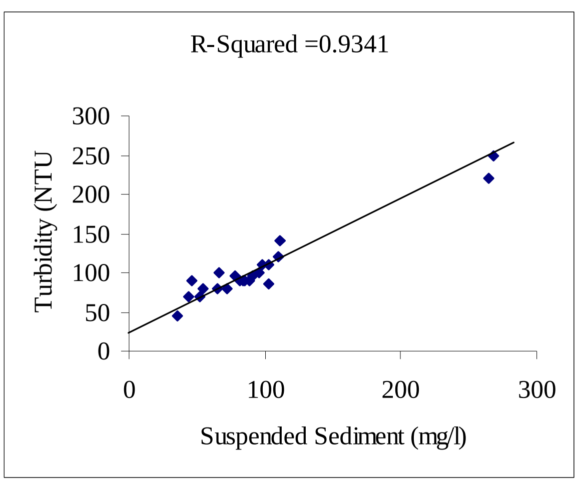


Figure 5. 11. Sediment-Turbidity Relationship for Nyang'ores River.

And for Amala River, the fitted equation also had a linear relationship with R^2 = 0.7496:

$$\textbf{Turbidity (NTU) = 40.32 + 0.9126 * Sediment (mg/l)} \qquad \textbf{(6)}$$

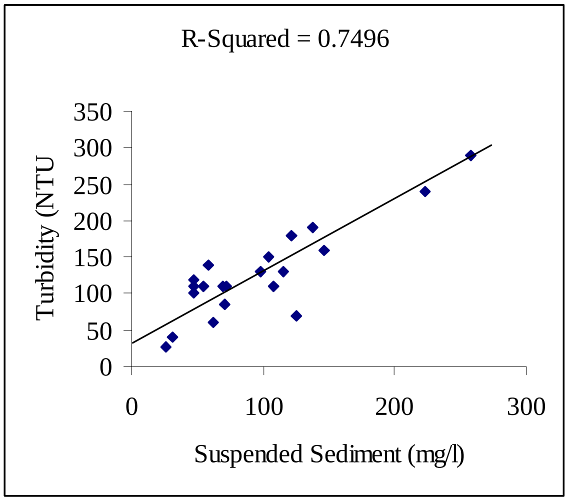


Figure 5. 12. Sediment-Turbidity Relationship for Amala River.

The water is more turbid in Amala River than at Nyang'ores River. Since it is easier to measure turbidity at the Bomet station, these relationships can be used to estimate suspended sediment concentration. Bartram and Ballace (1996) reported that when the suspended sediment is comprised mainly of silt + clay this procedure should be carried out regularly and then daily with automatic equipment during storms to reduce the high variability and capture intermediate sediment discharges.

5.2.5. Discussions on suspended sediment at Amala and Nyang'ores Rivers

The study shows that the water quality at the two regular gauging stations had a TSS of more than 30 mg/l, the maximum figures recommended by Kenya for domestic use and effluent discharge into the environment (Republic of Kenya, 2006a). The turbidity at the two RGS was more than 5 NTU recommended by WHO (Chapman, 1996) for drinking water and 50 NTU for aquatic life and recreational waters in Kenya (Republic of Kenya, 2006a). The methods used for discharge computation gave sufficiently accurate results (Table 5.4) which can be used by water managers.

Table 5. 4. Parameters a, b and R^2 from Regression Equations for the respective variables.

Equation (No.), Log = Logarithmic	A	B	R-Squared
Stage/Discharge - Nyang'ores (1): Log	-0.1165	0.3698	0.8357
Stage/Discharge – Amala (2): Log	0.0497	0.3698	0.8513
Sediment/Discharge – Nyang'ores (3): Log	19.768	22.42	0.5887
Sediment/Discharge – Amala (4): Log	28.182	31.007	0.5112
Turbidity/Sediment- Nyang'ores (5): Linear	32.620	0.7558	0.9341
Turbidity/Sediment – Amala (6): Linear	40.320	0.9126	0.7496

The trend was either a Logarithmic or linear relationship. The accuracy of any method however depends on so many factors, such as the accuracy of flow-depth determination, accuracy of current meters, samplers, weighing machines and turbidity meter. Nevertheless, usually the accuracy of flow measurement by Mid-section method employed in this study and by the Ministry of Water and Irrigation, Kenya, can be expected to provide an estimate within ± 5-10% of the true flow (Mutreja, 1986).

The problems associated with this rate of sediment pollution due to heavy soil run-off include: water users downstream of 1LA03 and 1LB02 may have to remove suspended sediment from their water supplies or may suffer a reduction in the quantity of water available because of reservoir siltation. The rapid reduction in the storage capacity of reservoirs due to siltation is a major sediment- related problem worldwide. Silt and clay will stay in suspension much long and move further within the reservoir or downstream in the river. Kenya must therefore seek environmentally sustainable options to curb the pollution of water, protect water catchments, and reassure communities on continued availability of safe water.

Reduced infiltration rates and excessive runoff caused by loss of ground cover **(**Terer, 2005) in the drainage basin of the Mara River have resulted in flashy flow regimes and flooding in down stream sections of the river. Silt loads carried by the river have increased, confirming previous baseline survey data (Singler and McClain, 2006). Rainfall has decreased over the last 30 years but sediment loading has increased 5 times. Deforestation can raise a river's suspended matter more than 100 times (UNEP, 1991). This is likely to be the case in this catchment and to realize Kenya's development targets and good neighborliness with Tanzania; this trend must be reversed urgently.

EPA (2003) has recommended the removal of at least 80 % of total suspended solids (TSS) from polluted runoff to control heavy metal, phosphorus and other pollutants. Structural measures to control runoff may include infiltration devices, such as infiltration trenches, infiltration basins, filtration basins, and porous and concrete block pavement and rely on absorption of runoff to treat urban runoff discharges. Filtration practices such as filter strips, grass swales, and sand filters treat sheet flow by using vegetation or sand to filter and settle pollutants. Detention practices like detention ponds, wet ponds, constructed urban wetlands, multiple-pond systems and water quality inlets temporarily impound runoff to control runoff rates, and settle and retain suspended solids and associated pollutants.

Runoff from urban centres or overflows of storm water is regulated in the developed world like the German regulations that require 90 % of all pollution loads from urban areas, including overflows, to receive treatment (Novotny, 1989). From the level of sediment pollution recorded in this study, NEMA and other statutory bodies should also recommend the removal of at least 80 % of total suspended solids (TSS) from runoff from urban centres in the Mara River Basin. This would translate to reduction from 95.16 to 19.03 mg/l for Nyang'ores River and from 97.43 to 19.49 mg/l for Amala River, concentrations that are within the acceptable limits.

5.3. Trace Metal Pollutants in Suspended Sediment

The concentration of toxic elements (Zn, Cu, Fe, Mn, Pb and others) in river water is an important factor to be considered in the planning and management of health river ecosystems. The elements in the 12 dried samples were identified by their spectral energies for qualitative analysis and the intensities of the emitted spectral lines enabled quantitative analysis using comparison counts of a standard element, Cadmium (^{109}Cd). The constituents of sediments during low and high flows were assessed against WHO (Chapman, 1996) and Kenya Guidelines (Republic of Kenya, 2006a). Though some of these are essential plant nutrients, almost all become phytotoxic at high levels and WHO and Kenya have set safe limits. EDXRF is a powerful nuclear analytical technique for heavy metals analysis because all elements emit characteristic radiation when subjected to appropriate excitation.

5.3.1. EDXRF analysis for Nyang'ores and Amala Rivers

Examples of the spectrum produced by the computer analyzer for Nyang'ores sediment at 1LA03 is shown in Figure 5.13.

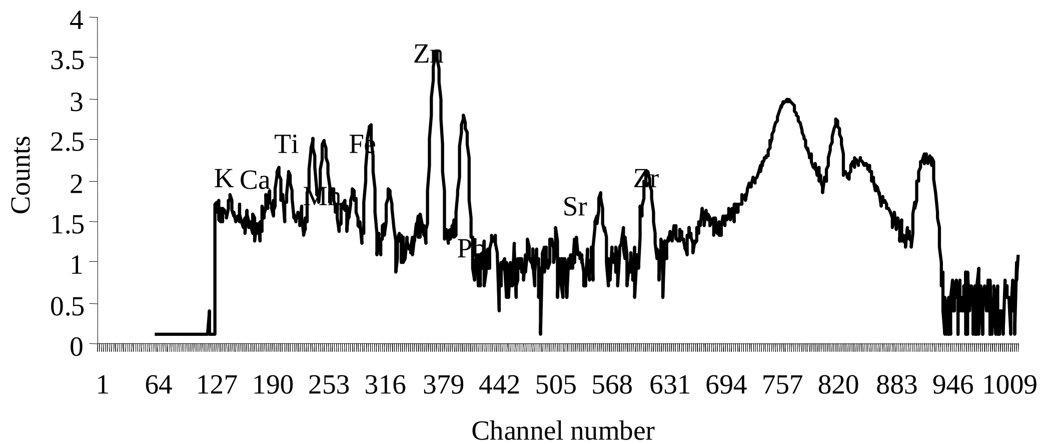


Figure 5. 13. Typical XRF spectrum for sample 10N5 from Nyang'ores River.

Each element, represented by the channel numbers, has a unique electronic configuration and produced two peaks. The emitted secondary radiation (peak) is a characteristic of that element. Zinc (Zn) and Iron (Fe) had the highest counts while lead (Pb) had the lowest in Nyang'ores samples. The second process on the right (after channel No.631) was scattering of the incident photons in all directions after collision with atoms. The scattering photons have either a longer wavelength or the same wavelength and therefore producing a similar curve (Sparks, 1978). Just like in Nyang'ores River, the main elements in Amala were Iron (Fe); Zinc (Zn), and Manganese (Mn).

Examples of the spectrum for Amala River sediment produced by the computer analyzer are shown in Figure 5.14.

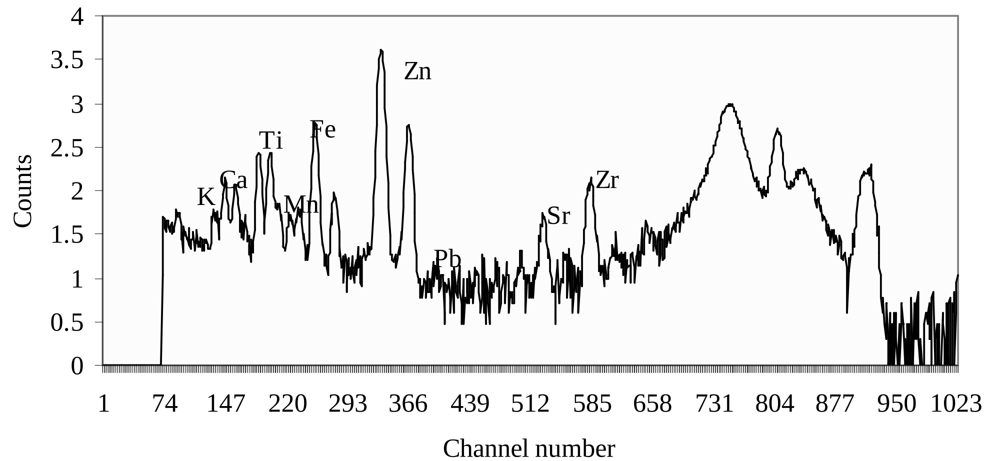


Figure 5. 14. Typical XRF spectrum for Sample 9A5 from Amala River.

Trace metal concentration is measured in microgram per gram (µg/g). For calculation of the load of a pollutant, the pollutant concentration in suspended sediment was multiplied by the mean suspended sediment concentration that had been measured earlier. For example, the XRF direct comparison of counts for Zinc concentration on 04/04/07 at Nyang'ores River was 1134.7 parts per millions (ppm). The suspended sediment concentration producing this Zinc concentration was 35.5 mg/l. Therefore the Zinc metal concentration is $(1134.7/10^6) * 35.5$mg/l = 0.04028 ppm. The main elements, with the highest counts, were Iron (Fe); followed by Zinc (Zn) and Manganese (Mn). The concentrations of the 3 metals for the different sampling dates are discussed further.

The calculated concentrations of the trace metals in Nyang'ores and Amala River samples are shown in Table 5.4 and 5.5 respectively.

Table 5. 5. Trace Metal present in the suspended sediments of Nyang'ores River.

Year 2007	Zinc (Zn)	Iron (Fe)	Manganese (Mn)	Lead (Pb)	Copper (Cu)	Titanium (Ti)	Vanadium (V)
Date	**Ppm**	**ppm**	**Ppm**	**ppm**	**Ppm**	**Ppm**	**Ppm**
04/04	0.040	0.010	0.000	0.0003	0.0003	0.0000	0.0000
14/04	0.256	0.638	0.029	0.0021	0.0014	0.0028	0.0000
25/04	0.099	0.248	0.011	0.0008	0.0004	0.0010	0.0000
17/05	0.261	0.652	0.027	0.0022	0.0014	0.0029	0.0014
20/06	0.075	0.059	0.003	0.0005	0.0003	0.0002	0.0004
02/07	0.114	0.071	0.003	0.0006	0.0007	0.0000	0.0000

Table 5. 6. Trace Metal present in the suspended sediments of Amala River.

2007	Zinc (Zn)	Iron (Fe)	Manganese (Mn)	Lead (Pb)	Copper (Cu)	Titanium (Ti)	Vanadium (V)
Date	**Ppm**	**Ppm**	**Ppm**	**Ppm**	**Ppm**	**Ppm**	**Ppm**
04/04	0.070	0.024	0.001	0.0003	0.0003	0.0000	0.0000
14/04	0.264	0.650	0.014	0.0020	0.0020	0.0020	0.0000
30/05	0.062	0.039	0.001	0.0006	0.0004	0.0000	0.0000
02/06	0.136	0.158	0.007	0.0009	0.0010	0.0000	0.0000
14/06	0.241	0.369	0.014	0.0020	0.0010	0.0010	0.0000
03/07	0.115	0.025	0.001	0.0004	0.0000	0.0000	0.0007

5.3.2. Zinc concentration in the Upper Mara River

Zinc was available at levels ranging from 0.040 mg/l to 0.261 mg/l throughout the period at 1LA03 and from 0.070 mg/l to 0.264 mg/l at 1LB02. Comparison of these data and the TSS in Table 5.7 indicates that the zinc pollution was 0.1% of the total sediment concentration

Table 5. 7. Zinc Concentration as a percentage of Suspended Sediment Pollution.

Date	1LA03 Sediment (mg/l)	Zinc (ppm)	%	Date	1LB02 Sediment (mg/l)	Zinc (ppm)	%
04/04	35.5	0.040	0.11	04/04	61.5	0.070	0.11
14/04	264.0	0.256	0.10	14/04	258.0	0.264	0.10
25/04	102.5	0.099	0.10	30/05	54.5	0.062	0.11
17/05	268.5	0.261	0.10	02/06	121.5	0.136	0.11
20/06	64.5	0.075	0.12	14/06	223.0	0.241	0.11
02/07	90.5	0.114	0.13	03/07	58.0	0.115	0.20

In discussing heavy metal pollution, Metcalf &Eddy Inc. (1991), reports that it is frequently desirable to measure and control the concentration of Zinc, among other priority pollutants such as excess Zinc in Mara River could be from zinc-coated (galvanized) containers and iron-sheets or dumpsites where waste of acidic foods that are usually added to water from commercial and industrial activities. There is no storm water and sewerage system in the shopping centres upstream of 1LA03 and 1LB02 and so the runoff that may be carrying zinc ions is not pretreated before discharge to the water channels.

It is reported by Merck & Co, Inc. (2003) that excessive absorption of zinc by humans for a long time can also suppress copper and iron absorption in the body and impair the immune system. The effects of toxicity may not show up for years, or levels may become toxic to humans only through bioaccumulation in aquatic organisms (UNEP, 1991). Symptoms of toxicity include a metallic taste in the mouth, nausea, vomiting and diarrhea. The free zinc ion in solution is highly toxic to plants, invertebrates, and even vertebrate fish. Zinc levels in the Mara River were not yet toxic being less than the safe limits; 1.5 mg/l for drinking water and 0.5 mg/l for effluent discharge and 2.0 mg/l for irrigation in Kenya (Republic of Kenya, 2006a). Other countries like EU and Canada set lower limit at 0.03 mg/l while Russia has a limit of 0.01 mg/l (Pearce, 1999) for fisheries.

Zinc levels in the study area could also be attributed to the high concentrations of Iron in Zinc that occurs in nature with other metals of which Iron is the most common (Dallars and Day, 1993). Zinc increases when Iron increases in Amala River. The concentrations of Iron, Zinc and Manganese at 1LA03 and 1LB02 for the different sampling dates are shown in Figure 5.15 and 5.16 for comparison.

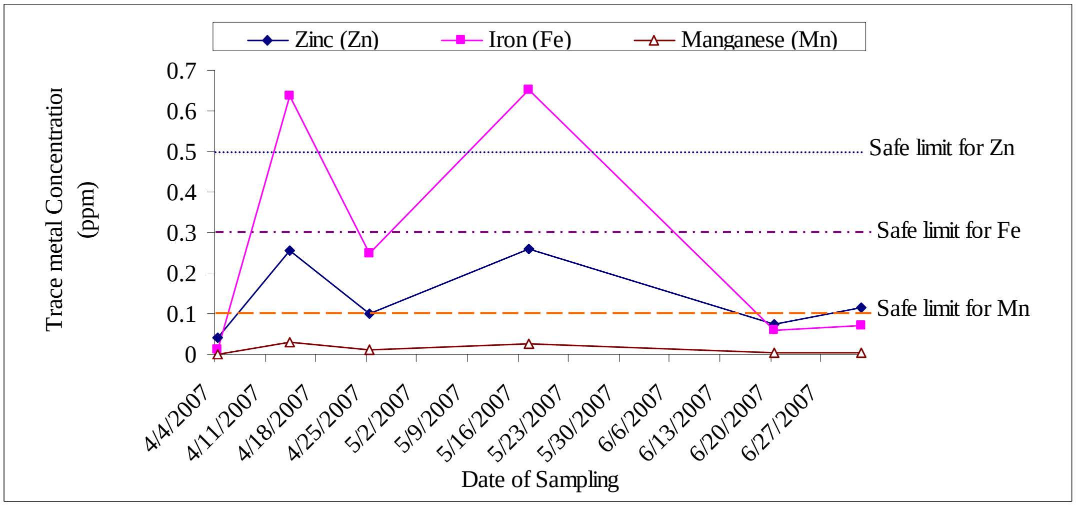


Figure 5. 15. Concentrations for Zinc, Iron and Manganese at Nyang'ores River on different sampling dates.

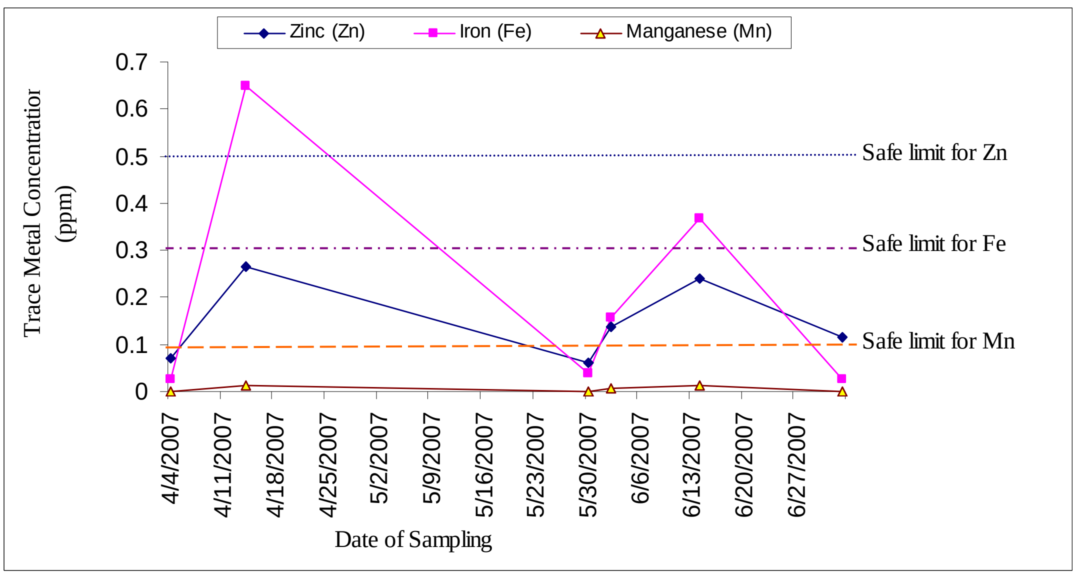


Figure 5. 16. Concentrations of Zinc, Iron and Manganese at Amala River on different sampling dates.

5.3.3. Iron Concentration in the Upper Mara River

From Figures 5.15 and 5.16, the levels of Iron pollution ranged from 0.024 mg/l in the dry period to 0.650 mg/l during the wet season in 1LB02 and from 0.010 mg/l (dry period) to 0.652 mg/l (wet period) in 1LA03. High levels of Iron were recorded on 14^{th} April 2007 (0.650 mg/l) and 14^{th} June (0.369 mg/l) in 1LB02 and on 14^{th} April (0.638 mg/l) and 17^{th} May (0.652 mg/l) at 1LA03.

Rate and amount of Iron concentration increase immediately after the drier period was higher than the Iron increase due to increased discharge in the middle of the rainy season (Appendix 7). Comparison was done between the two peaks of each of the graph and the respective flows and rainfall patterns for days before and during sampling for 5 main rain gauge stations in the upper Mara catchments (Figures 5.17 and 5.18).

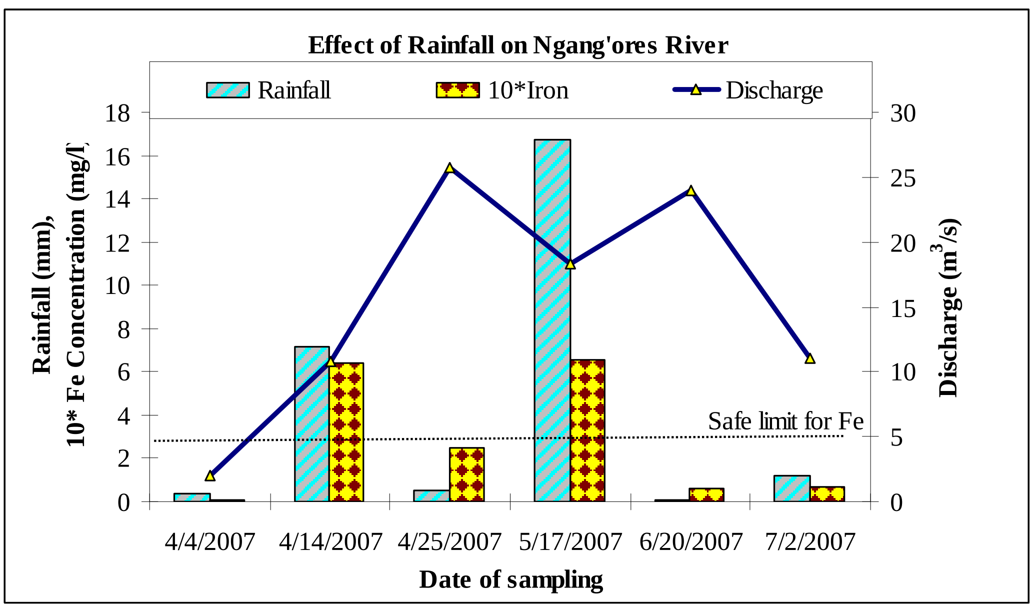


Figure 5. 17. The Impact of rainfall to Iron concentration in Nyang'ores River.

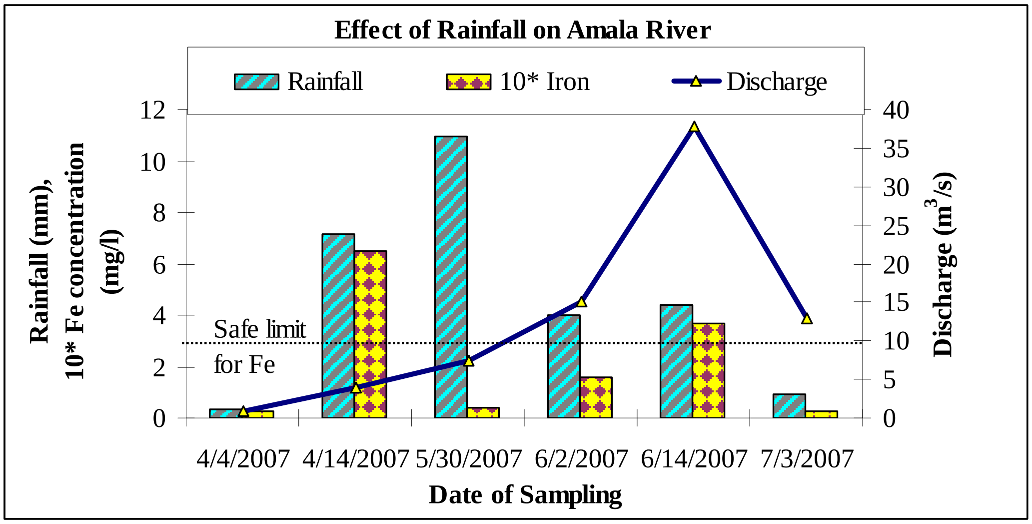


Figure 5. 18. The Impact of rainfall to Iron concentration in Amala River.

It was evident that Iron increased during the rising limb of flow in the hydrograph. Low metallic concentrations were observed in the drier periods and after a prolonged period of flooding. The iron pollution could be attributed to soil erosion in the study area and high organic matter in the swamps upstream. The Andosols in the agricultural zone upstream of 1LA03 and 1LB02 have high silt content and susceptible to serious erosion problems (Muchena *et al.*, 1988). These soils are susceptible to mass movement (slump and landslide) especially where thin soil layers are resting on unconsolidated volcanic ash deposits. The increased iron concentration could be related to geological and anthropogenic influence, soil erosion and run-off from point sources like rusted metallic articles at the shopping centres, scrap metal dump sites and any sludge lagoons upstream.

The iron concentrations in four samples were above the WHO maximum allowable level of 0.30 mg/l for drinking water but within the Kenya guidelines for irrigation water (1.0 mg/l) and discharge to the environment (10 mg/l). Above the 0.30 mg/l level, the water is objectionable due to yellow colour and a bitter taste and in fact some countries set the limits at lower levels. For example, EU the limit is 0.2 while in Russia it is 0.1 mg/l (Pearce, 1999). Therefore considering the downstream use of Mara River include tourism hotel industries; the allowable limits of pollutants for such significant rivers should be reviewed.

Comparing this range of concentration with the Mara Baseline water quality dataset (Appendix 8), the level of Iron pollution in 2004 was ≤ 0.10 mg/l .Thus the study indicated that iron pollution has increased in the recent past. Water treatment would therefore be necessary before consumption of Mara river water. Excessive iron can be toxic, because free ferrous iron reacts with peroxides to produce free radicals, which are highly reactive and can damage DNA, proteins, lipids, and other cellular components. Excess iron consumption causes vomiting, diarrhea, and damage to intestines and if consumed over a long period of time may damage coronary arteries (Merck& Co, Inc., 2003).

Emoyan *et al.* (2005) in a similar study in Nigeria, found out that iron concentration also increases during floods due to low dissolved oxygen content in the river system, in that Iron can easily be absorbed on particulate organic matter or complexes with colloidal organic matter in aquatic environment. Figure 5.19 shows that soil erosion and shopping centres upstream of the gauging sites could be the possible sources of trace metal pollution.

Figure 5. 19. Intensively cultivated and degraded area upstream of RGS at Bomet Bridge.

5.3.4. Other Metallic Pollutants in the Upper Mara River

The Manganese concentration ranged from 0.0001 mg/l to 0.029 mg/l in RGS 1LA03 and 0.001 mg/l to 0.014 mg/l at RGS 1LB02. Manganese is a mineral element that is both nutritionally essential and potentially toxic. Though the Manganese concentration was within the WHO safe limit of 0.10 mg/l (Chapman, 1996), the Government of Kenya has not yet set any limit on Manganese except that one is not allowed to discharge effluent into the environment beyond 10 mg/l of Manganese (Republic of Kenya, 2006a). Therefore Manganese pollution was only objectionable due to brownish-coloured stains imparted to laundry. In the U.S., the Environmental Protection Agency (EPA) recommends 0.05 mg/l and Russia 0.01 mg/l as the maximum allowable manganese concentration in drinking water (Pearce, 1999; EPA, 1976).

From Table 5.3 and 5.4, Lead (Pb) in 1LB02 had a reasonably constant concentration (0.0003 to 0.0020 mg/l) and WHO has set maximum allowable levels of 0.01 mg/l (Chapman, 1996). Small fish can be affected by doses as low as 0.001 mg/l and hence the concentration of lead (0.0022 mg/l) at 1LA03 would be a concern in countries like Canada which have set a limit of 0.001-0.007 mg/l in fisheries and aquatic life (Pearce, 1999). Lead is naturally distributed in surface waters due to weathering of minerals and atmospheric deposition (Merian, 1991). The constant Lead concentration in the study area could be from road run-off and areas of industrial and other technical uses of lead by the Bomet residents and other town dwellers upstream. There was a possibility of storm flush floods reaching the river from garages, petrol stations and dumpsites which are the source of electric storage batteries, petroleum products, chemical pigment and alloy leachate. The danger of emissions from high levels of tetraethyl lead products could not be ruled out after local people reported at one time having an oil spill from a boiler in one of the institutions along Nyang'ores River. Lead is a cumulative poisonous metal whose main target for toxicity is the nervous system, both in adults and children and so long-term exposure would cause a danger to the population.

Copper (Cu) concentration was in the range of 0.0003 to 0.0020 mg/l. The national maximum allowable level is 0.05 mg/l both for domestic and irrigation water (Republic of Kenya, 2006a) while other countries have stricter limits for fisheries, for example, in Russia the limit is 0.001mg/l, in Canada 0.002-0.004 mg/l, and in EU 0.005-0.112 mg/l (Pearce, 1999). Copper is toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions but it was not a problem in the Mara River.

Titanium concentration ranged 0 to 0.0020 mg/l at 1LB02 and 0.0029 mg/l at 1LA03. Titanium has a tendency to bio-accumulate in tissues that contain silica. An unknown mechanism in plants may use titanium to stimulate the production of carbohydrates and encourage growth. This may explain why most plants contain about 1 part per million (ppm) of titanium, food plants have about 2 ppm and horsetail and nettle contain up to 80 ppm. Since the Mara Titanium concentrations were in water, they were too little. The concentration of Vanadium was 0 to 0.0007 mg/l at 1LB02 and 0.0014 mg/l at 1LA03 well below the WHO maximum allowable dissolved levels for drinking water. However, it is reported that vanadium is toxic to many plants at relatively low concentrations (Metcalf & Eddy Inc., 1991) and therefore there is a need for closer monitoring.

5.3.5. Summary Discussion on Trace Metal Pollution

The mineral content of surface water in the upper Mara Basin is a function of the kind of rocks prevalent in the water's course, the nature of the soil over which the water flows from Mau Forest, and the pollution by human activities in the farms and towns upstream of gauging sites. The possible sources of the metallic pollution in the Upper Mara basin are anthropogenic activities in the commercial centres, natural soil erosion in farms and river system and point sources like solid waste dumpsites. Comparing the metallic concentration results with those obtained during the baseline survey (Appendix 8), there is an increase in trace metal concentration in the upper Mara basin. Rainfall data shows that the monthly rainfall variability is very marked. Specifically, in dry years, many stations register negligible amounts for several months, while in wet years, the rainfall amounts exceed the mean by three- and even four-fold. The high rainfall variability indicates that the Mara Basin is vulnerable to climatic extremes, thus creating the need for water infrastructure investments.

Although serious contamination was observed during the beginning of wet season only with iron, Zinc, Manganese and Lead results warrant further consideration and follow-up actions due to bioaccumulation and bio-magnification. The consumption of contaminated water, root crops and fish grown in such water exposes humans to high levels of risk, which can bioaccumulate resulting in adverse health effects. Chemical treatment like adding 10 ml of 1.2% sodium hypochlorite may be required to reduce excessive levels of iron, manganese, chalk, and organic matter. Such treatment is usually followed by clarification. Iron may be removed by aeration or chlorination to produce flocculants which can be removed by filtration. Manganese may be removed by aeration followed by adjustment of pH and up-flow filtration (ATSDR, 2005).

5.4. The Environmental Flow Assessment in the Mara River Basin

Surveys conducted as part of GLOWS and VICRES projects identified the many resources provided to local communities by an intact riverine ecosystem, and the state of ecosystem health desired by the community to ensure the provision of those services. The discussion focuses on suspended sediment and metal pollution, health risks that are principally caused by the consumption of affected fish and adsorption in crops irrigated with Mara River. There is also the danger of assuming that once the recommended environmental flow has been allocated, the river system will be healthy. The community and development agencies would become complacent and fail to routinely monitor and treat the water as required by the W.H.O. and Kenyan legislation. Although there is equilibrium between the aqueous salts and the adsorbed ions, it is possible for heavy metals to be accumulated where sediment is deposited (Pearce, 1999)

The results show two annual peaks, one of 12-13 m^3/s in April and May and the second of 17-20 m^3/s in August and September. The dry period had flows of less than 5 m^3/s from November to March while average flows were in June, July and October. This trend would therefore define an "average year" also referred to in literature as "maintenance" or "normal" year (King *et al.*, 2000).

5.4.1. Environmental Flow Assessment for Ecology

Barbus altianalis and *Labeo victorianus* fishes (Figure 5.20) were the most sensitive species documented in the Mara River and flow recommendations made for these species would be suitable for all other species. They have one breeding season that is closely linked to peaks flows.

Figure 5. 20. *Barbus altianalis* and *Labeo victorianus* fish species in Mara River Site in July, 2007.

Two species are very sensitive to reductions in water quality and quantity as well as changes in timing of flow events. The wet season base flows must therefore inundate lower banks and benches, allowing the input of nutrients from those systems to the river as well as allow fish passage over larger obstacles and recharge of wetlands to provide access to floodplain nursery grounds. Dry season base flows must maintain inundation of the riffles. During the March sampling event, the discharge of the Amala River (width of 10 m) was 1.2 m^3/s requiring a minimum average depth of 0.45 m to achieve 100% coverage of riffles at Sites 1 and 2. At the lower Mara River (width 27 m), the discharge in March was 7.5 m^3/s requiring a minimum average depth of 0.95 m due to differences in width of water surface. A threshold depth of 0.20 m is needed to allow upstream migration of the larger-bodied members of fish species (Welcomme *et al*., 2006) and therefore the flows were sufficient. The most common cause of changes in the health of flow regime of upper Mara catchment is human activity like land-use changes such as urbanization, deforestation and channel erosion. Hence findings of this study on the increased sediment pollution should inform the threat to the fishing industry.

At Site 1 (Amala), different macro invertebrates were present, for example the dragon flies (Figure 5.21).

Figure 5. 21. An adult Dragonfly (*Libellulidae*) at Site 1.

This suggests the river is in good condition at this site, with high habitat diversity, although the findings on sediment pollution show increasing degradation due to small scale anthropogenic activities such as grazing livestock and subsistence agriculture.

Site 2 (Middle Mara) had a reduction in the number of macro invertebrates indicating a rapid deterioration in water quality from the first to the second site. Site 3 (Lower Mara) showed a slight improvement in the presence of invertebrates indicating water quality at that site was on the border between good and bad. Because this site was located within the protected areas, human impacts were minimal; however, upstream degradation continued to impact these downstream locations.

The water may suddenly become anaerobic during low flows due to increase in effluent discharge from urban centres and tourist hotel facilities along the river. This is largely due to increased sediment load as a result of deforestation and unsustainable agricultural practices, increased feacal coli-forms and possible seepage of heavy metals from point sources like dumpsites and small scale mining.

There were several areas in the upper reaches of the river that had been cleared for cultivation or were already abandoned, as well as evidence of heavy grazing by livestock. In the vast middle part of Mara Basin, large trees such as *Diospyros abyssinica* and *Prunus africana* dominated the banks, declining into isolated thickets of shrubs 30 m away from the channel. This zonal delineation in response to bank terracing suggests the intact influence of flooding dynamics, linked to magnitude, duration and return period of high and low flows. The large trees present at the lower reach were *Acacia hockii* and one *Ficus sp*., typical of seasonally drained grasslands. There were also herbaceous species present indicating anthropogenic land disturbance, as well as evidence of heavy grazing by wildlife.

5.4.2. Sediment during the Maintenance (Average) Years

Figure 5.21 shows the Environmental Flow Recommendations for maintenance (average) year at Site 1. The Figure illustrates that during maintenance years the reserve is easily met and ample water is available for extractive uses. Environmental flow has priority over all water uses and the requirements of the reserve must be met before water can be allocated for other uses (Republic of Kenya, 2006b). Higher volumes of environmental flow may be required to compensate for sedimentation of reservoirs and water treatment losses along the Mara River to maintain the flows in Figure 5.22 of 1.00-2.00m/s.

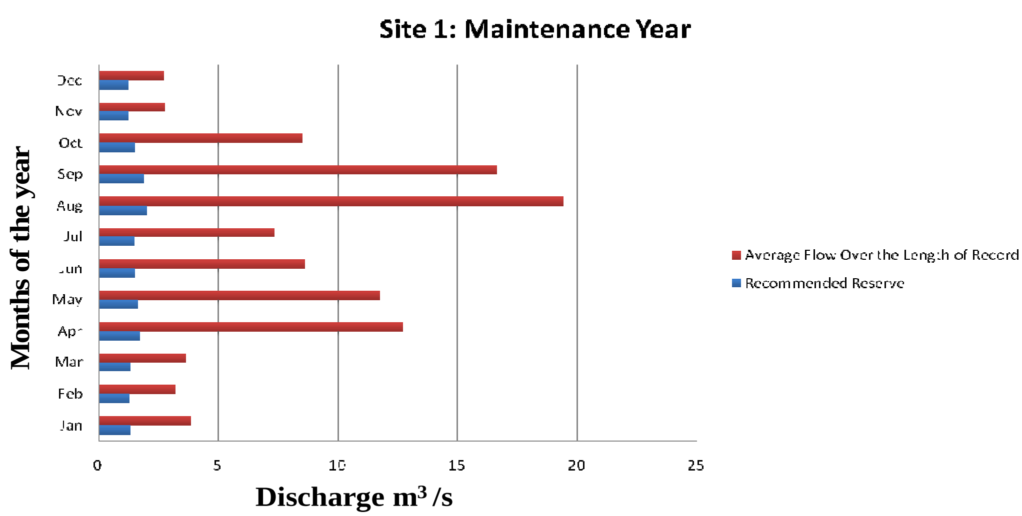
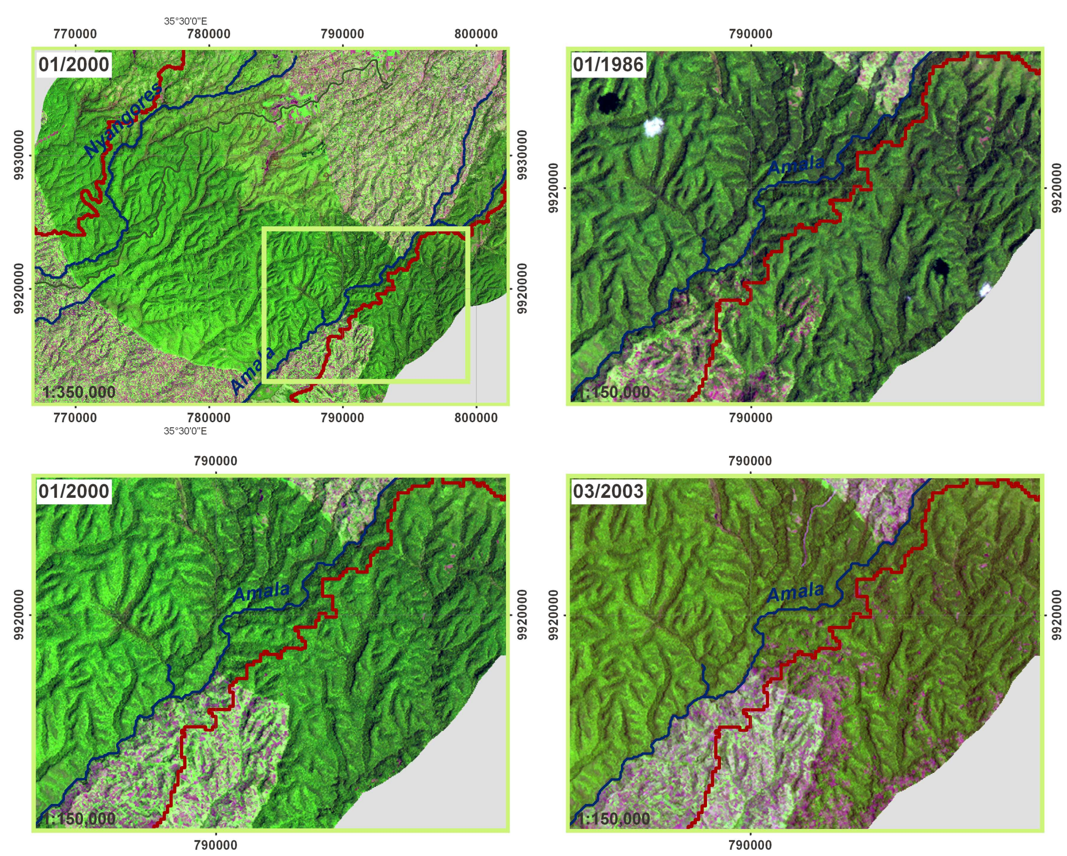


Figure 5. 22. Environmental Flow Recommendation for Site 1 in a maintenance year.

Increased sediment load may negatively impact aquatic biota by reducing light penetration, reducing suitable habitat, smothering fish fry, clogging gills and ultimately altering the biodiversity of the system. Therefore additional measures like water quality improvement and rehabilitation of the upper Mara basin are essential and should be combined as requirements to maintain the recommended environmental flow (reserve). Previous studies on hydrology in the Mara River (Mutie, 2006) and satellite imageries (Figure 5.23) on land use changes in the Mara River Basin showed that land restoration in the upper catchment is necessary for the river health to be restored.



Legend	**Land cover classification** (Source: Singler and McClain, 2006).
Green	Forest cover, old tree canopies, reeds
Purple	Succulent vegetation e.g. good cover crops like beans
Blue line	River water course
Red line	Water shed boundary

Figure 5. 23. Evidence of deforestation in the upper Mara basin from 1986 to 2003.

This evidence agrees with Mati (2005b) that land use/land cover changes have caused sharp rises in flood peaks, attenuation of hydrographs and reduction in base flows. Seasonal and flash floods in low-lying areas and urban centres may cause frequent loss of property and even life.

5.4.3. Environmental Flows in Drought Years (Flows below normal)

During drought years as shown in Figures 5.24, the recommended reserve (EFR) was a minimum of 0.30 m^3/s in January, March, April, June and July while a maximum value of 1.00 m^3/s was recommended for September. It is clear that the EFR was not being met during several months of the year at Kapkimolwa RGS 1LB02, Macro-reach Site 1. The environmental flow was met only in the month of September.

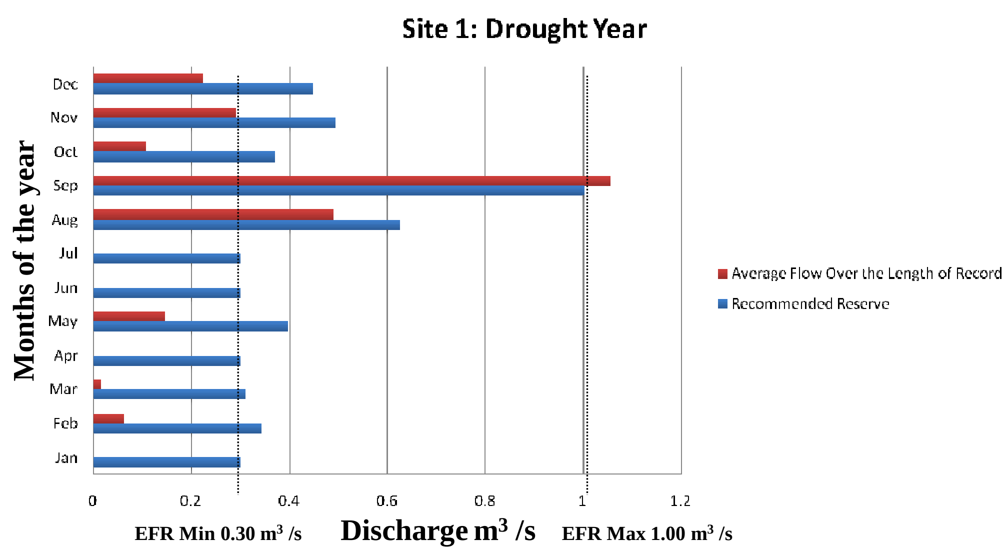


Figure 5. 24. Environmental Flow Recommendation for Drought year at Macro-reach Site 1.

The results of this EFA should be monitored to reveal whether the required reserve levels are lower than originally prescribed. However, the recommended reserve of 0.3-1.0 m^3/s is close to the figure suggested by a study done in Great Ruaha Catchment in Tanzania, where a flow of 0.5-1.0 m^3/s was recommended to sustain the environment in the park during the dry season for Great Ruaha River which flows through the Ruaha National Park (Kashaigili, 2005).

Site 2 had a similar condition in a below normal year. The recommended reserve had an EFR minimum 1.00 m^3/s in the months of March and a maximum of 4.00 m^3/s in the month of September (Figures 5.25).

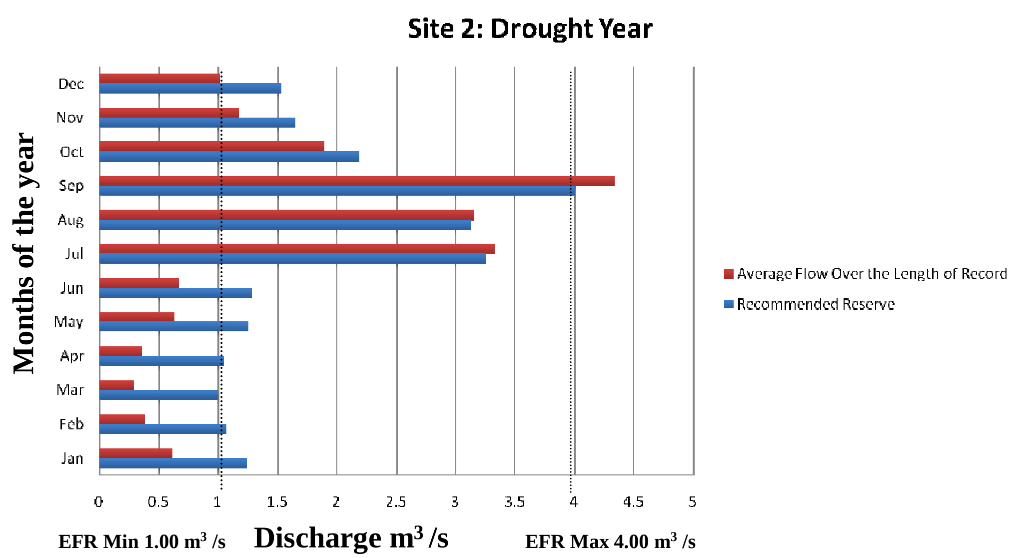


Figure 5. 25. Environmental Flow Recommendation for Drought year at Macro-reach Site 2.

Hence the EFR was not being met in many months of the year at Mara Safari Club, Macro-reach Sites 2. The environmental flow was met only in the months of July, August and September. Secondly, the levels of abstraction are unsustainably high during drought years affecting the prescribed reserve flow levels. Most of water available for abstraction is concentrated in a few months when flows are high. Far less water is available for abstraction during dry season months. Thirdly, land-use practices in the upper catchment may have sufficiently altered the hydrograph of the river that drought year low flows are unnaturally low.

5.4.4. Impact of Sediment Pollution in Wet Years (Flows above normal)

The water quality at macro-reach Sites 2 and 3 are expected change with sediment load according to the Resource Quality Objectives (RQOs) identified by the Lake Victoria South Catchment Management Strategy (LVSCMS). According to the LVSCMS the identified RQOs in the Upper Mara was E1L1C3 (Appendix 9). The maximum allowable turbidity for high Ecological and high Livelihood class (E1/L1) is 50 NTU. Yet the quality of water at macro-reach Site 1 recorded higher turbidity mean of 129 NTU suggesting there is need for rehabilitation in the upper catchment to reduce turbidity. There is urgent need to protect what is left and possibly restore what has been lost.

The flood events that may take place during both the drought and the maintenance years are shown in Figure 5. 26. The months with flood flows were April, May, August and September for maintenance years while drought years recorded flood events only in September

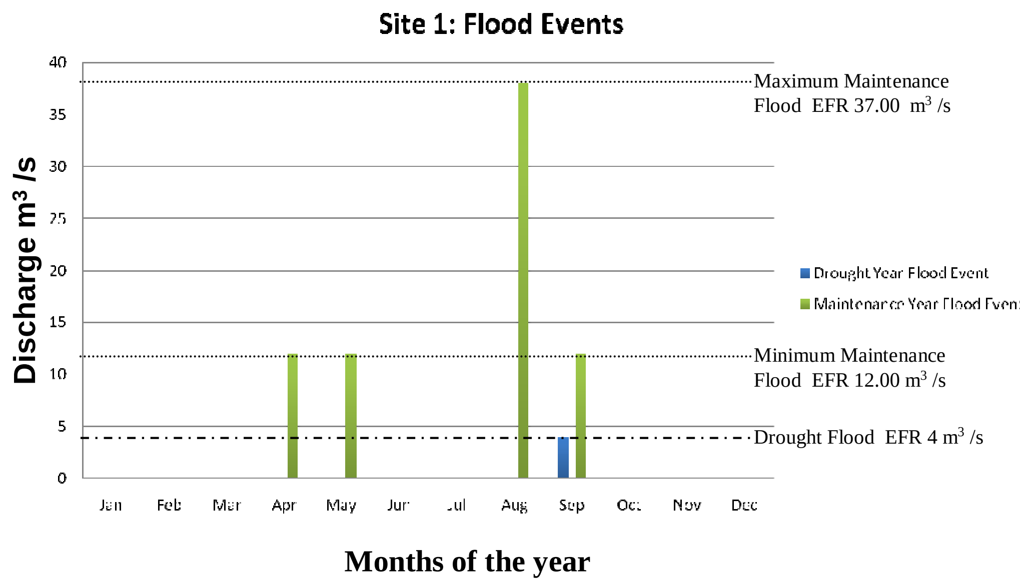


Figure 5. 26. Flood Flow during Maintenance and Drought years at macro-reach Site 1.

At Kapkimolwa Bridge (Site 1), the concentration of most metals increased with increase in sediments mobilized following the rains in the upper reaches of the Amala River. It is important to note, however, that the percent of flow held in the reserve varies over the course of a year, as the recommended reserve mirrors the natural high and low flows of the system. Therefore to increase beneficial flows during drought years requires reducing the abstractions and rehabilitating the river system to reduce suspended sediments.

The main concern is the anthropogenic, natural and point sources that become more active during the wet periods. For the upper Mara ecosystems to function adequately, appropriate water flows of suitable quality are required. The surplus supply is not stored and since there is less population pressure at the lower reaches, this may accounts for higher flows at site 3. At Site 3, the New Mara Bridge station on the border between Kenya–Tanzania and Maasai Mara National Reserve – Serengeti National Park, the reserve accounts for, on average, just 35% of the average monthly flow recorded over the years that flow data were available for Mara Mine gauging station during maintenance (Figure 5.27)and drought years (Figure 5.28).

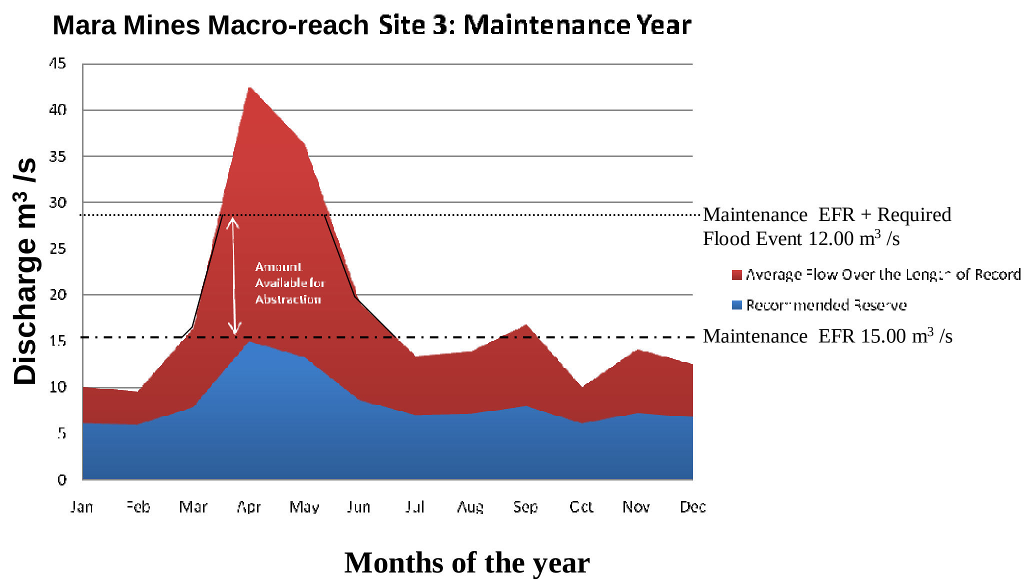


Figure 5. 27. Enviromental Flow Revcommendation for Maintenance Year at Macro-reach Site 3.

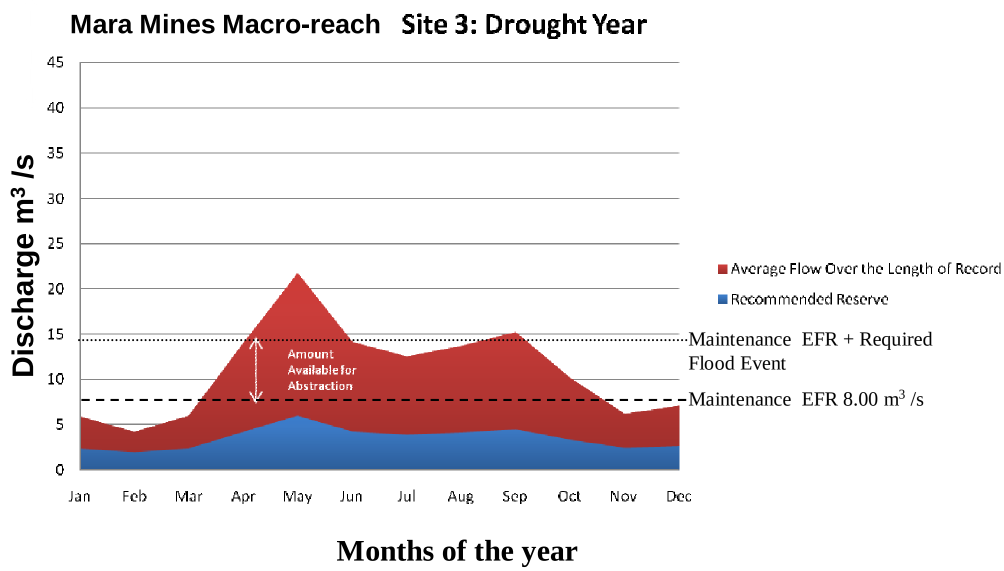


Figure 5. 28. Environmental Flow Recommendation for Drought Year at macro-reach Site 3.

5.4.5. Discussion on Impacts of Sediment pollution

The study shows that the water pollution is steadily increasing. Unless effort is made to build up records, and understanding of the processes and trends, the changeover from safe (tolerable) conditions to intolerable conditions may come as a sudden event. The main causes of the upper Mara catchment degradation are poor farming methods, most times next to the riverbanks, population pressure (forest excision for resettlement) and deforestation for agricultural land and riverine vegetation cut for fuel wood (Mati, 2005b).

The upper and middle parts of the basin have been cleared to give way to agriculture and settlements. Saw millers and subsistence farmers have removed most of the forest cover making the land prone to soil erosion and high evaporation. This environmental degradation is unfortunate because these forest areas are the main water catchments for the Mara River, sources of forest products, and dry season grazing areas for the pastoral Maasai community. The grazing lands have reduced but now hold more livestock increasing degradation due to pressure on the land.

The Mara River will need stabilization with clear erosion zone limits along the river banks for the basin to benefit from excess water during wet years without excessive sediment loading. The riverbanks incorporate small-scale habitat diversity, stretches of the river that included runs, pools and riffles that are disturbed due to increased water depth and destructive anthropogenic activities. The communities along the Mara River Basin should therefore be made aware of the different methods for water quality improvement and reduction of sediment pollution. Development agencies and WRMA should put in place measures to reduce the negative impacts.

The science of environmental flows has become the accepted way for assessing the sustainability of river ecosystems for people and nature into the future. National policies and laws need to recognize the importance of providing for environmental flows. Procedures should be drawn for establishing and enforcing flow requirements. This process will place great demands on science: ecosystem requirements for water, as well as knowledge of the socioeconomic impacts of different flow regimes on water users will need to be assessed in each case. At this stage, few countries have undertaken the studies needed for establishing these environmental flows (ILEC, 2005).

It is evident that the sediment load of the Mara River has been increasing as compared to earlier sediment measurements. The increase is mostly during the rainy season when the sediment load transported by the rivers reflects the catchment soil loss and higher levels of pollution. The water managers should therefore integrate environmental flow management into every aspect of land and water management. Environmental flow assessment and management should be a basic requirement of Integrated Water Resource Management (IWRM); environmental impact assessment (EIA); strategic environmental assessment (SEA); infrastructure and industrial development and certification; and land-use, water-use, and energy-production strategies in the Mara River Basin.

From this study, the iron content increased with increase in flow. Metallic pollution would increase probably due to increased erosion as a consequence of forest clearing, intensification of agricultural activities in the upper catchments, cultivation along the river banks, and overgrazing. This analysis showed droughts and wet years tend to persist. A general downward trend in rainfall is observed in Kenya since the 1990s. With the median of sediment concentration of 85.0 mg/l at Amala River, the water is of poor quality. Such a trend can potentially be attributed to the deforestation of the Mau complex which serves as Mara's water tower.

CHAPTER SIX

6.0. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations from the research findings of the study on the upper Mara River Basin.

6.1. Conclusions

The conclusions are mainly based on the study results from the two upstream stations at Nyang'ores and Amala Rivers.

6.1.1. Suspended Sediment Concentrations

1. Suspended Sediment concentrations in the Mara River were above allowable Kenyan standards (30 mg/l) for domestic uses and effluent discharge into the environment. The study provided new knowledge on the Nyang'ores and Amala Rivers in the upper Mara River. This high sediment pollution in the upper reach was attributed to increased agricultural activities, settlement in forest catchment and growing commercial centres along the rivers. Soil conservation and storm water management in the upper catchment is therefore necessary for the river health to be restored and to adjust to climate change.

2. The Stage- discharge rating curves showed good coefficient of determination (R^2) at 0.84 and 0.85 for Nyang'ores and Amala Rivers respectively. The relationship between turbidity and sediment concentration indicated a higher level of linearity than the logarithmic discharge-sediment relationship. The R^2 values for turbidity were 0.93 and 0.75 for Nyang'ores and Amala respectively. The developed sediment rating curves had R^2 values of 0.59 and 0.51 for Nyang'ores and Amala Rivers respectively. This indicates that the discharge and turbidity measurement at the two gauging stations can be recommended as sediment monitoring tools to give an indication of sediment load. Annual rating curves can be developed in a similar manner.

6.1.2. Metallic Pollution in Suspended Sediment

3. There is little systematic monitoring of water quality in the Mara River Basin. Comparison of the study data and available historical data found that metallic pollution has increased in the recent past. The high level of Iron concentration at 0.638 and 0.652 mg/l at RGS 1LA03, Nyang'ores River, and 0.650 mg/l at RGS 1LB02, Amala River, were above recommended standards of 0.30 mg/l. Other pollutants included Zinc, Manganese and Lead. The source was likely geological and overland storm runoff.

6.1.3. Environmental Flows

4. The recommended reserve flow levels in the two rivers for maintenance years was between 1.00-2.00 m^3/s and ample water is available for extractive uses. However, during the drought years, the environmental flow recommendation of 0.30-1.00 m^3/s exceeded the available flow in all months except September at Site 1. Increased sediment loads may negatively impact on aquatic biota by reducing light penetration, reducing suitable habitat, smothering fish fry, clogging gills and ultimately altering the biodiversity of the system.

5. EFA using Building Blocks Methodology has been successfully applied in Mara and the need to employ integrated Watershed Management strategies in transboundary river basins where all stakeholders are involved. The results of this study show clear evidence of a trend in which unacceptable alterations of the Mara River's flow regime has taken place.

6.2. Recommendations

6.2.1. Implementation

1. The environmental flow allocations should be considered in combination with other complementary mitigation measures such as rehabilitation of the catchment and the removal of at least 80 % of total suspended solids from runoff coming from urban centres in the Mara River Basin. An integrated water management plan should be developed and implemented.

2. There is need to stop further deforestation, settlement in catchment and encourage soil conservation, planting of environmentally friendly trees, storm water management and prohibit destruction of the river banks.

3. Although serious contamination was observed during the beginning of wet season only with Iron, yet Zinc, Manganese and Lead results also warrant further consideration and follow-up actions due to bioaccumulation and biomagnifications.

There is need to conduct an annual water pollution survey.

4. Water treatment would be necessary before consumption of the Mara River water irrespective of the season. The recommended reserve is to be considered in all other water allocations in the basin. Environmental Flow Assessments using Building Blocks Methodology should be employed in other basins in Kenya.

6.2.2. Research

5. Further research on dissolved metal pollutants, climate change and watershed modeling is recommended to influence decisions on policy direction, land and water development activities. There should be a concerted effort to stimulate research and raise awareness about the important services provided by Mara ecosystem and the need to factor these services into decision-making in the basin resource development.

6. Determine the critical problems hindering the development agencies to implement the EFR and to determine the appropriate environmental flow that will allow for maximal development without undermining critical ecosystem functions and services.

7. Find out what mechanism should be put in place for research findings to be factored in government policies and strategic plans for the Mara River Basin.

REFERENCES

Aboud, A.A., Obweyere, G.O. Mutinda, M. M. and Raini, J. A. (2004). A Rapid Participatory Socio-economic Assessment of the Mara River Basin. Mara River Basin Initiative, www-Eastern Africa. Regional Programme Office (EARPO).WWF, Nairobi.

Anakeya, J.E. (2001). Concept Paper for an Integrated Water Conservation Project in the Mara Catchment Basin MENR unpublished.

A.P.H.A. (1995). Standard methods for the examination of water and wastewater 19th Ed. American Public Health Association.

(ATSDR) Agency for Toxic Substances and Disease Registry (2005). Toxicological Profile for lead (*Draft for Public Comment*) Department of Health and Human Public Health Service, Atlanta, GA: U.S.

Bartley, G.E. (1993). The current status of trace element speciation in natural waters: Trace element speciation in surface waters, (Ed.) G. G. Leppard. Plenum Press. New York. Pp. 17-36.

Bartram, J. and Ballace, R. (Ed.). (1996). Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes, U.N.E.P. /W.H.O., Geneva.

Brisbane Declaration (2007). The Brisbane Declaration final document of 5th November, 2007 at the 10th International River *Symposium* and International Environmental Flows Conference held in Brisbane, Australia on 3-6 September, 2007. www.unesco.org/water/pdf/brisbane_declaration.pdf .

Bugenyi, W.B. and Balirwa, J.S. (2003). East African Species Introductions and

Wetland Management: Socio-political Dimensions. Pp. 79-103 *in:* Conservation, Ecology, and Management of African Fresh Waters. Crisman, T.L., L.J. Chapman and C.A. Chapman. (Eds.). The University Press of Florida, Gainesville, Florida.

Chapman, D. (Ed.) (1996). Water Quality Assessments A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring. 2nd edition, Chapman & Hall, London.

Dallars, H.F. and Day, J.A. (1993). The effect of water quality variables on riverine ecosystems: A review, Water research commission Project. No. 351. Pretoria. South Africa. 200pp.

Davis, R. and Hirji, R. (2003). Environmental Flows: Concepts and Methods, The World Bank, Water Resources and Environment Technical Note C1, C2, C3, Washington D. C., USA.

Dwasi, J.A. (2002). Transboundary Environmental issues in East Africa: an Assessment of the Environmental and Social economic impacts of Kenya's Forestry Policy on Tanzania. Manuscript.

(EAC)East African Community (2009). Assessing Reserve Flows for the Mara River, Kenya and Tanzania. Technical Report under the auspices of the Lake Victoria Basin Commission.

EFA-MRB. (2008). Environmental Flow Assessment, Mara River Basin, Kenya-Tanzania (EFA-MRB). 2008. World Wide Fund for Nature- Eastern Africa Regional Programme Office, 39p.Unpublished.

Emoyan, O. O., Ogban, F E. and Akarah, E. (2005). Evaluation of Heavy Metals Loading of River Ijana in Ekpan – Warri, Nigeria *Journal of Applied Sciences & Environmental Management, Vol. 10, No. 2, 2005, Pp. 121-*

127 .

(EPA) U. S. Environmental Protection Agency (1976). National Interim Primary Drinking Water Regulations, U. S. Environmental Protection Agency, Office of Water Supply, EPA 570/9-76-003.

(EPA) U. S. Environmental Protection Agency (2003). U. S. Environmental Protection Agency, Polluted Runoff (Non point Source Pollution). http://www.epa.gov/OWOW/NPS/MMGI/Chapter4/ch4-2a.html.

(FAO) Food and Agriculture Organization (1997). The Digital Soil and terrain Database of East Africa (SEA), Notes on the Arc/Info files. Version 1.0.

Frenken, K. and Bousquet, M. (1997). Water Resources Development: Usutu and Ngwavuma river basins. Volume 1: Main report.

Garde, R.J. and Raju, K.G.R. (1995). Mechanics of Sediment Transportation and Alluvial Stream Problems (2$^{nd\ Ed}$.), Wiley Eastern Limited, New Delhi, India.

Gereta, E., **Wolanski, E**., **Makus, B**., and **Serneels, S**. **(2001).** Use of an hydrological model to predict the impact on the Serengeti ecosystems of deforestation, irrigation and the proposed Amala Weir water diversion project in Kenya. Page 1-8. Website:http://www.zgf.de/ mitarbeiterbereich/ pdf/ Amala Study.pdf

Gereta, E.J., Wolanski, E. and Chiombola, E.A.T. (2003). Assessment of the Environmental, Social and Economic impacts on the Serengeti Ecosystem of the Developments in the Mara River Catchment in Kenya.

Guy, H. P. and Norman, V. W. (1970). Field methods for measurement of Fluvial Sediment: USGS Techniques of Water-Resources Investigations, Book 3, Chapter 2. USA.

Haan C.T., Barfield, B.J., and Hayes, J.C., (1994). Design Hydrology and Sedimentology for Small Catchments, Academic Press, San Diego, California.

Hoffman C., Melesse A. & McClain M. (2009). Geospatial Mapping and Analysis of Water Availability-Demand-Use within the Mara River Basin, *Hydrological Processes* (in revision). Florida International University, Miami, USA.

Hongo, H. (2000). The relationship, between Human Activities in the Fringing Wetlands of Lake Victoria and Causes of Pollution to the Lake Victoria.

ILEC (2005). Managing Lakes and their Basins for Sustainable Use: a Report for the Lake Basin Managers and Stakeholders, International Lake Environmental Committee Foundation: Kusatsu, Japan.

Indeje, M., Semazzi, F.H. and Ogallo, L.J. (2000). ENSO signals in East African rainfall seasons, *Int. J. Climatol*., 20, 19 – 46.

IUCN (2000). Forest cover and forest reserve in Kenya, Policy and Practice, Working Paper No.5.

Jaetzold, R., & Schmidt, H. (1983). Farm Management Handbook of Kenya, Vol. II, Part B, Central Kenya, Ministry of Agriculture, Nairobi.

JICA (1987). The study of Integrated Regional Development Master Plan for the Lake Basin Development Area. Final Report Vol. 5. Water Resources/ Transport/ Energy.

Julien, P.Y. (1995). Erosion and sedimentation, Cambridge University Press.

Kashaigili, J.J., *et al*. (2005) Physics and Chemistry of the Earth 30 (689-697).

King, J.M., Tharme, R. and De Villiers MS. (2000). Environmental flow assessments for rivers: Manual for the building block methodology.

TT131/00, The Water Research Commission, Private Bag X03, 0031 Rietfontein, Pretoria, South Africa.

Kitheka, J.U., Obiera, M. and Nthenge, P. (2003). River Discharge, Sediment Transport and Exchange in the Tana Estuary, Kenya. Accessed March 26, 2009. http://cat.inist.fr/?amodele=afficheN&cpsidt=16814558

Krhoda, G.O. (2001). Preliminary phase-Project Development and Stakeholders analysis; the Hydrology of Mara River, Mara River Catchment Basin Initiative: WWF-Eastern Africa Regional Program Office (EARPO).

Linsley, Ray K. (1988). Hydrology for Engineers, SI metric Edition, MCGraw-Hill, Book Company, London.

LVEMP/COWI (2000). Integrated water quality/ Limnology Study for Lake Victoria; Consultant Technical Report. Dar-es-salaam.

Machiwa, P. (2001). Assessment of Pollution Loading into Lake Victoria from Terrestrial Sources: The Case of Phosphorus. A paper presented at The National Technical Workshop in Mwanza on 6th-10th, August 2001.

Machiwa, P. (2002). Water Quality Management and Sustainability: the experience of Lake Victoria Management Project 3rd WaterNet/Warfsa Symposium, Dar-es-salaam.

Mati, B. M., Mtalo, F., Gadain H., Mutie, S.M., Patrick, H., G.E. Mtalo. (2005a). Land use changes in the Transboundary Mara: A threat to Pristine Wildlife Sanctuaries in East Africa. Paper presented at the 8th International River Symposium, Brisbane, Australia. www.riversymposium.com/index.php.

Mati, B. M., Gadain H., Home, P. (2005b). Land Cover change effects on flow regime: *Proceedings of the 2nd International ISCRAM Conference* (B.

Van de Walle and B. Carle, eds.), Brussels, Belgium, April 2005.

Mati, B. M., Mutie, S.M., Gadain, H., Home, P., and Mtalo, F. (2008). Impacts of land-use/cover changes on the hydrology of the transboundary Mara River, Kenya/Tanzania, *Lakes & Reservoirs: Research and Management* 2008 **13**: 169–177.

Merck & Co., Inc. (2003). The Merck Manual of Medical Information, Second Home edition, Merck research Laboratories, New Jersey, USA.

Merian E. (1991). Metals and their compounds in the Environment, Occurrence, Analysis and Biological Relevance UCH, Weintrein – New York.

Metcalf & Eddy Inc. (1991). Waste Water Engineering, Treatment, Disposal and Reuse, McGraw Hill, New York.

Muchena F. N., Mbuvi, J.P. and Wokabi, S.M. (1988). Report on Soil and Land use in Arid and Semi-arid Lands of Kenya, Ministry of Environment and Natural Resources, National Environment Secretariat, Nairobi.

Mutie, S.M. (2006). Modelling the Influence of Land Use Changes on the Hydrology of Mara River using USGS Geospatial Stream Flow Model, Unpublished MSc Thesis, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.

Mutreja, K.N. (1986). Applied Hydrology, Tata McGraw-Hill publishing Co. Limited, New Delhi.

(NTEAP) Nile Basin Initiative Transboundary Environmental Action Project (March 2005). National Nile Basin Water Quality Monitoring Baseline Report for Kenya accessed January 26, 2006 at URL. http://www.nileteap.org/docs/publications/WQ/WQ Baseline report Kenya.pdf.

Njigua, J. (2006). Development of water allocation model for sustainable water resources management in Mara River Basin in Kenya, Unpublished. MSc Thesis, Department of Civil Engineering, University of Zimbabwe.

Novotny, V. (Ed.). 1989. Handbook of Urban Drainage and Wastewater Disposal, John Wiley & Sons, Inc., New York.

Pearce, G. R., Chaudry, M. R. and Ghulam, S. (1999). A Simple Methodology for Water Quality Monitoring, HR Wallingford, Report OD 142, United Kingdom.

Republic of Kenya (1992). The Study on the National Water Master Plan, Sectoral Report (B), Hydrology, July 1992. Ministry of Water Resources, Nairobi, Kenya.

Republic of Kenya (2000). The Environmental Management and Coordination Act, 1999, No. 8 of 1999, Commenced 14th January 2000, Nairobi.

Republic of Kenya (2002a). The Water Act, 2002, Nairobi.

Republic of Kenya (2002b). The Agriculture Act, Cap 318(as amended by 11 of 1993 and 2 of 2002), Nairobi.

Republic of Kenya (2004). Strategy for Revitalizing Agriculture 2004-2014, Ministry of Agriculture and Ministry of Livestock and Fisheries Development, Nairobi, Kenya.

Republic of Kenya (2005). Strategic Plan of the Ministry of Water and Irrigation (2005-2009), Final Edition, Nairobi.

Republic of Kenya (2006a). The Environmental Management and Coordination (Water Quality) Regulations (2006), Kenya Subsidiary Legislation, 2006, Nairobi.

Republic of Kenya (2006b). The National Water Resources Management Strategy

(NWRMS) (2006-2008) First Edition - January 2006.

Republic of Kenya (2007). Kenya Vision 2030, First Edition, Ministry of Planning and National Development, Nairobi.

Rosenberg, D.M., McCully, P. and Pringle. C.M. (2000). Global-scale environmental effects of hydrological alterations: *Bioscience 50*: 746-751.

Simons, D.B., and Senturk, F. (1992). Sediment Transport Technology, Water resources Publications, Fort Collins, CO.

Singler, H, and McClain, M. (2006). Report of the Global Water for Sustainability (GLOWS) Program. Mara River Basin Water Quality Baseline Assessment – May 2005 (Draft).

Sparks, C. J. Jr. (1978). Inelastic Resonance Emission of X Rays; Anomalous scattering Associated with Anomalous Dispersion, The American Physical Society.

Stern, R., Rijks, D., Dale, I. and Knock, J. (2006). Instat Climatic Guide, Statistical Services Centre, the University of Reading, United Kingdom.

Swallow B., Okono, A., Ong, C. and Place, F. (2003). Case Three. Project title- Trans Vic: Improved Land Management across the Lake Victoria Basin. Accessed March 26, 2009 at URL. http://www.fao.org/wairdocs/tac/y4953e/y4953e07.htm .

Terer, J. K. (2005). The Study of Hydrologic Characteristics and Management Practices in Agricultural River Catchments: The case of Nyongores River Catchment, Mara River Basin M.Phil. Thesis. Moi University, Eldoret, Kenya. Unpublished.

The Holy Bible (1984). *New International Version*, 1973, 1978, 1984. International

Bile Society, Used with permission of Zondervan, *Grand Rapids, Michigan, U.S.A*

UNEP (1991). Freshwater Pollution, UNEP/GEMS Environmental Library No.6, Nairobi, United Nations Environmental Programme.

Valimba, P., Mtalo, F. W. Servat, E. and Mati, B. M. (2004). Evidence of changing flow regime in the Mara River basin in Kenya/Tanzania, Project Report to VicRes, Civil Engineering, University of Dar es Salaam.

Welcomme, R.L., Winemiller, A.K.O, and Cowx, I.G. (2006). Fish environmental guilds as a tool for assessment of ecological condition of rivers, River Research Applications 22: 377–39.

World Bank (2004). Water Resources Sector Strategy: Strategic Directions for World Bank Engagement. International Bank for Reconstruction and development/ The World Bank, Washington D.C., USA

WREM (2008). Mara River Basin Monograph. Draft Final Report. Water Resources and Energy Management (WREM), International Inc. Atlanta, Georgia Institute of Technology, U.S.A (unpublished).

APPENDICES

APPENDIX 1

Variety of Ways Communities Utilize the Mara River.

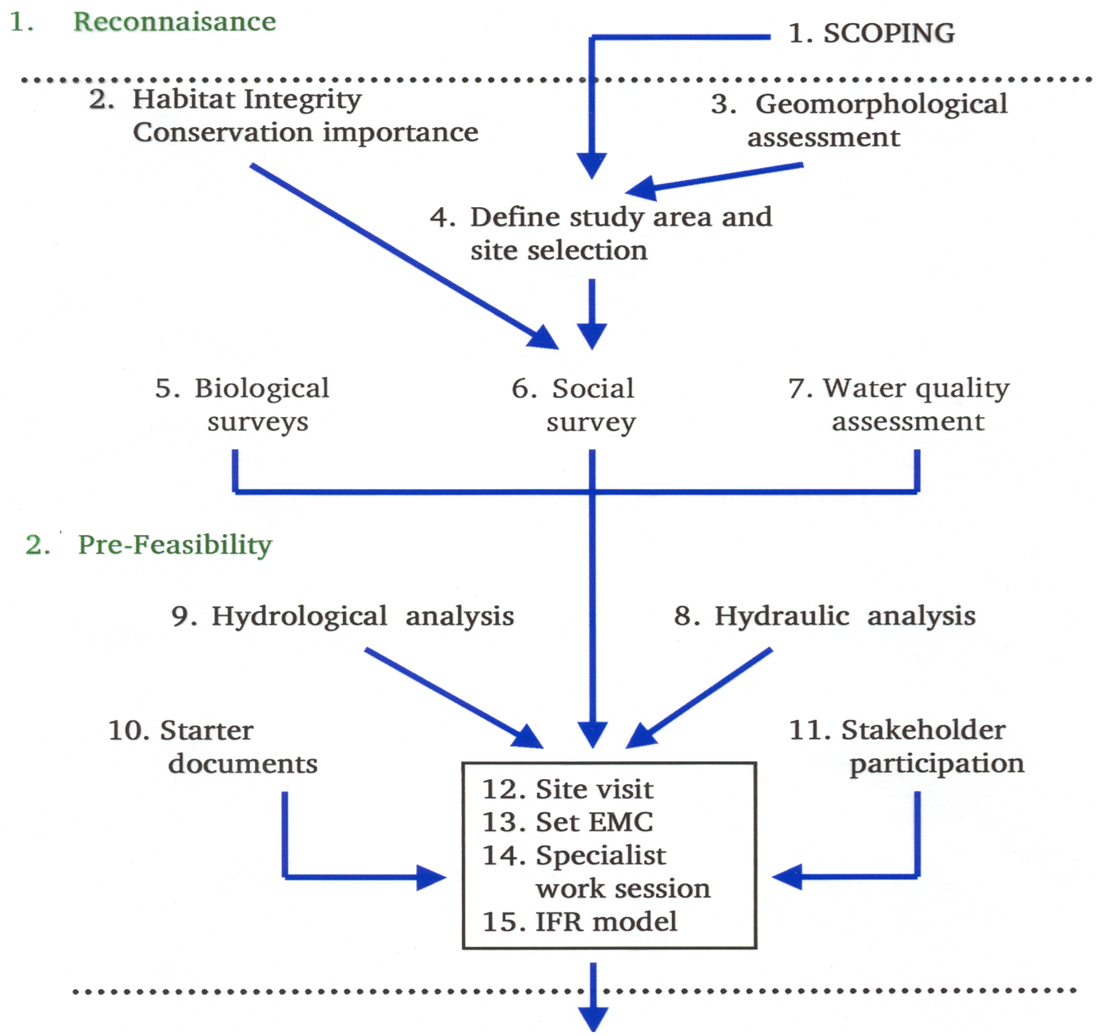
Resources	Resource use	Desired state of the river
Water	Water for livestock	Sufficient water to provide for livestock, even during droughts, while maintaining acceptable quality for human consumption
	Domestic use	High enough water quality for human consumption at all times, including low sediment and impurity loads
	Irrigation farming	Sufficient water to sustain crops during the dry season when precipitation is low
	Habitat for fish	Dynamic flow regime to cue fish breeding events
	Recreation, e.g. swimming Hotel sites	Sufficient water to allow swimming Adequate water supply and stable river banks to allow construction of hotels and restaurants
River ecosystem	Industrial use, e.g. water mills, mines	Sufficient water to maintain industry practices
	Generation of hydroelectric power.	Sufficient water levels for hydroelectric power generation
	Cultural practices (e.g. baptism, circumcision, naming ceremonies)	Presence of deep pools to meet cultural needs of the community
Fish	Food	Healthy fish populations
Vegetation	Habitats for wildlife	Intact riparian zone that provides habitat and camouflage for wildlife
	Food	Healthy populations of important food plants
	Medicine	Flow regimes that foster growth of medicinal herbs that are only found in the riparian zone
	Construction material	Intact riparian zones that provide habitat for vines used in construction of the Maasai manyattas
	Cultural/traditional artifacts e.g. rungus	Intact riparian zones that provide habitat for culturally important tree species
	Charcoal	Presence of large tree species that may be used in charcoal production
Soil sediments	Soil sediments for art works on houses	Functioning sediment generation process to provide fertile soil
	Sand harvesting	Functioning sediment generation process to provide sands
Wildlife	Tourist attraction e.g. crocodile and hippopotamus	Intact habitat to foster thriving wildlife populations

Source: Personal communication

APPENDIX 2

Building Blocks Methodology for Environment Flow Assessment

Most of the engineering tasks are in Stage 1.



EFA Engineering Tasks to develop In stream-Flow Requirement (IFR) Model. (Source: King *et al.*, 2000).

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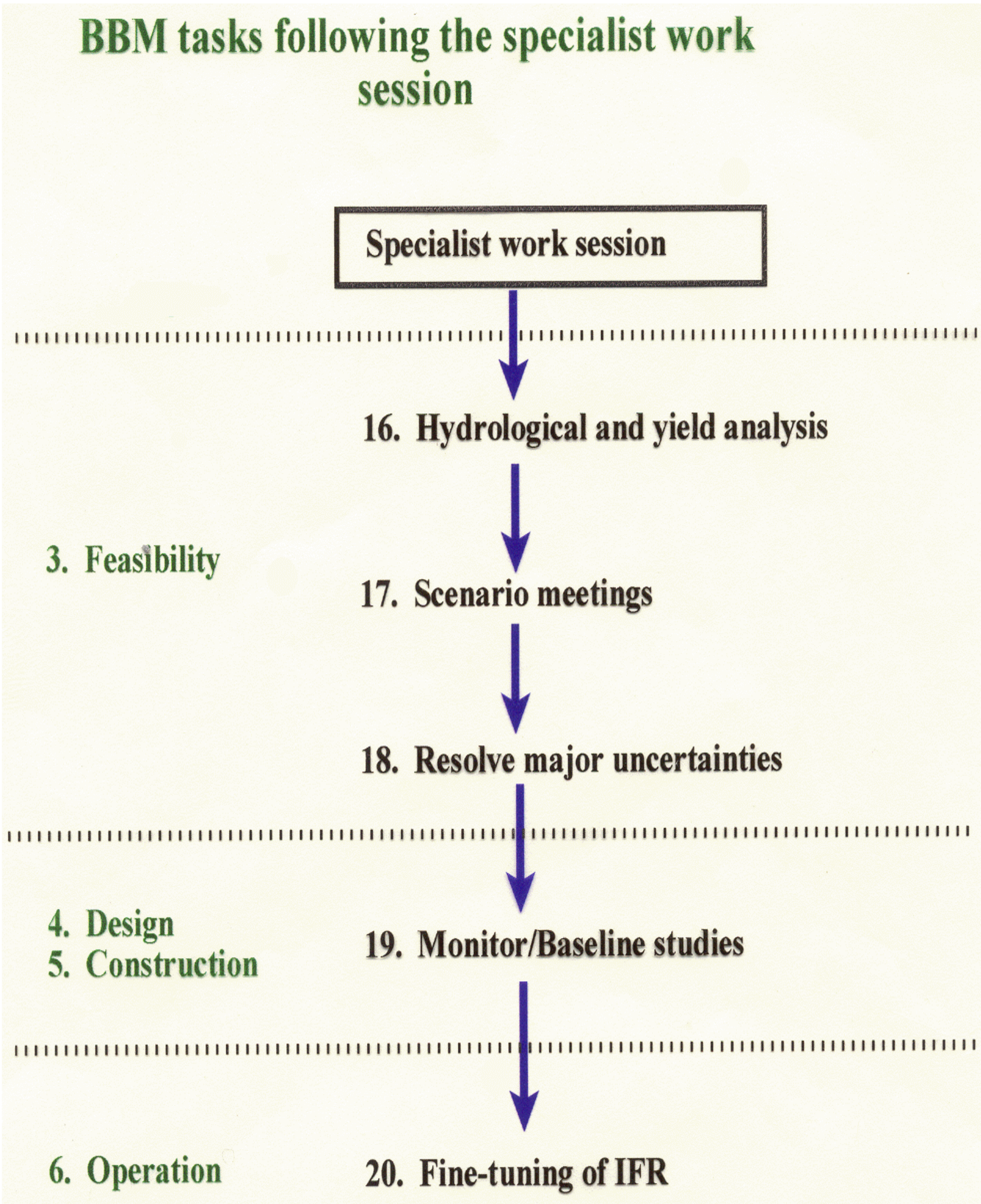
APPENDIX 3

The additional BBM Tasks following the specialists work.



Additional BBM Tasks. (Source: King *et al.*, 2000).

APPENDIX 4

Suspended Sediment Sampling Sheet. **JKUAT, 2007.**

PART 1: SUSPENDED SEDIMENT SAMPLING.

River name…………………………..R.G.S.NO………..DATE……………

Time……………………………..Gauge Height………………………..m

Partial Discharges in m^3/sec

Vertical No……………….

Depth (Vertical/Point)…………… m D.I.P. ………………. m ……………….

Vertical No……………….

Depth (Vertical/Point)……………m D.I.P. ……………… m ……………….

Vertical No……………….

Depth (Vertical/Point)……………m D.I.P ………………. m ……………….

Sampler:

Sampled by: Gibson & Co.

Total No. of samples…………………..Total Discharge……………. m.^{3}/sec

Samples checked by……………………samples sent to lab by……………...

Date……………….

PART 2: LABORATORY DETERMINATION REPORT

REGISTER SAMPLE NO.						
LAB. SAMPLE NO.						
TURBIDITY N.T.U.						
TOTAL SEDIMENT CONCENTRATION (PPM)						

Other Parameters:

Mean Sediment concentration…………………ppm or mg/l.

Sediment Discharge:…………………………...tonnes/day

Entered by………………………………………Date………………

APPENDIX 5

Daily Rainfall, Discharge, and Sampled Suspended Sediment Pollution of Upper Mara river Basin.

River	Date	Rainfall in the Upper Mara Basin, mm						Discharge	Sediment Loading		
	Date	Kaisugu	Oleguruone	Bomet	Kericho	Nyang'ores	Gauge	Flows	Sediment	Turbidity	Loading
	Month/Day	9035075	9035126	9035143	9035279	9035302	M	m^3/s	Mg/l	NTU	tons/day
Nyang'ores	2/08/2007	0.0	0.0	0.0	0.0	7.7					
	2/09/2007	0.0	0.0	0.0	0.0	0.0	1.18	21.83	96.0	100	181.1
	3/01/2007	0.0	0.0	0.0	0.0	0.7					
	3/02/2007	0.0	0.0	15.1	2.0	4.2	0.54	7.98	52.5	70	36.2
	3/14/2007	0.0	0.0	0.0	0.0	5.2					
	3/15/2007	5.5	0.0	1.0	0.0	3.3	0.41	3.36	44.0	70	12.8
	3/22/2007	0.0	0.0	0.0	1.0	7.3					
	3/23/2007	0.0	0.0	0.0	0.0	5.5	0.37	2.98	46.5	90	12.0
	4/03/2007	0.0	0.0	0.0	0.0	3.4					
	4/04/2007	0.0	0.0	0.0	0.0	0.0	0.32	2.05	35.5	45	6.3
	4/13/2007	0.3	0.0	0.0	5.3	0.0					
	4/14/2007	8.3	20.0	0.0	32.4	5.2	0.59	10.75	264.0	220	245.2
	4/17/2007	23.1	0.0	4.0	7.6	16.8					
	4/18/2007	3.5	8.6	8.9	41.6	6.2	0.51	7.41	110.5	140	70.7
	4/24/2007	0.0	0.0	1.0	4.6	0.0					
	4/25/2007	0.0	0.0	0.0	0.0	0.0	1.14	25.76	102.5	110	228.1
	5/01/2007	3.1	0.0	0.0	6.5	6.9					
	5/02/2007	6.0	9.0	9.0	3.5	0.0	0.63	10.05	54.0	80	46.9
	5/05/2007	8.0	3.5	13.2	1.7	7.7					

Nyang’ores	Date	Kaisugu	Oleguruone	Bomet	Kericho	Nyang'ores	Gauge	Flows	Sediment	Turbidity	Loading
	Month/Day	9035075	9035126	9035143	9035279	9035302	M	m^3/s	mg/l	NTU	tons/day
	5/06/2007	26.9	0.0	0.0	1.0	12.5	0.62	9.72	77.5	95	65.1
	5/16/2007	9.4	25.8	3.4	18.8	60.9					
	5/17/2007	4.8	15.5	7.8	3.4	17.3	1.05	18.29	268.5	250	424.3
	5/25/2007	6.7	20.0	32.1	2.4	36.1					
	5/26/2007	17.2	16.7	2.3	0.9	0.7	0.86	16.23	98.0	110	137.4
	5/28/2007	14.2	0.0	0.0	0.5	2.5					
	5/29/2007	0.0	12.0	21.1	25.4	0.0	0.76	17.82	88.0	90	135.5
	5/31/2007	7.5	0.0	30.0	22.5	17.5					
	6/01/2007	28.3	0.0	0.0	1.2	7.3	0.93	16.75	109.5	120	158.5
	6/03/2007	0.0	13.1	0.0	14.4	0.0					
	6/04/2007	14.2	4.1	5.4	20.1	6.5	0.96	19.72	103.0	85	175.5
	6/05/2007	0.7	2.6	0.0	22.3	10.5					
	6/06/2007	0.0	1.2	2.7	0.2	0.0	1.02	21.19	72.0	80	131.8
	6/14/2007	10.7	4.8	0.0	2.5	0.0					
	6/15/2007	0.0	20.0	12.5	29.3	0.0	1.15	21.20	84.0	90	153.9
	6/16/2007	2.3	33.0	0.0	1.0	0.0					
	6/17/2007	26.3	5.5	0.0	0.7	0.0	1.26	24.19	85.0	90	177.7
	6/19/2007	0.0	0.0	0.7	0.0	0.0					
	6/20/2007	0.0	0.0	0.0	0.0	0.0	1.17	24.00	64.5	80	133.7
	6/22/2007	0.0	0.0	0.0	22.5	0.0					
	6/23/2007	10.2	8.0	0.0	0.0	0.0	0.96	18.42	66.0	100	105.0
	6/28/2007	0.0	10.6	0.0	0.4	0.0					
	6/29/2007	0.0	8.0	0.0	0.0	0.0	0.76	14.50	81.5	90	102.1
	7/01/2007	3.2	0.0	0.0	3.3	0.0					

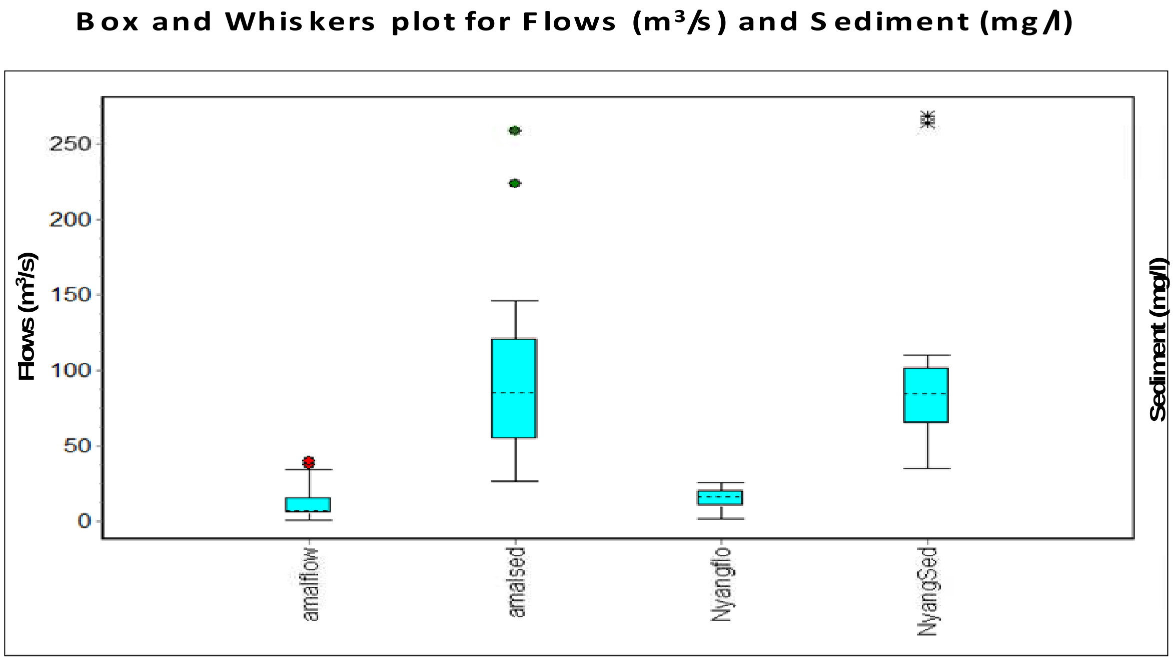
Amala River	Date	Kaisugu	Oleguruone	Bomet	Kericho	Nyang'ores	Gauge	Flows	Sediment	Turbidity	Loading
	Month/Day	9035075	9035126	9035143	9035279	9035302	M	m^3/s	mg/l	NTU	tons/day
	7/02/2007	4.3	0.0	0.0	1.6	0.0	0.67	11.07	90.5	95	86.6
Amala River											
	2/09/2007	0.0	0.0	0.0	0.0	0.0					
	2/10/2007	2.0	2.3	0.0	35.5	0.0	0.84	16.74	115.0	130	166.3
	3/02/2007	0.0	0.0	15.1	2.0	4.2					
	3/03/2007	0.0	0.0	10.8	0.0	3.4	0.45	4.78	138.0	190	57.0
	3/14/2007	0.0	0.0	0.0	0.0	5.2					
	3/15/2007	5.5	0.0	1.0	0.0	3.3	0.29	2.31	47.0	120	9.4
	3/22/2007	0.0	0.0	0.0	1.0	7.3					
	3/23/2007	0.0	0.0	0.0	0.0	5.5	0.27	1.45	47.0	100	5.9
	3/25/2007	0.0	3.4	5.4	1.6	19.1					
EFA	3/26/2007	0.0	0.0	4.3	0.1	6.4	-	1.24	26.4	28	2.8
Amala River	4/03/2007	0.0	0.0	0.0	0.0	3.4					
	4/04/2007	0.0	0.0	0.0	0.0	0.0	0.22	0.89	61.5	60	4.7
	4/13/2007	0.3	0.0	0.0	5.3	0.0					
	4/14/2007	8.3	20.0	0.0	32.4	5.2	0.44	3.92	258.0	290	87.4
	4/18/2007	3.5	8.6	8.9	41.6	6.2					
	4/19/2007	6.6	10.0	59.7	5.9	18.1	0.47	6.05	121.0	180	63.2
	4/25/2007	0.0	0.0	0.0	0.0	0.0					
	4/26/2007	17.2	16.7	2.3	0.9	0.7	0.67	13.15	104.5	150	118.7
	4/30/2007	0.0	0.0	0.0	32.9	0.0					
	5/01/2007	3.1	0.0	0.0	6.5	6.9	0.52	6.71	72.5	110	42.0
	5/07/2007	1.7	3.1	0.0	11.0	7.6					
	5/08/2007	8.2	0.0	0.0	1.5	3.4	0.52	6.31	70.0	110	38.2

Amala River	Date	Kaisugu	Oleguruone	Bomet	Kericho	Nyang'ores	Gauge	Flows	Sediment	Turbidity	Loading
	Month/Day	9035075	9035126	9035143	9035279	9035302	M	m^3/s	mg/l	NTU	tons/day
	5/24/2007	8.1	17.0	10.8	3.4	0.0					
	5/25/2007	6.7	20.0	32.1	2.4	36.1	0.50	7.26	70.5	85	44.2
	5/29/2007	0.0	12.0	21.1	25.4	0.0					
	5/30/2007	10.4	16.4	2.8	1.6	20.0	0.47	7.45	54.5	110	35.1
	6/01/2007	28.3	0.0	0.0	1.2	7.3					
	6/02/2007	0.0	0.0	0.0	3.5	0.0	0.70	15.14	121.5	180	158.9
	6/04/2007	14.2	4.1	5.4	20.1	6.5					
	6/05/2007	0.7	2.6	0.0	22.3	10.5	0.67	13.96	97.5	130	117.6
	6/13/2007	9.2	11.5	0.0	3.2	2.2					
	6/14/2007	10.7	4.8	0.0	2.5	0.0	1.26	37.86	223.0	240	729.5
	6/15/2007	0.0	20.0	12.5	29.3	0.0					
	6/16/2007	2.3	33.0	0.0	1.0	0.0	1.30	39.99	146.0	160	504.4
	6/18/2007	0.0	0.0	0.0	1.5	0.0					
	6/19/2007	0.0	0.0	0.7	0.0	0.0	1.23	34.56	125.5	70	374.7
	6/21/2007	14.5	0.0	3.2	0.0	0.0					
	6/22/2007	0.0	0.0	0.0	22.5	0.0	0.90	24.95	47.0	110	101.3
	6/26/2007	0.0	0.0	0.8	2.0	0.0					
	6/27/2007	0.0	12.6	2.8	4.5	0.0	0.74	16.84	107.5	110	156.4
	7/2/2007	4.3	0.0	0.0	1.6	0.0					
	7/3/2007	3.5	0.0	0.0	0.0	0.0	0.66	12.89	58.0	140	64.6
	7/15/2007	8.0	0.0	0.0	0.0	0.0					
EFA-429	7/16/2007	0.5	0.0	0.0	0.0	0.0	0.59	5.53	31.5	40	15.1

Daily Rainfall (day before and during sampling) for 5 stations in the Basin (Source: Kenya Meteorological Department, 2008)

APPENDIX 6

Box and Whiskers plot for Flows (m^3/s) and Sediment (mg/l).



Amalflow= Flow (m^3/s) at Amala and Nyangflo= Flow (m^3/s) at Nyang'ores River
Amalsed= Sediment (mg/l) at Amala and NyangSed= Sediment (mg/l) at Nyang'ores River

APPENDIX 7.

Average Rainfall for 5 stations in Upper Mara Basin and Corresponding Flows and Iron (Fe) loading.

	Kaisugu	Oleguruone	Bomet	Kericho	Nyang'ores	Mean/day	Average (2 days) (mm)	Discharge m^3/s	Fe (ppm)
4/03/2007	0.0	0.0	0.0	0.0	3.4	0.68			
4/04/2007	0.0	0.0	0.0	0.0	0.0	0.0	0.34	2.05	0.010
4/13/2007	0.3	0.0	0.0	5.3	0.0	1.12			
4/14/2007	8.3	20	0	32.4	5.2	13.18	7.15	10.75	0.638
4/24/2007	0.0	0.0	1	4.6	0.0	1.12			
4/25/2007	0.0	0.0	0.0	0.0	0.0	0.0	0.56	25.76	0.248
5/16/2007	9.4	25.8	3.4	18.8	60.9	23.66			
5/17/2007	4.8	15.5	7.8	3.4	17.3	9.76	16.71	18.29	0.652
6/19/2007	0.0	0.0	0.7	0.0	0.0	0.14			
6/20/2007	0.0	0.0	0.0	0.0	0.0	0.0	0.07	24	0.059
7/01/2007	3.2	0.0	0.0	3.3	0.0	1.3			
7/02/2007	4.3	0.0	0.0	1.6	0.0	1.18	1.24	11.07	0.071
4/03/2007	0.0	0.0	0.0	0.0	3.4	0.68			
4/04/2007	0.0	0.0	0.0	0.0	0.0	0.0	0.34	0.89	0.024
4/13/2007	0.3	0.0	0.0	5.3	0.0	1.12			
4/14/2007	8.3	20	0.0	32.4	5.2	13.18	7.15	3.92	0.650
5/29/2007	0.0	12	21.1	25.4	0.0	11.7			
5/30/2007	10.4	16.4	2.8	1.6	20	10.24	10.97	7.45	0.039
6/01/2007	28.3	0.0	0.0	1.2	7.3	7.36			
6/02/2007	0.0	0.0	0.0	3.5	0.0	0.7	4.03	15.14	0.158
6/13/2007	9.2	11.5	0.0	3.2	2.2	5.22			
6/14/2007	10.7	4.8	0.0	2.5	0.0	3.6	4.41	37.86	0.369
7/02/2007	4.3	0.0	0.0	1.6	0.0	1.18			
7/03/2007	3.5	0.0	0.0	0.0	0.0	0.7	0.94	12.89	0.025

APPENDIX 8

Baseline Water Quality Dataset.

Water quality dataset Kenyan Mara modified from NTEAP (2005) with comparisons to data collected for the GLOWS March 2006 water quality baseline assessment. Grey shading indicates GLOWS sampling sites, data in *italics* are from the Narok District Water Office and **bold** data are modified from the Narok and Bomet District Water Offices.

	Station Name	Matecha Bridge	*Matecha Bridge*	*Matecha Bridge*	*Matecha Bridge*	**Matecha Bridge**	Kapkimolwa Bridge	*Kapkimolwa Bridge*	*Kapkimolwa Bridge*	*Kapkimolwa Bridge*	**Kapkimolwa Bridge**
Date	dd/mm/yy	2/5/05	*21/7/04*	*29/7/04*	*5/8/04*	**16/12/04**	2/5/05	*21/7/04*	*29/7/04*	*5/8/04*	**16/12/04**
Temperature	C	16.58	*16.9*	*14.2*	*15.1*	**19.6**	19.89	*17.7*	*15.1*	*15.2*	**19.2**
pH		7.45	*7.4*	*7.3*	*7.4*	**7.1**	7.34	*7.5*	*7.3*	*7.4*	**6.9**
Alkalinity	Ppm	31	*21*	*13*	*18*	**40**	40	*43*	*16*	*20*	**40**
Conductivity	$\mu S/cm^2$	55	*310)*	*40*	*50*	**110**	85	*160*	*50*	*110*	**110**
TDS	g/L	0.04	*0.15*	*0.02*	*0.04*	**61**	0.06	*0.07*	*0.02*	*0.05*	**60**
Turbidity	NTU	44.5				**180**	115				**180**
Total Hardness	Ppm	24	*9*	*7*	*7*	**20**	28	*23*	*10*	*12*	**22**
Calcium Hardness	Ppm	14	*<50*	*<50*	*<50*	**<50**	16	*<50*	*<50*	*<50*	**<50**
Bromine	(mg/L)		*0.31*	*0.1*	*0.2*	**0.2**		*0.29*	*0.28*	*0.13*	**0.27**
Fluoride	(mg/L)		*1.49*	*0.32*	*0.29*	**0.75**		*0.61*	*0.38*	*0.36*	**0.81**
Nitrate	(mg/L)	0.03	*<1*	*<1*	*<1*	**1.1**	0.02	*<1*	*<1*	*<1*	**1.1**
Sulphate	(mg/L)		*5.4*	*6.4*	*5.6*	**11**		*16.2*	*8.8*	*7.5*	**12**
Iron	(mg/L)		*0.07*	*0.07*	*0.09*	**0.1**		*0.07*	*0.1*	*0.07*	**0.1**
Copper	(mg/L)					**<0.05**					**<0.05**

Appendix 8 continued: Baseline Water Quality Dataset.

	Station Name	Mulot Bridge	*Mulot Bridge*	*Mulot Bridge*	*Mulot Bridge*	**Mulot Bridge**	Emarti Bridge	*Emarti Bridge*	*Emarti Bridge*	**Emarti Bridge**
Variable	Unit									
Date	dd/mm/yy	2/5/05	*21/7/04*	*29/7/04*	*5/8/04*	**16/12/04**	2/5/05	*21/7/04*	*29/7/04*	**16/12/04**
Temperature	C	21.16	*18.1*			**19.5**	22.13	*17.6*	*15.3*	**19.5**
pH		7.42	*7.6*	*7.4*	*7.7*	**6.9**	7.53	*7.3*	*7.4*	**6.8**
Colour	(Pt/Co)					**15**				**15**
Alkalinity	ppm	52	*36*	*19*	*29*	**42**	56	*39*	*22*	**46**
Conductivity	μS/cm^2	107	*160*	*70*	*130*	**120**	146	*330*	*280*	**120**
TDS	g/L	0.08	*0.08*	*0.03*	*0.06*	**0.08**	0.10	*0.16*	*0.13*	**0.08**
Turbidity	NTU	112				**200**	55.4			**300**
Total Hardness	ppm	30	*19*	*14*	*14*	**21**	30	*21*	*15*	**22**
Calcium Hardness	ppm	16	*<50*	*<50*	*<50*	**<50**	22	*<50*	*<50*	**<50**
Chloride	(mg/L)					**<0.5**				**<0.5**
Bromine	(mg/L)		*0.09*	*0.43*	*0.18*	**0.28**		*0.2*	*0.15*	**0.3**
Fluoride	(mg/L)		*0.7*	*0.4*	*0.43*	**0.8**		*0.96*	*0.49*	**0.98**
Nitrate	mg/L	0.02	*<1*	*<1*	*<1*	**1.3**	0.00	*<1*	*<1*	**1.5**
Nitrite	(mg/L)		*<0.01*	*<0.01*	*<0.01*	**0.02**		*<0.01*	*<0.01*	**0.02**
Sulphate	(mg/L)		*38.2*	*7.3*	*8*	**12.3**		*19.8*	*21.8*	**12.3**
Iron	(mg/L)		*0.07*	*0.06*	*0.08*	**0.11**		*0.05*	*0.09*	
Copper	(mg/L)					**<0.05**				

Appendix 8: Continued: Baseline Water Quality Dataset.

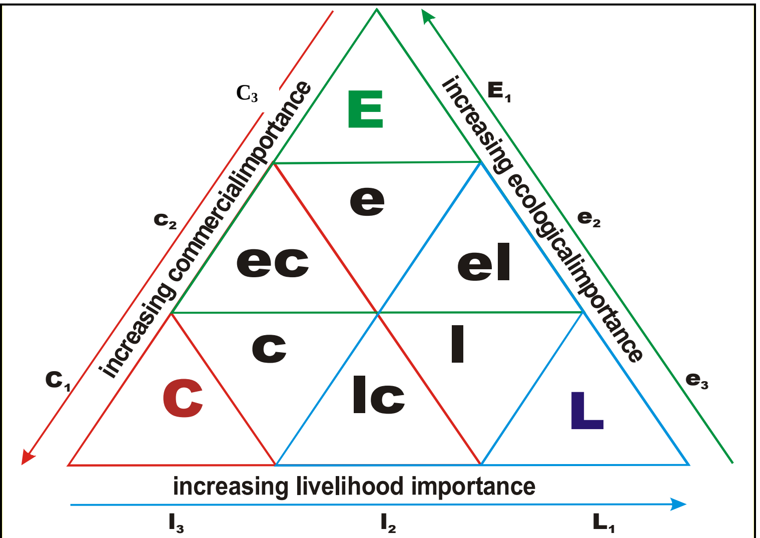
	Station Name	Old Mara Bridge	**Old Mara Bridge**	**Old Mara Bridge**	New Mara Bridge	**New Mara Bridge**	**New Mara Bridge**	**Mara Serena**	**Mara Serena**	**Nyangores River (Ope**	Nyangores River (Intake	Nyangores River (T.Mst.	Nyangores River (T.M.Const. SW
Date	d/m/yy	6/5/04	**15/12/04**	**16/11/04**	6/5/04	**15/12/04**	**16/11/04**	**15/12/04**	**16/11/04**	5/2/04	5/2/04	5/2/04	5/2/04
Temperature	C	23.07	**20**	**18.3**	22.18	**20.1**	**19.2**	**20.6**	**19**	23	23	23	24
pH		7.19	**6.5**	**7.2**	6.90	**6.3**	**6.4**	**6.5**	**6.5**	8	8	7.9	7.6
Colour	(Pt/Co)		**18**	**10**		**20**	**10**	**20**	**13**	58	58	60	64
Alkalinity	ppm	56	**48**	**46**	60	**50**	**42**	**48**	**39**	20	20.1	20	19.8
Conductivity	*m*S/cm^2	119	**130**	**110**	117	**130**	**130**	**130**	**120**	71.4	70.9	76	117.3
TDS	g/L	0.08	**0.08**	**0.05**	0.08	**0.1**	**0.06**	**0.1**	**0.05**				
Turbidity	NTU	900	**340**	**50**	1999	**350**	**120**	**350**	**100**	22.8	22.6	23	26.4
Dissolved Oxygen	mg/L									8.8	8.9	6.8	6.7
Total Hardness	ppm	40	**23**	**20**	61	**25**	**21**	**25**	**21**	13	12.9	13	13.1
Calcium Hardness	ppm	24	**<50**	**<50**	40	**<50**	**<50**	**<50**	**<50**	1.4	1.4	1.6	1.5
Magnesium Hardness	ppm	16			21					2	2.1	2.2	2.1
Chloride	(mg/L)		**<0.5**	**<0.5**		**<0.5**	**<0.5**	**<0.5**	**<0.5**	3.8	3.7	4.2	4
Bromine	(mg/L)		**0.32**	**0.32**		**0.2**	**0.2**	**0.32**	**0.32**				
Fluoride	(mg/L)		**0.97**	**0.5**		**0.98**	**0.98**	**0.98**	**0.94**				
Nitrate	mg/L	0.00	**1.3**	**1**	0.00	**1.5**	**1.3**	**1.5**	**1.1**				
Nitrite	(mg/L)		**0.02**	**0.01**		**0.04**	**0.02**	**0.04**	**0.01**				
Sulphate	(mg/L)		**11**	**12.9**		**14**	**12.3**	**13.9**	**11**				
Iron	(mg/L)			**0.12**		**0.15**		**0.16**	**0.13**				
Copper	(mg/L)			**<0.05**		**<0.05**		**<0.05**	**<0.05**				
Manganese	(mg/L)									<0.01	<0.01	<0.01	<0.01
Free CO_2	(mg/L)									2.4	2	2.4	2.3
Oil & Grease	(mg/L)									Nil	Nil	Nil	0.1

APPENDIX 9

Changing Water quality Objectives of Environmental Flows

(Source: Republic of Kenya, 2006b)

Parameter	Units	Class E1, L1	Class E2, L2	Class E3, L3
Biochemical Oxygen demand (5 days at 20°C)	mg/L	30	80	150
Chemical Oxygen demand	mg/L	50	100	200
Total Dissolved Solids	mg/L	1200	2000	3000
pH	pH Scale	6.5-8.5	6 - 9	5-10
Temperature	°C	±2	±5	±10
Total Coli forms	Counts/100ml	100	500	1000
Turbidity	NTU	50	100	200
Ammonia -NH_3	mg/L	0.5	1.5	3
Nitrate-NO_3	mg/L	10	20	50
Total Phosphorous	mg/L	2	10	20
Fluoride	mg/L	0-1.5	1.5-2.0	>2.0
Manganese	Mg/L	0.03	0.05	0.1



Water Resource Classification
(Source: Republic of Kenya, 2006b)

The water resources are classified as being of high (1), medium (2) or low (3) in importance to ecology (E), livelihood (L) and commercial development (C). Each type of demand is divided into three classes of importance – high (1), medium (2) and low (3). This results in nine classes as shown in the figure.